German Committee for Steel Construction Reports from Steel

DASt
FOSTA Forschungsvereinigung Stahlanwendung e. V.

Issue 2022/6

Analysis of the fire resistance of steel structures with reactive fire protection systems taking into account the aging behavior AiF No.: 20470N

Summary of the research project AiF No.: 20470N

The aim of the research project was to develop a proposal for extending the test procedures for assessing the aging behavior of smoke and fire protection systems for a service life of more than 10 years. Short-term trials should form the basis for this. The assessment of aging behavior requires that the mechanisms of aging are sufficiently known. In addition, numerical simulations were used to create the methodological prerequisites for calculating the heating and load-bearing behavior of steel structures with aged smoke and fire protection systems.

In the research project, the results of fire tests from smoke and fire protection system approval tests were systematically analyzed for the first time. Short-term and long-term tests on commercial products from the past 30 years were evaluated. Based on the available data from the test reports of the approval tests on the durability of the fire protection systems, no significant degradation of performance due to aging phenomena can be observed. There is no evidence of any temporal degradation. However, it should be noted that the data analyzed refers to products that have passed the tests and received approval. A classification of the thermal protective effect of the specimens of the short-term tests over a service life of ten years into the results of the long-term tests provides a good agreement for the available data. However, it is not possible to estimate whether the artificial weathering within the short-term tests really reflects a service life of ten years due to the small amount of data and the generally unchanged thermal protective effect of the aged samples.

In the research project, experimental investigations were carried out on a water-based and epoxy resin-based guide formulation. On the one hand, deficiency formulations were produced by reducing individual functionally relevant components and examined in fire tests. In all of the deficiency formulations examined, despite the absence of individual functionally relevant components, the smoke and fire protection system reacted to form a thermally effective protective layer. As a result of the reduction of the substances APP, PER and MEL, a change in the level of thermal protection was observed in both of the tested formulations. The differences between the standard formulation and the various deficien-

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cy formulations were most evident in the water-based smoke and fire protection system. In the case of the epoxy resin-based smoke and fire protection system, the differences in thermal protection were much less pronounced. A clear, direct connection between the reduction of functionally relevant components and the thermal protective effect of the smoke and fire protection systems cannot be established, especially for small temperature differences, since the fire tests are subject to certain fluctuations and tolerances. The results of the fire tests, TG analyses and ATR-FTIR measurements have shown that a change in the concentration of functionally relevant components realized during the production of smoke and fire protection systems affects the thermal decomposition behavior and the thermal protective effect. However, the functionally relevant components in the smoke and fire protection system types investigated are probably present in such a comprehensive proportion that, in the event of a fire, even with a moderate reduction in concentration, a stable and thermally effective protective layer can still form. Furthermore, the deficiency formulations can only reflect chemical changes in the smoke and fire protection system, but not the structural changes resulting from weathering, such as pore enlargement, blistering and cracking, or delamination of the coating from the steel component. However, the structural degradation of the smoke and fire protection system microstructure is a major factor in declining performance and durability.

On the other hand, test specimens coated with the two standard formulations were subjected to the accelerated weathering cycles of EAD 350402-00-1106 (2017). To evaluate the long-term aging behavior, the test cycles were also repeated several times (3x and 6x).

In summary, increasing the weathering time led to a greater degradation (blisters, cracks and delamination) of the investigated water-based smoke and fire protection system. In particular, the swelling caused by the high humidity and subsequent shrinkage during the drying phase promote the formation of cracks. Overall, an increase in TSD with increasing weathering was observed. In addition to the structural changes, short-term weathering also caused a change at the chemical level of the water-based smoke and fire protection system. In the TG analyses, changes in the range of 230 – 250 °C are visible. The reaction of APP and PER takes place in this temperature range. The result of this chemical reaction can also be determined from the changes in the spectrum in the ATR-FTIR measurements of the weathered samples. No significant differences are evident in the DSC analyses. The color measurements did not show any significant differences due to weathering. However, no correlation between the changes in the thermoanalytical methods and the thermal protective effect could be established. The information is primarily used to identify the chemical composition of a smoke and fire protection system.

In fire tests with the water-based guide formulation, a reduced thermal protective effect of the weathered samples was observed. This is probably due to a change in the foam structure. Investigations carried out after the fire test showed a fine-pored and homogeneous foam in the unweathered samples. In contrast, larger bubbles or cavities are also present in the weathered samples. When assessing the influence of the weathering time, it should be noted that the smoke and fire protection system has partially or completely detached from individual samples after 6 weathering cycles, i.e., there is no longer sufficient adhesion. As a result, the thermal protective effect of the smoke and fire protection system is greatly reduced or lost altogether. However, if the repeated weathering of the smoke and fire protection system does not lead to delamination, no significant difference in thermal protection effect is noticeable between the different weathering durations (1x, 3x, and 6x Z1). In the expansion analysis and the heating tests in the electric furnace at the LUH, a decrease in expansion with increasing weathering time and a resulting decrease in the thermal protection effect were determined. From the investigations it can be concluded that the changes in the surface structure are related to the thermal protective effect in the fire tests. A cross-section through the foam structure of water-based smoke and fire protection systems shows that the inner structure also degrades and has a higher proportion of larger gas inclusions with increasing weathering time.

In summary, for the epoxy resin-based smoke and fire protection system, the increase in weathering time did not lead to any significant structural or chemical changes, except for the color change. This is surprising because the tested smoke and fire protection system was tested without a protective top-coat and with the most demanding weathering scenario according to EAD 350402-00-1106 (2017) (Type X). The optical color changes as well as fine network cracks and open pores that occur with the weathering time in the epoxy resin-based smoke and fire protection system are considered to be unproblematic with regard to performance in the event of fire. Overall, no degradation of the thermal protective effect of the epoxy resin-based coating could be detected in the fire tests or in the thermoanalytical procedures. A large cavity is formed and not a fine-pored foam structure like with the waterbased smoke and fire protection system.

Numerical simulations were carried out in the project using a simulation approach based on a 3D finite element model, which explicitly considers the foaming behavior of the smoke and fire protection system in thermo-mechanically coupled analyses. For this purpose, the material parameters of density, specific heat capacity and expansion factor derived from the experimental investigations are directly taken into account in the numerical model. Depending on the measured parameters and an approach for the observed degradation of the morphology due to weathering, the model has also been defined for aged smoke and fire protection systems. The simulation method can be used to evaluate the fire resistance of steel components with aged smoke and fire protection systems.

The research report provides an example of an extrapolation of the results to I-profiles.

Based on the literature review and the results of the experimental and numerical simulations, a proposal for a test concept for the verification of a service life of smoke and fire protection systems for more than 10 years was derived. The proposal is based on a catalog of different criteria, several of which should be met.

Gefördert durch:

INDUSTRIELLE GEMEINSCHAFTSFORSCHUNG

AiF Forschungsnetzwerk Mittelstand

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

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