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The impact of the aging of intumescent fire protective coatings on fire resistance

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ABSTRACT

The paper is aimed at determining fire resistance of various intumescent fire protective coatings intended for the protection of steel structures dependently on the simulated operating conditions and atmospheric factors having affected the materials for a certain period. Fire resistance was determined upon applying four methods. The first of them was a method of theoretical calculations. The other methods were experimental ones: a) the fire resistance was established upon using samples of steel double-T profiles covered with fire protective coatings; b) the fire resistance was established after aging the samples at a laboratory upon applying the cyclic freezing-thawing; and c) the fire resistance was established after aging the samples in outdoor shed for 12 months with subsequent heating of the samples according to the standard methodology. The statistical analysis of the obtained fire resistance data shows that there was practically no connection between the values of indicators of fire resistance of non-aged samples calculated theoretically and determined in the experimental way and the indicators of fire resistance of aged samples. The mechanism of material aging taking place as a result of simulated operating and climatic factors is similar for all coatings. However, different coatings are differently affected by aging due to their composition and complexity of the structure. Thus forecasting the fire resistance indicators for different coatings after their aging on the base of the values of the primary fire resistance indicator is impossible.

However, a strong link had been obtained and an equation usable for forecasting the fire resistance time (determined according to the standard ISO 834 fire curve) after 12 months of operation of the coating in the outdoor shed according to the results of fire resistance of intumescent fire protective coatings after 60 artificial aging cycles at the laboratory had been deduced.

1. Introduction

The loss of bearing capacity by metal constructions during a fire is associated with structural deformations [1]. Because of good thermal conductivity of the metal, it transmits heat rapidly from the point of fire, thus helping the fire to spread [2–5]. It was found that unprotected, loaded steel structural elements heated up to (450–550) °C collapsed under the real loads [6,7], (as it is pointed out in the document of Construction technical regulation STR 2.05.11:2005, the temperature of 500 °C is the critical temperature of the steel); at the time of fire, the temperature of 400–1200 °C is achieved, thus the focus should be placed on fire resistance of designed metal bearing structures and their protection [8]. In addition, assessing the impact of the aging of coating intumescent materials themselves on fire protection of such structures is important as well.

The aging of materials is a very complex process that depends on the structure, composition and properties of the materials as well as on the diversity of climate, including air temperature changes, the nature and amount of precipitation, the intensity of solar electromagnetic radiation, wind direction and speed, the change of air humidity, especially when numerical values of such indicators are sufficiently different in individual regions [9].

Assessing the aging process of intumescent fire protective coatings is a very difficult task because of their complicated structures (linear, planar, three-dimensional [10,11]) and compositions (organic synthetic, polymeric, oligomeric, and/or yet monomeric binders; inorganic and organic flame-retardant additives for improving the fire resistance; other functional additives, such as hardeners, pigments, aggregates, etc. [12–17]).

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The complexity of composition of intumescent fire protective coatings did not enable forming a general and uniform opinion about the detailed mechanism of operation of fire protective paint. Only general effects of the key components were determined. The conducted research enables better assessing the properties (especially fire resistance) of newly produced paints only; however, it disregards stability of such coatings in the run of time under simulated and actual operating conditions.

The standard EN ISO 12944-2 [18] establishes a connection between the environmental categories and the composition and thickness of different protective coating systems required to ensure short-term, mid-term or long-term protection against corrosion; however, intumescent fire protective coatings have two different contacts: one contact - with the external environment or with additional protective coatings, and the other one - with the substrate, i.e. the surface covering steel structures, or the surface with increased corrosion-resistance of the structure. Cohesion of coatings changes during operation [19].

Coatings are artificially aged at laboratories upon using the special chambers where the natural processes are simulated. The research for determining the duration of operation can be accelerated having enhanced aging factors. UV radiation and acid deposition taking place at a time were determined to strengthen each other's effect and accelerate decomposition [20,21].

Scientists [22] performed the aging of fire protective epoxy paint and cement plaster under the natural conditions. They used metal plates covered with different fire protective paints. Different epoxy resins, which are known for increased resistance to environmental effects, were used as binders of all coatings. The aging of coatings took about 10 years. The aging procedure was carried out by exposing metal plates to seawater and humid air. After a systematic inspection of the samples, permanent corrosion signs were observed, including micro-cracks between the coating and the base and evident surface erosion in the affected areas. After 8 years, it was found that the coating had peeled on the sides up to 10 mm deep, the surface had flaked up to 3 mm. After 10 years, the coating came off one plate. After 10.5 years, a part of the coating flaked at the surface of all samples. It was found that after 30 years of natural aging, intumescent coating did not perform its function [23].

During the tests (according to the standard fire curve in the furnace) performed with steel plates having different fire coatings applied and subjected to aging cycles, the time before achieving the critical temperature of 500 °C was determined and the calorific values and residue values of steel treated with fire retardant solution depending on location used for natural ageing purposes (in a conditioning room, indoors, outdoors under the roof and outdoor shed) were presented in the paper [24]. The number of artificial simulated aging cycles was found to affect the thickness of resulting foam, which decreases by up to 40%; furthermore, the fire resistance of coatings was determined to decrease by up to 50%.

The paper [25] reports the results of an experimental study of degradation in fire protection performance of two types of intumescent coating after different cycles of accelerated hydrothermal aging tests. Results of the degradation mechanism study reveal that hydrophilic components of intumescent coating move to the surface of the coating and can be dissolved by moisture in the air, which can destroy the intended chemical reactions of these components with others and deter a formation of the desired effective intumescent char. As compared to samples without hydrothermal aging, after 42 cycles of hydrothermal aging (to simulate 20 years of exposure to an assumed exposure environment), the effective thermal conductivity of type-U intumescent coating was 50% higher and that of type-A intumescent coating - 100% higher than that of the fresh coating.

Researchers [26] reported the results of an experimental study of degradation in fire protection performance of intumescent coating for steel elements after different times of immersion in the hydrochloric acid solution. After acid erosion, the thickness of the coating decreased, the surface became rough and cracks and broken holes appeared on it. A prediction method of remained fire resistance property for the acid erosion coatings was proposed, by comprehensively considering the trends of changes of the physical and chemical characteristics of the corroded coating.

Water [27] was found to be the principal environmental factor affecting the durability of intumescent coatings. Fire resistance of samples after degradation was verified in furnace tests. As a result of these tests, a new testing method was proposed for evaluating the durability of intumescent coatings by considering high-temperature and high-humidity weather conditions. Nano coating was determined [28] to have the good expanding effect and fire-resistant property. These authors examined the impact of aging of samples on fire resistance in the laboratory for 500 h each.

In Ref. [29], it was examined how different methods of heating could determine different results of fire protective coatings. The volumetric method of heating is stricter, because a larger area of sample is exposed to fire and so the fire resistance is lower, as compared to samples subject to one-side heated tests. Starting with testing steel plate to determine primary values of fire protective coating characteristics is useful for small scale testing.

Having conducted the search in literature, it may be concluded that the issues related to the simulation of climatic durability tests and their adaptation and use for specific environments were not have been sufficiently examined. The results of accelerated aging of construction products in climatic test chambers were vaguely linked to their durability in nature, because very few tests with fire protective coatings were conducted. New fire protective coatings are certified and meet all fire safety requirements; however, it is doubtful whether their properties will remain unchanged throughout the entire period of their use.

The aim of this paper is to examine the impact that different aging methods on the effectiveness of fire protective coatings used to cover double-T steel profiles.

2. Materials and methods

1 m long double-T profile IPE 120 columns were selected for fire resistance tests. Fig. 1 illustrates the double-T steel profile IPE 120 with its dimensions. The section factor coefficient of double-T steel profiles was calculated according to LST EN 1993 1-2, p. 4.2.5.1 [30] and is equal to 360 m^{-1}. Fire resistance tests and calculations of steel double-T profiles IPE 120 [31] covered in intumescent fire protective coatings were conducted upon following the provisions of the LST EN 13381 standard [32]. The fire tests were carried out in a furnace according to the ISO 834 standard fire curve, described by the equation (1). The maximum difference of temperature between thermocouples is 10–30°. The temperature deviations in the furnace comply with the provisions of the EN 1363-1 standard.

$$T = 345 \cdot \log_{10}(8t+1)+T_o \quad (1)$$

T – temperature in furnace after time t, °C; t – time, min, T_o – primary temperature in furnace, °C.

Detailed combinations of sample materials are presented in Table 1.

The samples were cleaned using metal brushes, degreased and left to dry. The thinner “Thinner 646” (a mixture of aromatic hydrocarbons and alcohols) manufactured by Danushis Chemicals was used for degreasing steel surfaces of the samples. The degreased samples were covered with appropriate anti-corrosive primers (EDG or AG), the thickness of the dried coating whereof was measured using “Mega Check” device and varied from 40 to 50 μm. Then, intumescent fire protective paint of an appropriate brand, namely, Steelguard FM585, Steelguard FM550 or Char 21, was used. The thickness of such a dry coating was measured using “Mega Check” device and varied in the range of 410–540 μm. In certain cases, when different protective paints (ADD or SDD) were additionally used, the thickness of dry coating whereof varied in the range of 40–50 μm. 10 measurements of thickness of the coating were carried out on each double-T profile, evenly distributed over the entire