Proceedings IRG Annual Meeting (ISSN 2000-8953)

IRG/WP 16-30701

THE INTERNATIONAL RESEARCH GROUP ON WOOD PROTECTION

Section 3 **Wood protecting chemicals**

Fire retardant treated wood products – Properties and uses

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Paper prepared for the 47th IRG Annual Meeting
Lisbon, Portugal
15-19 May 2016

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www.irg-wp.com

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ABSTRACT

Wood is combustible, but can still perform very well in fire, especially for load bearing structures. However, visible wood surface may not fulfil the fire requirements in building codes and fire retardant treatments may be an option. The highest reaction to fire classification for combustible products may then be reached. However, the excellent fire performance of the virgin fire retardant treated, FRT, wood products may degrade over time, especially in outdoor applications. Two cases of long term durability of FRT wood products exist and standard procedures are available for limited hygroscopicity and maintained fire performance after weathering. Structural degradation may also occur, but is relevant only for load-bearing uses. Recommendations on end uses and suggestions for further research are included.

Keywords: fire retardants, long term durability, reaction to fire performance, wood products

1. INTRODUCTION

The combustibility of timber is one of the main reasons that too many building regulations and standards strongly restrict the use of timber as a building material. Fire safety is an important contribution to feeling safe, and an important criterion for the choice of materials for buildings. The main precondition for increased use of timber for buildings is adequate fire safety.

European standards for fire safety in buildings deal mainly with harmonised methods for verification. These standards exist on the *technical level*, but fire safety is on the *political level* governed by national legislation. National or local authorities will also in the future set the level of requirements to maintain present national safety levels. However, they refer increasingly to the European methods for fire testing and classification.

World-wide, several research projects on the fire behaviour of timber structures have been conducted the last decades, aimed at providing basic data and information on the fire safe use of timber. Novel fire design concepts and models have been developed, based on extensive testing. The current improved knowledge in the area of fire design of timber structures and wood products, combined with technical measures allow the safe use of timber structures and wood products in a wide field of applications (Östman et al 2010). As a result, many countries are revising their fire regulations, thus permitting greater use of timber.

Wood is combustible, but can still perform very well in fire, especially for load bearing structures. The reason is that wood burns with well-known charring rate and below the char layer normal wood remains and high requirements on structural fire resistance can be fulfilled. However, visible wood surface may not fulfil the highest reaction to fire requirements in national building codes and fire retardant treatments may be an option.

2. BUILDING FIRES WITH TWO MAIN STAGES

There are two different stages of a fire scenario to be considered in the fire safety design of buildings in relation to building materials and structures. These are the initial and the fully developed fire, see Figure 1. In the initial fire, the building content e.g. furniture is of major importance both for the initiation of the fire and its development, but this is not regulated in building codes. Surface linings may sometimes play an important role in the initial fire, especially in escape routes, since those are required to be without any furniture and furnishing. Limitations of the reaction to fire of surface linings are required in most building codes. In the fully developed fire, i. e. after flashover in a room, the performance of load bearing and separating structures is important in order to limit the fire to the room or fire compartment of origin. This is called the fire resistance of the building structure.

Generally speaking, timber structures can obtain high performance for fire resistance, while the properties of wood or wood-based linings in the initial fire may be less favourable and also more difficult to quantify.

Chemical treatments with fire retardants may reduce or delay the combustion of wood-based panels and have usually the best effects in the initial fire stage. In a fully developed fire, such treatments usually have no or limited effects, e. g. on the charring rate.

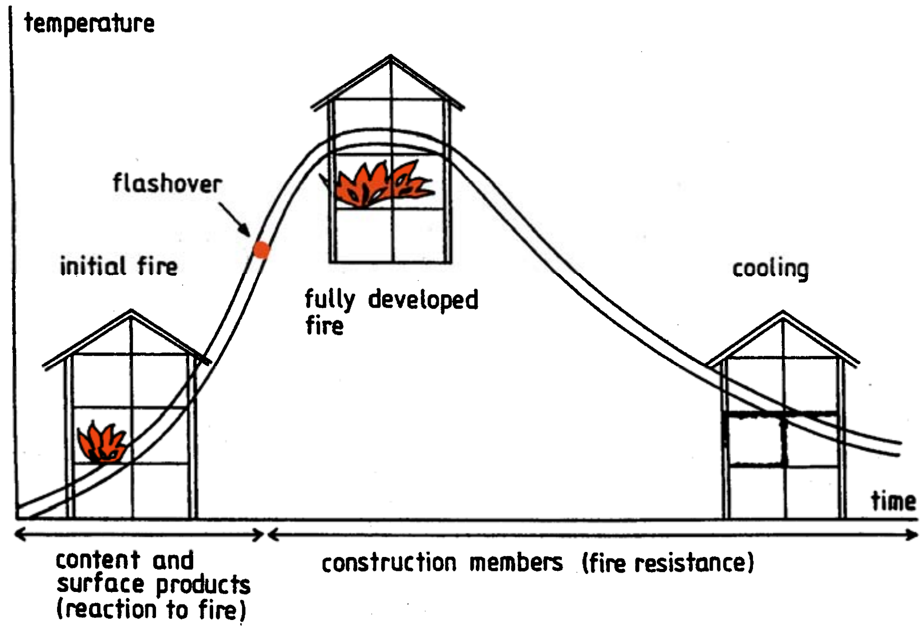

Figure 1. There are two main stages that are relevant for the fire safety in buildings in relation to building materials and structures. The *first stage* is the initial fire in which the properties of surface linings may be important. The *second stage* is the fully developed fire that occurs after flashover in a room. Then the load bearing and separating structures are essential to limit the fire to the room of origin.

2.1 Reaction to fire - Material properties

Reaction to fire means the response from materials to an initial fire attack and includes properties like time to ignition, flame spread, heat release and smoke production, see Figure 2. These properties are relevant in the early fire development, which is the stage when wood products may contribute to fires.

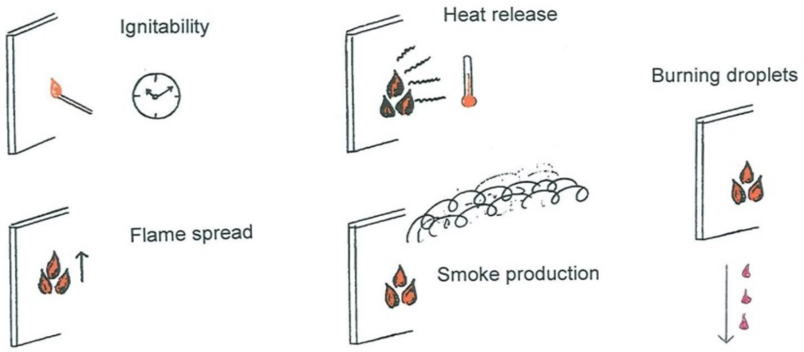

Figure 2. Reaction to fire properties of surface products such as wall and ceiling linings.

2.1.1 European classes for the reaction to fire performance of building products

The European classification system for the reaction to fire properties of building construction products was introduced by a Commission decision in 2000. It is often called the Euroclass system and consists of two sub systems, one for construction products excluding floorings, i.e. mainly wall and ceiling surface linings, see Table 1, and another similar system for floorings. Both sub systems have classes A to F of which classes A1 and A2 are non-combustible products. This European system has replaced the earlier national classification systems, which have formed obstacles to trade.

The European classification system for reaction to fire performance is based on a set of EN standards for different test methods (EN 13823, EN ISO 11925-2, EN ISO 9239-1) and for classification systems (EN 13501-1). Three test methods are used for determining the classes of combustible building products, see Table 2. The methods are illustrated in Figure 3. For non-combustible products, additional fire test methods are used.

The European system has to be used for all construction products in order to get the CE- mark, which is the official mandatory mark to be used for all construction products on the European market. Different product properties have to be declared and may vary for different products, but the reaction to fire properties are mandatory for all construction products. The normal route is that each manufacturer tests and declares their own products individually.

However, products with known and stable performance may be classified as groups according to an initiative from the EC. This is a possibility for wood products that have a fairly predictive fire performance. Properties such as density, thickness, joints and type of end use application may influence the classification. The procedure is called CWFT, Classification without further testing and has been used for a wide range of wood products (Östman and Mikkola 2006), but it is limited to untreated wood products, since different fire retardants may have different influence on the fire performance. Fire retardant wood products thus need to be tested and classified individually to reach the CE- mark.

Table 1. Overview of the European reaction to fire classes for building products excl. floorings.

Euro class	Smoke class	Burning droplets class	Requirements according to			FIGRA	Typical products
			Non comb	SBI	Small flame	W/s	
A1	–	–	x	–	–	–	Stone, concrete
A2	s1, s2 or s3	d0, d1 or d2	x	x	–	≤ 120	Gypsum boards (thin paper), mineral wool
B	s1, s2 or s3	d0, d1 or d2	–	x	x	≤ 120	Gypsum boards (thick paper), fire retardant wood
C	s1, s2 or s3	d0, d1 or d2	–	x	x	≤ 250	Coverings on gypsum boards
D	s1, s2 or s3	d0, d1 or d2	–	x	x	≤ 750	Wood and wood-based panels
E	–	- or d2	–	–	x	–	Some synthetic polymers
F	–	–	–	–	–	–	No performance determined

SBI = Single Burning Item, main test for the reaction to fire classes for building products;
FIGRA = Fire Growth Rate, main parameter for the main fire class according to the SBI test.

Table 2. European test methods for the reaction to fire classes of combustible building products.

Test method	Construction products excl. floorings	Floorings	Main fire properties measured and used for the classification
Small flame test EN ISO 11925-2	X	X	Flame spread within 60 or 20 s.
Single Burning Item test, SBI EN 13823	X	–	- FIGRA, FIre Growth RAte; - SMOGRA, SMOke Growth RAte; - Flaming droplets or particles
Radiant panel test EN ISO 9239-1	–	X	- CHF, Critical Heat Flux; - Smoke production

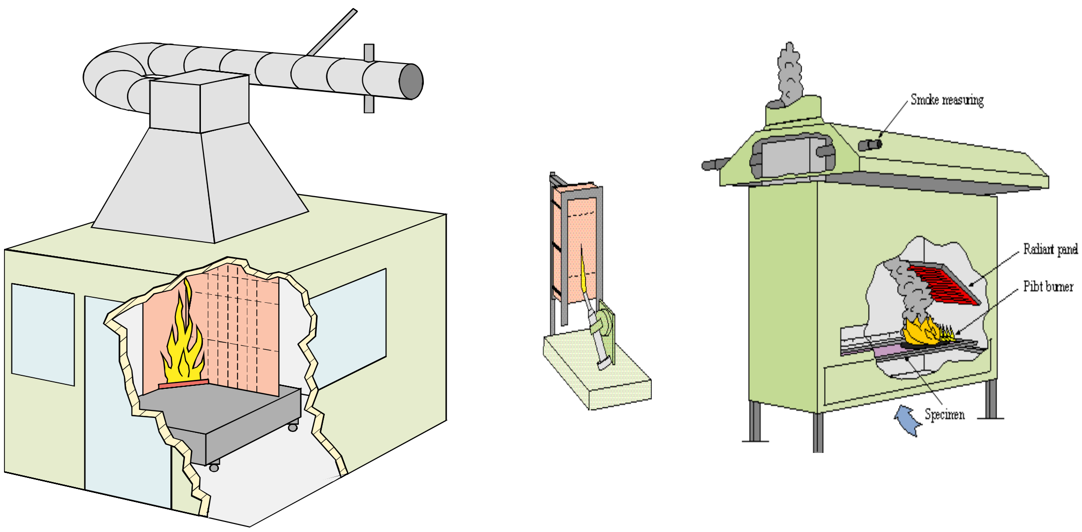

Figure 3.
To the left The SBI test, Single Burning Item test, EN 13823 (sample size 1.5 x 1.5 m);
in the middle Small flame test, EN ISO 11925-2 (sample size 0.09 x 0.25 m) and
to the right Radiant panel test for floorings, EN ISO 9239-1 (sample size 0.23 x 1.05 m).

2.2 Fire resistance - Structural fire performance

Fire resistance means that structural elements, e. g. wall and floor elements, shall withstand a fully developed fire and fulfil requirements of insulation, integrity and/or load bearing capacity, see Figure 4. The fire exposure is usually according to the so-called standard time-temperature curve. This curve is defined in the international standard ISO 834 and referred to in almost all national building codes. It specifies a fire exposure with ever increasing temperatures, which building elements are expected to withstand for a specified period of time, e.g. 60 minutes. Wood structures can obtain high fire resistance, e g REI 60, REI 90 or even higher.

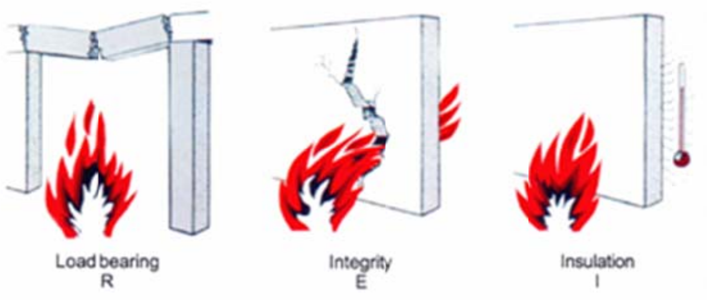

Figure 4.
Performance criteria for fire resistance. They are used together with a time value, e.g. REI 60 for an element that maintains its load bearing and separating functions in 60 minutes.

3. FIRE RETARDANT TREATMENTS FOR WOOD PRODUCTS

It is relatively easy to obtain an improved fire performance of wood products. Most existing fire retardants are effective in reducing different reaction-to-fire parameters of wood such as ignitability, heat release and flame spread. The highest European and national fire classifications for combustible products can be reached (Östman et al 2001). However, high retention levels have to be used compared to ordinary preservation treatments used to protect wood against biological decay.

Fire retardant treatments for wood are numerous and can be divided into three general types:

- those incorporated into wood composite products and wood-based panels during manufacture
- those pressure impregnated into solid wood, plywood, particleboard and hardboard industrially, but after manufacture
- those applied, as paints or surface coatings, industrially after manufacture or in-situ after the wood products have been installed in a building.

Fire retardants may influence the reaction to fire properties, but for the fully developed fire, the influence is minor (Nussbaum). One exception is intumescent paints that may delay the time for start of charring and thus increase the fire resistance of timber structures.

In any case, fire retardants cannot make wood non-combustible.

However, the excellent fire performance of the virgin FR wood products may degrade with time, especially in outdoor applications. Thus, when exposed to high humidity, the FR chemicals may migrate in the wood towards the surface and may ultimately be leached out. Even at moderate outdoor humiditiy and indoors, the fire performance may deteriorate because the FR chemicals migrate away from the surface towards lower concentration regions deeper inside the material thus increasing flammability of the product, see 3.3.

3.1 Formulations

Although manufacturers maintain a mystique about their formulations, the actual fire retardant chemicals have a long history of use. These chemicals include those based on phosphorus, nitrogen, boron, silica and their combinations where the behaviour can be synergistic. Examples are mono-ammonium phosphate, di-ammonium phosphate, ortho-phosphoric acid, ammonium sulphate, borax/boric, acid/boric oxide/disodium octoborate and melamine phosphate. The chemicals are used in either solid or liquid form, depending on the wood product and on the way of their application.

Fire retardant chemicals work in several ways, e. g.

- promotion of char formation
- conversion of volatile gases to non flammable gases such as water vapour and carbon dioxide
- forming a glaze barrier at the surface
- forming an intumescent foam barrier at the surface
- free radical termination in the gaseous phase

3.2 End uses

Interior linings and claddings are probably the main end use of fire retardant treated wood products. Improved reaction to fire class is required for surface linings in larger and higher buildings in most national building codes, e. g. in escape routes, flats in higher residential buildings, public buildings, assembly halls, sport arenas.

Exterior use as e. g. facades may also be possible, and the fire requirements may be full filled, but the long term durability of the reaction to fire properties are difficult to reach, see 3.3.

There are also a lot of special applications e. g. exhibitions, packages, transportation on land and sea and off-shore. Mining applications have traditionally been an important end use of fire retardant wood products.

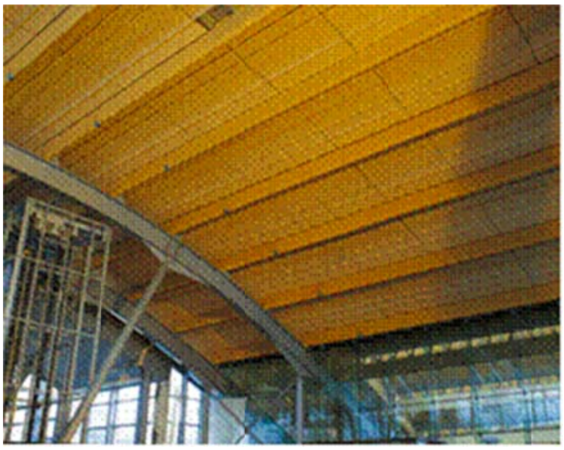

Figure 5.
Interior wall and ceiling panels are suitable applications for fire retardant treated wood. Example from Gardermoen airport in Oslo, Norway.

3.3 Durability classes for fire performance – Principles and methods

Fire retardants may considerably improve the reaction to fire properties of wood products, but the durability in interior and exterior applications needs to be addressed. Requirements on durability of the fire performance are not mentioned explicitly in most building codes. This is probably partly caused by unawareness of the problem, but may also be due to the lack of procedures.

The problems with maintained reaction to fire performance over time have been known for a long time in the US and the UK, but are not so well known in the rest of Europe. A US study on exterior exposure of North American products during ten years (LeVan and Holmes 1986) and a literature review (Östman et al 2001) have been published.

Two cases of durability of the fire retardant treatment of wood products can be identified. One is the risk for high moisture content and migration of the fire retardant chemicals within the wood product and salt crystallisation on the product surface. These hygroscopic properties of the treated wood-based product can be evaluated by exposure to high relative humidity.

The other case is the risk for decreased fire performance due to loss of the fire retardant chemicals by leaching or other mechanisms. This case is mainly for exterior applications, e. g. as façade claddings. Maintained fire performance over time has to be verified.

A European system with Durability of Reaction to Fire performance, DRF, classes has been developed in order to guide the potential users to find suitable FRT wood products (CEN/TS 15912), see Table 3. The system is based on a North American system (ASTM D 2898, ASTM D 3201) and a previous Nordic system (NT Fire 054). It consists of a classification system for the properties over time of FRT wood and suitable test procedures. The testing is illustrated in Figure 6-8.

The technical specification CEN/TS 15912 is currently being transformed to a full European standard.

Table 3. Requirements for DRF classes of FRT wood products according to CEN/TS 15912.

DRF class	**Intended use**	**Fire class Initial**	**Performance requirements for different end uses**	
			Hygroscopic properties	**Fire performance after weather exposure**
ST	Short term	Relevant fire class	-	-
	Interior, dry applications	- " -	Limited moisture content Minimum visible salt	-
	Interior, humid applications	- " -	Limited moisture content Minimum visible salt	-
	Exterior applications	- " -	- " -	Maintained fire performance

Further details are given in CEN/TS 15912.

The relevant fire class shall be verified according to EN or IMO systems (EN 13501-1, IMO FTP Code). Maintained fire performance after weather exposure shall be verified according to ISO 5660 or the European system (EN 13501-1).

Figure 6.
ISO 5660, Cone calorimeter, with sample size 100 x 100 mm.
Used for product development and for verifying the reaction to fire performance after weathering.

Figure 7. Accelerated ageing of FRT wood panels according to NT FIRE 053 and CEN/TS 15912 (with box open).

Figure 8. Natural field weathering of FRT wood panels exposed both vertically (90°) and at 45° slope outside Stockholm, Sweden.

3.4 Durability of reaction to fire performance - Results

Several long term studies have been published on the durability of the reaction to fire performance of FRT wood products, e.g. (Östman and Tsantaridis 2015 and 2016)

The reaction to fire performance is reduced both after accelerated ageing and natural field exposure for most of the FRT products, see Figure 9-10. Only a few FRT products maintain a high fire performance. The best performance is found at high retention levels and for FRT products with paint as a protective surface coat. The other FRT products were more or less degraded during the weathering, regardless of a protective coat or not. For products with low retention of FR chemicals and low initial fire class, the fire performance could not be evaluated.

The accelerated ageing thus seems to be equivalent to maximum five years of natural field exposure. However, it should be noted that the field exposure includes also a certain degree of acceleration. The 45° exposure was intended to include some acceleration, but no major difference to the vertical (90°) orientations was found. This may be explained by the lack of protection on the rear sides of the vertical panels, which were open to the weather exposure. On the other hand, the panels at 45° slope, were at least partly protected on the rear side from direct influence of rainfall and snow. In a real end use, e.g. as a facade cladding, the rear side is totally protected. Such conditions have to be studied further before a more clear guidance on the accelerating factors can be established.

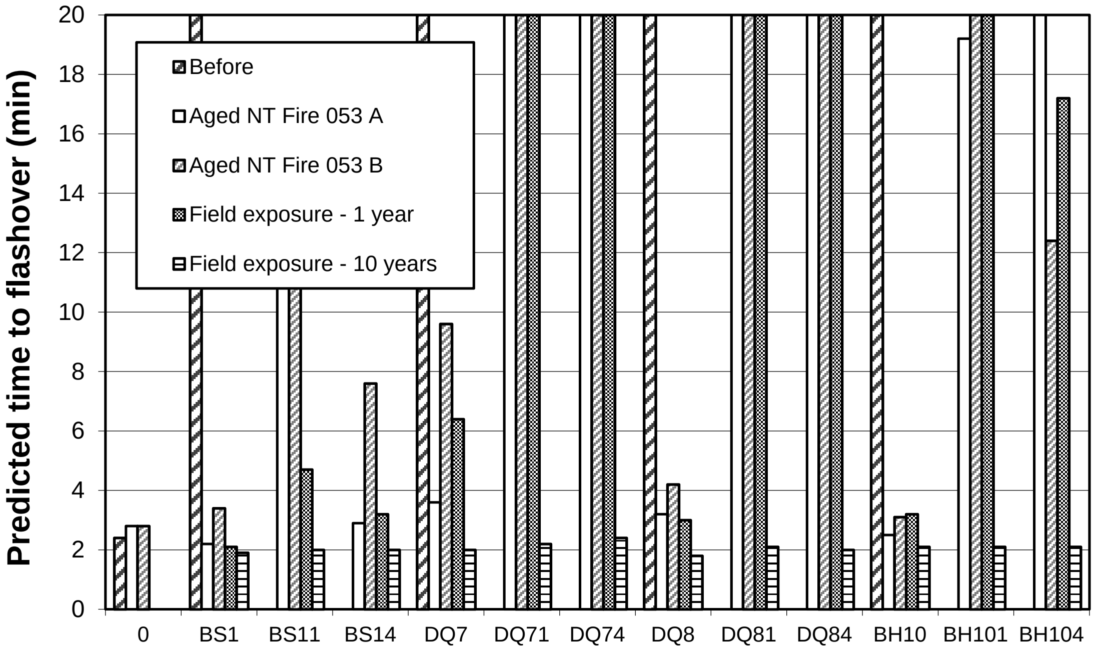

Figure 9. Reaction to fire performance (as predicted time to flashover) before and after accelerated ageing according to NT FIRE 053 Method A and B, and after natural weathering at 45º slope during up to 10 years. Untreated spruce (0) and FR treated (BS, DQ and BH) spruce. Surface coatings with paints number 1 and 4 are included.

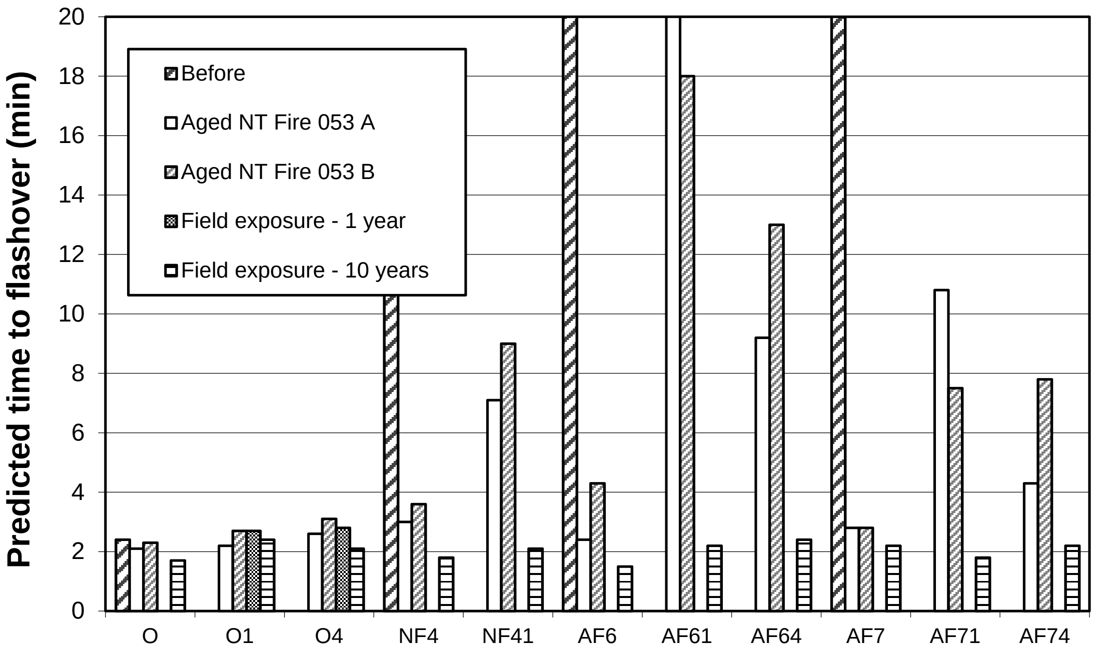

Figure 10. Reaction to fire performance (as predicted time to flashover) before and after accelerated ageing according to NT FIRE 053 Method A and B, and after natural weathering at 45º slope during up to 10 years. Untreated spruce (0) and FR treated (NF and AF) spruce. Surface coatings with paints number 1 and 4 are included.

The mass loss during accelerated ageing and natural weathering may be used as an indicator of the maintained reaction to fire performance over time. Some data are presented in Figure 11.

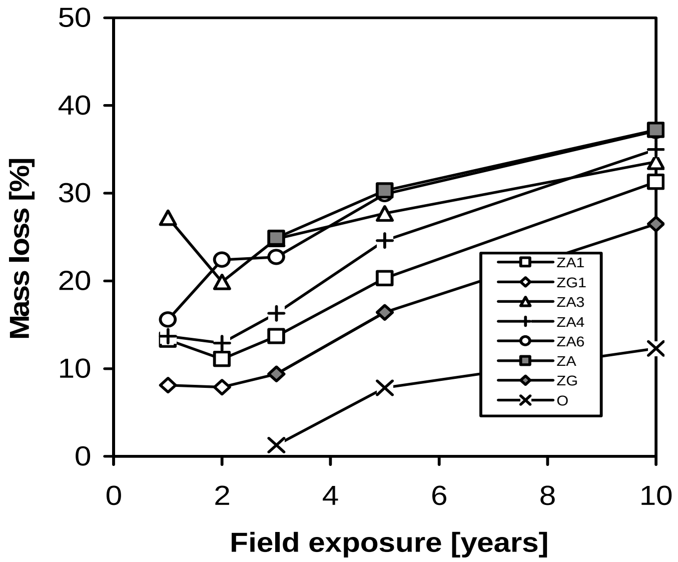

Figure 11. Mass loss during natural weathering of FRT and untreated wood up to ten years.

3.5 Structural degradation of FRT wood products

It has been observed that FRT wood, mainly but not exclusively plywood, used as roof sheathing has lost its strength during service conditions. Several incidents have occurred. Extensive studies have been performed mainly in the USA and the main phenomena seem to have been explained (LeVan and Winandy 1990; LeVan et al. 1990; Winandy et al. 1991 and 1998; Winandy 1995 and 1997; Lebow and Winandy 1999; Wang and Rao 1999). High temperatures in the roof structures have initiated a decay process in the wood caused by some types of fire retardants. New standards to predict the behaviour have been developed (ASTM D 5516, ASTM D 5664 and ASTM D 6305). A review of more than 10 years research has recently been published (Winandy 2001). Examples of results are given in Figure 12.

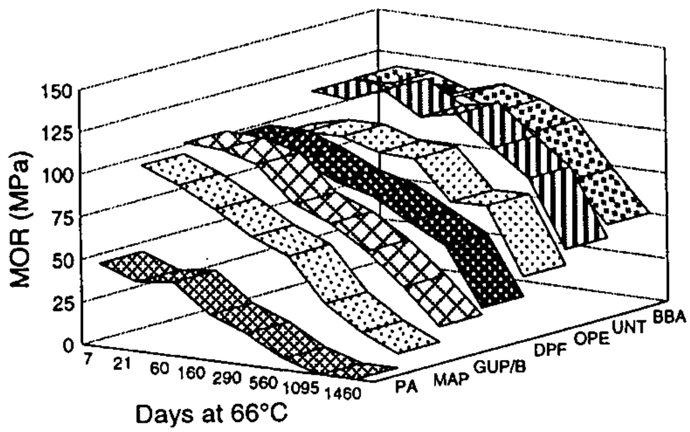

Figure 12. Change in bending strength over steady-state exposure of up to 4 years at 66 ^{o}C for untreated, UNT, wood and wood treated with phosphoric acid, PA, monoammonium phosphate, MAP, guanylurea phosphate/boric acid, GUP/B, dicyandiamid-phosphoric acid-formaldehyde, DPF, organophosphonate ester, OPE, and boriax/boric acid, BBA. (Winandy 2001).

The mechanical strength is important for several applications of FRT wood products in the USA, while in Europe it seems to be less important, since FRT wood is mainly used for non-structural purposes. In most cases other properties, e.g. durability against weathering, are considered to be far more essential.

Conclusions and suggestions for further work

Main conclusions are:

- Fire retardant treatments, FRT, may improve the reaction to fire performance of wood products. The highest reaction to fire classification for combustible products may then be reached.
- FRT has limited or no effect on the fire resistance of full building elements, since the charring rate is not changed significantly. One exception is intumescent coatings that may delay the start of charring and thus increase the fire resistance of timer elements.
- However, the excellent fire performance of the virgin FRT wood products may degrade over time, especially in outdoor applications. A system with Durability of Reaction to Fire performance (DRF) classes to evaluate the fire performance of FRT wood products over time at humid and exterior conditions has been developed. It provides a very useful supplement to requirements on the fire performance in national building codes and enables to guide potential users to find suitable and reliable FRT wood products.
- The fire properties of FRT wood products may be maintained after accelerated ageing and natural weathering if the retention levels are high enough, but several FRT wood products loose most of their improved reaction to fire properties during weathering.
- Paint systems contribute considerably to the weather protection and are usually needed to maintain the reaction to fire performance at exterior applications.
- Structural degradation of FRT wood used as roof elements may occur, but it is relevant only for load-bearing uses which is common in Northern America.
- The main use of FRT wood is as surface linings in interior applications, e. g. in escape routes, flats in higher residential buildings, public buildings, assembly halls, sport arenas.

Suggestions for further work:

- There is a need to develop new FRT wood products with improved long term durability of the reaction to fire performance at exterior applications. Industrial objectives are new markets for such wood products e.g. in multi-storey facades.
- The relationship between accelerated and natural weathering in different climates in order to further develop the conditions for accelerated weathering should be studied by international cooperation.
- Consideration also needs to be given to protection against biological decay.
- Cost and time effective durability screening tests for FRT wood products should be developed.
- All these aspects have to be combined with requirements for service life predictions and an overall ecological performance.

In the meantime, requirements on the long term durability of the fire performance of FRT wood products should be included in product specifications, certification documents and in the national building regulations in order to support the use of reliable FRT wood products. It is especially important for wood products intended for exterior use.

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