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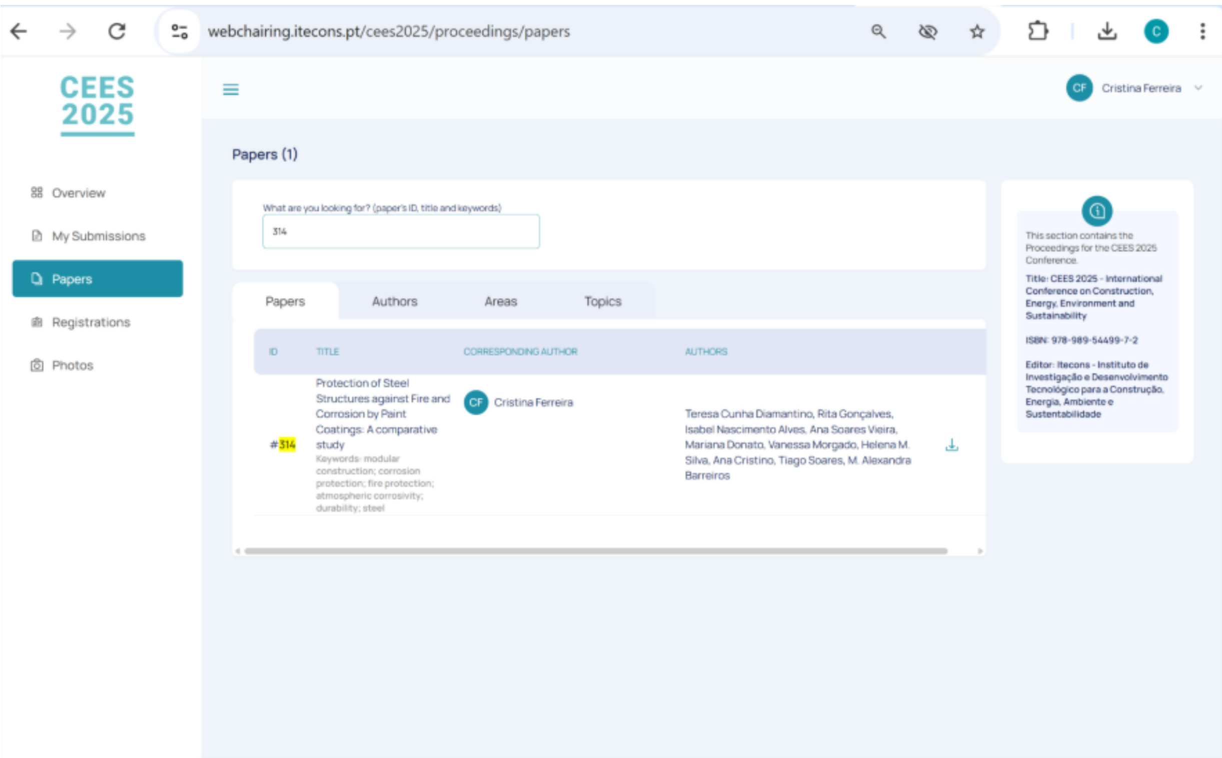

Protection of Steel Structures against Fire and Corrosion by Paint Coatings: A comparative study

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Abstract. Steel structural systems in modular construction must be protected against corrosion and fire exposure. The durability of both protective properties plays a key role in ensuring long-term service life and minimizing maintenance costs. The present work aims to validate anticorrosive protection systems for steel structures, with and without fire protection properties, evaluating degradation mechanisms and assessing the compatibility of intumescent layers with anticorrosive coatings, in terms of their impact on corrosion resistance and fire protection properties.

Keywords: Structural steel, anticorrosive coatings, intumescent layers.

1 Introduction

Steel structural systems in modular construction are exposed to different atmospheres that must be known to specify suitable protection systems properly. It is crucial to study the performance and durability of different coating protection systems, to assure aesthetic, functional, and economic aspects, as well as to safeguard human safety and the environment. To prevent corrosion, steel structures are typically protected against the expected stresses of corrosion during their service life. However, these modular systems also demand effective fire protection, as unprotected steel structures can develop significant damage or collapse during fire exposure due to steel's high thermal conductivity and rapid loss of mechanical properties at high temperatures (> 550 ºC).

When specifying anticorrosive and fire protection systems for steel to be exposed to different atmospheres, the durability of both protective properties plays a key role in ensuring long-term service life and minimizing maintenance costs. Comparative studies of anticorrosive and fire-resistant coatings are essential to provide knowledge on the durability of modular steel structures in environments with different corrosivities. The present work aims to validate anticorrosive protection systems of steel structures, with and without fire protection properties, through artificial ageing tests according to ISO 12944-6:2018 standard [1], and also through the evaluation of degradation mechanisms after natural exposure in atmospheric testing site. It also aims to understand the compatibility of both types of protection systems and how the presence of intumescent layer affects the anticorrosive performance of the coatings. The studies are being carried out for C3 and C5 corrosivities and high durability (C3-H, C5-H) protection systems. This work focuses on the results of the laboratory tests obtained for C3-H systems.

2 Materials and Methods

Samples of blast cleaned S275 JR steel were coated by painting with different protection systems A, B, C and D. Paint systems composition is described in Table 1 and Table 2. The anticorrosive coating systems with intumescent layer tested were specified for fire resistance time of 90 minutes, a critical design temperature of 500 ºC, a massivity of 100 m^{-1} and have the CE mark.

Table 1. Composition of anticorrosive paint systems without intumescent layer (A, B, C and D) for C3-H.

Paint systems	Paint system composition	Nominal thickness (μm)
A	**Primer** - epoxy zinc phosphate	130
	Topcoat - high solids aliphatic acrylic polyurethane	50
B	**Primer** - epoxy with zinc phosphate	120
	Topcoat - acrylic polyurethane / aliphatic isocyanate	60
C	**Primer** - activated zinc epoxy	40
	Topcoat - two-component polyurethane / aliphatic isocyanate, zinc phosphate	80
D	**Primer** - epoxy zinc phosphate	120
	Topcoat - acrylic polyurethane	60

Table 2. Composition of anticorrosive paint systems with intumescent layer (AI, BI, CI and DI) for C3-H.

Paint systems	Paint system composition	Nominal thickness (μm)
AI	Two-component epoxy intumescent	3806
BI	**Primer** - epoxy / with zinc phosphate	120
	Intumescent – single-component acrylic coating	1000
	Topcoat - acrylic polyurethane / aliphatic isocyanate	60
CI	**Primer** - activated zinc epoxy	40
	Intumescent – single-component acrylic coating	1118
	Topcoat - two-component polyurethane / aliphatic isocyanate, zinc phosphate	80
DI	**Primer** - epoxy zinc phosphate	120
	Intumescent – two-component based on methyl methacrylate	3000
	Topcoat - acrylic polyurethane	60

Anticorrosive performance of paint systems was evaluated according to ISO 12944-6:2018 standard [1] through neutral salt spray test (480 h) and water condensation test (240 h). Degradation of the coatings was assessed by visual inspection of the surface (for blistering, rusting, cracking and flaking), by determination of the corrosion at the scribe (after neutral salt spray) and by cross-cut test (systems without intumescent layer) or pull-off test (systems with intumescent layer).
Systems with intumescent layer were also evaluated relatively to thermal insulation capacity when exposed to a temperature of 600ºC in a small oven. The coated panels were mounted on a frame to form the oven door so that the coating system faces the side of the oven, and the temperature of the steel panel could be monitored at the back. For this assessment, four thermocouples were attached to the back of the steel panels and the temperature was monitored for 2 hours with the oven at 600 ºC. The evaluation of the coatings in terms of their insulation capacity, before and after ageing (neutral spray test 480 hours), was carried out by comparing the steel panel temperature curves for the studied systems.
Cross-section scanning electron microscopy and energy dispersive spectrometry (SEM-EDS) analysis were used to assess the morphology and elemental composition of paint coatings. Samples are also being tested by natural exposure according to ISO 2810:2020 [2] in an atmospheric testing site with C5 environmental corrosivity (for steel), in Sines, Portugal (37.9558500N, 8.8853100W) [3].

3 Results and Discussion

Results of the assessment made after neutral salt spray and water condensation tests for B, C and D protection systems without intumescent layers meet the normative requirements of ISO 12944-6 standard [1]: absence of blistering, rusting, cracking and flaking; corrosion at the scribe (as average value) must be smaller or equal to 1.5 mm; classification of cross-cut test between 0 and 2 (2 of 3 samples must comply with these requirements). Concerning protection system A, no defects were observed on the surface of the samples after neutral salt spray test and cross-cut test before and after ageing provided satisfactory results (classification 1-2).

Nevertheless, SEM observation of sample A, before artificial ageing, allowed to identify some points of lack of adhesion between the primer and the topcoat. Moreover, after water condensation test (240 h) blistering was found in the visual assessment of paint system A (see Fig. 2). Blistering and the observed adhesion failures between the primer and the topcoat may be associated with the application process. However, it can also be related to topcoat moisture permeability and failure of adhesion to the primer.

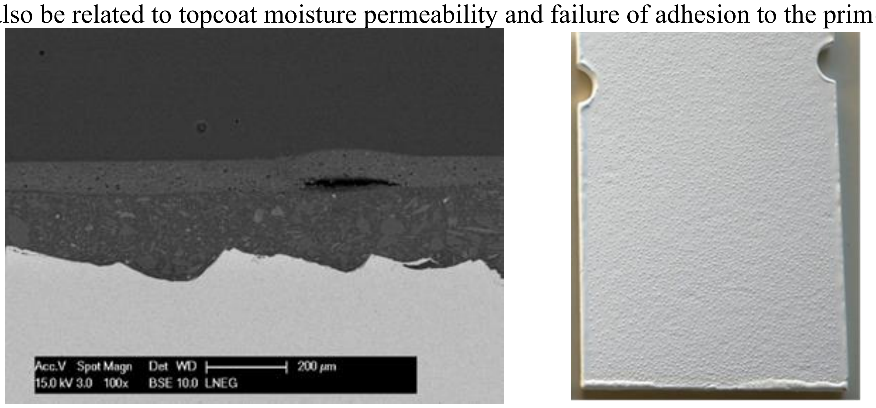

Fig. 1. Left - SEM image from protection system A with a zone of lack of adhesion between the primer and the topcoat before artificial ageing. Right - Blistering observation after water condensation test for paint system A.

At the end of 24 hours after the completion of this test, blistering completely disappeared. On the other hand, at the end of the neutral salt spray test (480 h) the samples did not present blistering, cracking or flaking. Corrosion points were observed on samples of paint systems B, C and D but in all cases, the requirements of ISO 12944-6 standard were observed on 2 of 3 samples. Corrosion at the scribe presented values between 0.3-0.4 mm (A) and 1.0-1.4 mm (B) and values of cross-cut test were 1-2, meeting also the normative requirements for this test, corrosivity category C3, high durability.

Concerning protection systems with intumescent layer, although all of them comply with the requirement regarding surface degradation (absence of defects: blistering, rusting, cracking and flaking) after ageing (neutral salt spray and water condensation tests), none of the coating systems simultaneously met the requirements defined for pull-off adhesion test, before and after artificial ageing. According to ISO 12944-6:2018 [1], adhesion strength must meet a minimum of 2.5 MPa (at least two out of every three samples must comply with these requirements), and failure between steel and the first layer must be 0%, unless the value exceeds 5 MPa. Coating systems AI, BI and DI do not meet the requirements before and after ageing (it should be noted that in some cases coating systems BI and DI, although giving average values that meet the requirement, fail because they give individual values below the minimum required for each determination). Coating system CI was the most successful, meeting the salt spray and humidity tests, but not the requirements before ageing. In conclusion, coatings demonstrated varied performance, with only limited compliance under specific conditions. These results show discrepancies in the effectiveness and durability of adhesion to the substrate and between the layers of the coating system. In order to explain the differences in the behaviour of the different systems studied, further studies will have to be carried out and possibly complementary methods will have to be used. In fact, the method used, described in ISO 12944-6:2018 [1], was defined for conventional corrosion protection systems and does not cover intumescent coatings. However, durability assessment of systems with anticorrosive protection and fire resistance requires comparative studies that consider both types of coatings, taking into account requirements of this ISO standard and EAD 350402-00-1106 document devoted to reactive coatings for fire protection of steel elements [4]. Regarding the measurement of corrosion at the scribe after the neutral salt spray test, the values presented are in accordance with the normative requirements for all coating systems. Nevertheless, it was found that the intumescent layers for protection systems BI and CI are very sensitive to water exposure, which requires extreme care in the application of the topcoat, since any defect in the surface may compromise the system's performance in terms of fire protection.

In terms of thermal insulation capacity, the coating systems BI, CI and DI maintain their performance after ageing (neutral spray test 480 hours) under the conditions mentioned. Coating system AI shows a greater variability of results before and after ageing, requiring more tests to conclude on its thermal insulation capacity after ageing.

Regarding natural exposure at an atmospheric testing site, all samples were exposed, and environmental parameters have been continuously monitored (see Fig. 3).

Fig. 3. Samples exposed at the testing site with category C5 (for steel) environmental corrosivity.

4 Conclusions

The work performed allowed the validation of anticorrosive paint systems for steel structures to be used in modular construction through normalised tests specified in EN ISO 12944-6 standard [1]. However, it demonstrated that for the validation of paint corrosion systems with intumescent coatings integrated methodologies are needed. Although EAD 350402-00-1106 [4] states that if the coating system claims to provide corrosion protection, it must be evaluated according to EN ISO 12944-1 [5] with the methods defined in EN ISO 12944-6 [1], these methodologies have been developed for corrosion protection coatings and do not cover intumescent coatings. These integrated studies will allow the suitability of the methods used to be assessed and will provide a better understanding of the need to develop different methods so that systems can provide adequate corrosion and fire protection.

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Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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