Wood Corrosion in Historical Roof Constructions

Ascertaining and Classifying the Extent of Damage in Saxony-Anhalt
Developing and Assessing a Rapid Test Procedure (MATE)

Concise Version of the Report

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1. Overview of the goals and scope of the project

Instances of wood corrosion in historical roof trusses have been observed in the German states of Sachsen-Anhalt, Brandenburg and Thüringen repeatedly since the 1990s. Numerous churches are affected, as well as town halls, palaces and other buildings. The magnitude of the damage and the possibility of the destructive processes continuing and causing irreparable damage to the entire construction make this problem relevant in economic and cultural-heritage terms and also with regard to occupational health and safety.
Wood corrosion refers to fraying in areas of the wood close to the surface. These damage symptoms are found primarily with constructions that were treated with flame retardants.


Photo 1 (left) *Heavy corrosion*
Photo 2 (right) *Light corrosion*

Forty-three cases of suspected damage caused by wood corrosion, ambient climatic influences, application of chemical substances, and a history of treatment with flame retardants and wood preservatives were researched from 2008 to 2010 in Saxony-Anhalt. The project was funded by the German Federal Environmental Foundation (DBU), the Federal Office for Building and Regional Planning (BBR), the Ministry of Culture and Education of the State of Saxony-Anhalt and the Evangelical Church in Central Germany (EKM). It was revealed that almost all these buildings, with only seven exceptions, were treated with flame retardants and/or wood preservatives. In around a third of the cases the treatment resulted in acute damage and in another third the damage was latent. Only slightly over a third of the roof constructions studied in the project revealed no corrosion damage. The project also involved conducting a toxicological evaluation of the flame retardants and wood preservatives detected. Subsequently the consequences for occupational health and safety and for the use of the affected buildings were presented.

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2. Causes of the damage

Salts such as ammonium phosphate, various fluoride compounds and other inorganic salts with mineralising properties were employed in the past as flame retardants. One reason for the damage is that salts are hygroscopic. When the humidity of the ambient air and on the surface of the wood rises, the salts go into solution, and when the humidity falls they crystallise out. The crystallisation pressure breaks down the structure of the wood.

Another reason is that the addition of a water molecule to salts of weak bases or strong acids leads the salt molecule to dissociate. In the course of this reaction, known as hydrolysis, ammonium sulphate combines with water vapour from the surrounding air to form sulphuric acid; ammonium phosphate forms phosphoric acid. These acids attack the wood over a prolonged period. Ammonium fluoride can pose an acute or chronic health hazard.

The resulting structural damage on the surfaces of corroded timber, particularly where this weakens timber joints, is relevant from a static point of view.

3. Flame-retardant salts in timber

Damage is found in constructions that were treated with phosphates, sulphates and/or fluorides. Phosphates and sulphates can be considered the reference substance for the risk of corrosion. The total salt content is possibly also important, in which case the fluoride value would have to be added to that of phosphate/sulphate. On the other hand phosphoric acid is more damaging to timber than hydrofluoric acid.

Wood samples from the surface of the 43 roof constructions studied in the project showed a wide range of values for sulphate and phosphate content. Peak values were 29,400 mg phosphate/kg wood and 29,000 mg sulphate/kg wood. Considerable corrosion damage had occurred in both instances. At the same time, the deeper layers of wood (5mm+) in these two buildings revealed only a low salt content. This was also the case with other buildings studied, albeit in less acute form. In other instances, high salt concentrations of over 3,000 mg were found both on the surface and deep in the wood, without this having led to corrosion. This goes to show that the application of large quantities of flame retardants cannot be the sole cause of wood-corrosion damage.

We propose the following categorisation on the basis of the test results obtained:

Phosphate and/or sulphate

< 800 mg/kg wood	little risk of corrosion
< 2,000 mg/kg wood	moderate risk: monitoring of the wood required every 5 years
> 2,000 mg/kg wood	high risk of corrosion: monitor the wood every 1–2 years, note any changes in use, temperature and humidity!

4. Attic temperature and humidity

The temperature and humidity measurements taken in the course of at least one year in 12 buildings in the scope of the MATE project verify that the ambient climate can influence degenerative processes. Badly corroded roof constructions show significantly greater temperature and humidity fluctuations than less badly damaged roof trusses and they are frequently subjected to condensation moisture. Analysis of the absorbent properties of the flame-retardant salts revealed that the equilibrium moisture content of the salts is not constant but fluctuates within a range of 63–76% relative humidity. The salt is in crystalline form below this range, while above it complete dissolution occurs. The flame-retardant salts in attics with frequent and large fluctuations of relative humidity of 76%–100% therefore absorb humidity with increasing intensity and speed. The accelerated dissolution of the salts facilitates their faster redistribution and concentration in the wood. In drier environmental conditions with relative humidity below 63% the salts release the moisture and crystallise out. The crystallisation pressures that occur contribute to structural wood damage from the surface inwards.

Owners and managers of affected buildings are therefore advised to take long-term measurements of the temperature and relative humidity in attics affected in order to be able to estimate the risk of corrosion (or the further course of the damage) and to gain initial values for the development of individually tailored remedial measures.

5. The composite sample as a "rapid test" method

One of the objectives of the MATE project was to develop a method for rapid testing that was simple and easy to use on site. Different approaches (combined measurements based on studying the conductivity, microwave examination, infrared spectrography and X-ray fluorescence) have to date produced only unsatisfactory results that may be partly misleading. The research group therefore recommends that a composite sample of the wood be taken and tested to detect DDT, lindane, PCP, fluorides, phosphates and sulphates in accordance with the instructions developed by MATE. This laboratory analysis provides reliable information on previous chemical treatment of each particular construction.

6. Results of archival research

The timbers most prone to corrosion are those that were treated with flame retardants as of 1942 following a decree by Hermann Göring, Minister of Aviation of the German Reich, after the first incendiary bombing raids on German cities. Painstaking archival research on three buildings in Sachsen-Anhalt in the scope of the MATE project show extensive wood-preservative application after 1945 as well; in some cases multi-purpose compounds designed to prevent fire, fungus and insect damage were employed. Not only roof constructions but also wooden components of church interiors and other built-in structures were affected. The archives revealed no references to chemical analyses having been conducted before application of the chemical substances, so it seems likely that intentional or unintentional multiple application occurred; some exceedingly high concentrations have been detected, which makes this explanation plausible.

7. Biocide content of wood and ambient air

MATE involved analysis of the extracted wood samples to determine their content of DDT, lindane (γ-HCH) and pentachlorophenol (PCP). Some roof constructions were shown to contain significant concentrations of these substances. DDT was the most widely used chemical in wood-preservation applications in the former German Democratic Republic. The ascertained peak values of up to 6,000 mg DDT/kg wood can only have been attained by multiple applications. There is a link to atmospheric conditions here, too: in badly corroded structures the biocides were concentrated very strongly on the surface.
The application of insecticides for preventative wood preservation also took place after 1945 in the Federal Republic of Germany;[7] here lindane tended to be used as the main biocide.

Analysis of air samples from frequently used rooms below the level of the roof was intended to show the effect of the timber's biocide content on the ambient air in the respective building as a whole. Airborne biocide values measured in the MATE project reached maximums of 803 ng DDT/m³ air, 460 ng lindane/m³ air and 310 ng PCP/m³ air.

8. Toxicological evaluation of the results of wood and air tests

The project documented the nationally and internationally recognised guideline values for DDT, lindane, PCP and fluoride. It developed recommendations and

[7] Products based on the active ingredients DDT and lindane did not come onto the market until after 1945, often not until the 1950s.

measures for dealing with the constructions affected and was always oriented towards practical applications.
Toxicological evaluation of the detected wood-preservative contaminations suggests that all the risks were tolerable, at least in the instances studied.
No particular measures are required such as imposing restrictions on the time spent attending church services or participating in church or palace sightseeing.

9. Conclusions for occupational health and safety

There are various scenarios defined by the use requirements of the respective building that pose possible health hazards. One scenario involves attics that are affected but are rarely used (e.g. entered only for maintenance purposes). Another is where remedial action is definitely required. A third hazard scenario is where the contamination is detectable in the air of rooms below roof level, such as in the body of a church. What these case studies have in common is that they confront the buildings' owners (or other persons responsible) with the question of what should be done.
Two other aspects emerge here. On the one hand, the persons responsible need information on how to comply with the legal requirements, including the question of whether taking no action would contravene legal provisions and regulations. On the other hand, there is the issue of dealing with the contamination in a meaningful and sensible way. What measures should be taken even when there is no explicit, statutory requirement to take remedial action?

Risk situations: working in contaminated areas

In the Federal Republic of Germany the legislator and the statutory accident insurance (Workers' Compensation Boards) have enacted detailed sets of regulations for cases where people are found to be working in a contaminated environment.
They entail that the owners of buildings must comply with their obligation to investigate the situation and inform all affected parties before the beginning of any works,[8] i.e. they are legally bound to examine the areas where the works are to take place, and if any harmful substances are found the information is to be communicated to all persons and bodies concerned. The results of their investigations are to be duly documented and a Work and Safety Plan is to be drawn up.
The release of noxious substances in the form of dust – and thus the spread of the hazard – varies greatly from job to job at the building site. Job-specific risk assessments are therefore to be elaborated to define the occupational health and safety measures in each case.
Although wood-preservative and flame-retardant contamination in attics varies greatly and occupational health and safety practices need to be adapted to the conditions at each individual building site, no guideline values are yet under discussion for determining in practice which areas should class as contaminated.[9]
Independent of the particular remedial measures, which are usually carried out by specialised firms under direction and supervision of the Workers' Compensation Boards, the attention and fiduciary duty of the owners and persons responsible now comes to focus on their own staff or voluntary helpers.

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[8] According to the Workers' Compensation Boards' Occupational Health and Safety Regulations for Contaminated Areas, BGR 128, the concept of "works" encompasses the production, maintenance, alteration and removal of buildings and structures. See also the new TRGS 524 regulations (2010).
[9] The BGR 128 regulations define "contaminated areas" as sites, buildings, structures, objects, soil, water, air and other media contaminated with hazardous synthetic or natural substances over and above a low background level that poses no health risk. BGR 128 also stipulates that adequate ventilation must be provided and that the concentration of noxious gases, vapours or dust, which pose a risk to health and for which workplace limits apply, must not exceed 10% of this value.

Despite the differences in their working conditions, the protection of these persons is of top priority at all times.

The owner's knowledge of possible contaminations must therefore be improved, i.e. the buildings or attics should be examined independently of any planned remedial action. If contamination is ascertained, the staff must be informed and the protection of their health is to be ensured. This can often be achieved through simple, cost-effective measures (protective clothing and respiratory protection).

Owners can thus fulfil their fundamental legal obligations – to observe the labour protection laws in general and, in relation to particular buildings where contamination cannot be excluded, to comply with their obligation to investigate the situation and provide information.

Detailed knowledge of the requirements to be made of the specialised firms, which should facilitate their selection, is to be provided through a set of guidelines for the responsible administrative staff.

10. Recommendation for the decontamination of affected roof constructions

There is no body of experience, as yet, on the long-term effects of chemical methods for decontaminating timber constructions affected by corrosion (e.g. masking, neutralisation). A follow-up study and comparative evaluation of buildings refurbished since the 1990s has yet to be undertaken. The MATE research group therefore recommends that the persons and bodies concerned take preliminary steps (arranging laboratory analyses of wood and dust samples to detect flame retardants and wood preservatives, taking temperature and humidity measurements in the attic over at least one year, and researching the building's history of flame-retardant and wood-preservative treatment). However, they should otherwise limit themselves to removing dust from the attic rooms and, in acute cases of damage, to cleansing the wooden surfaces of frayed particles.