# Eco-efficient High Fire Performance Wood-based Products by Chemical Modification

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## ABSTRACT

A long term experimental study on the maintained reaction to fire performance of fire retardant treated, FRT, wood products over time is presented. It is performed according to a new Nordic system and includes accelerated ageing according to different procedures and natural weathering up to five years. A range of FRT wood products have been evaluated, some of them with a protective paint coat. Among the FR treatments, trials with furfurylated and thermally modified wood are presented. Furfurylation of fire retardant treated wood resulted in excellent protection for one type of fire retardant chemical, while the opposite route, by post treatment with fire retardants, resulted in only modest improvement of the reaction to fire performance. The hypothesis was that the fire retardant chemicals should be encapsulated in the furan polymer and thereby ensure long term outdoor performance, although this has not yet been tested.

## INTRODUCTION

Chemical modification with fire retardants may considerably improve the reaction to fire properties of wood-based products and the highest fire classifications for combustible products can be reached, but the durability of the fire retardant treatments has not been fully addressed. Two cases of durability of the fire retardant treatment of wood-based 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. The other case is the risk for decreased fire performance due to loss of the fire retardant chemicals by leaching or other mechanisms.

Earlier trials (unpublished) have shown that thermal modification and furfurylation of wood may result in inferior reaction to fire. However, combination with FR treatments may improve the reaction to fire performance. A further objective is that the fire retardant chemicals might be better fixed in the modified wood than in unmodified wood, e.g. by incorporation in the furan polymer in furfurylated wood.

## METHODOLOGY

A new Nordic 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-based products, see Table 1. It consists of a control system for the durability properties of FRT wood-based and suitable test procedures are published as a Nordtest Method NT Fire 054. European standardisation is underway (prEN 15912).

***Table 1: Requirements for DRF (Durability of Reaction to Fire performance) classes of FRT wood-based products in interior and exterior end use applications according to NT Fire 054***

| **DRF class** | | **Existing fire requirements** | **Additional performance requirements at different end use of fire retardant wood-based products** [a)] | |
|---|---|---|---|---|
| | **Intended use** | **Reaction to fire class, initial** | **Hygroscopic properties** | **Reaction to fire performance after ageing** |
| **0** | Short term | Relevant fire class | - | - |
| **Int** INT | Interior applications | - " - | - Moisture content < 30 %<br>- No visible salt at surface<br>- No exudation of liquid | - |
| **Ext** EXT | Exterior applications | - " - | - " - | Maintained reaction to fire performance [b)] after<br>- Accelerated ageing or<br>- Natural weathering |

a) To be fulfilled using material produced using the same manufacturing process and having a similar retention level as for the reaction to fire performance.

b) Criteria for fire testing according to ISO 5660 after weather exposure: RHR ≤ 100 kW/m$^2$ during 1200 s testing time or $THR_{600s}$ not increased more than 20 % compared to testing before weather exposure.

### *Hygroscopic properties at interior end use*

The hygroscopic properties of wood products have been determined according to NT Build 504. The method includes the calculation of equilibrium moisture content at two climates, 50 % RH at 23 °C and 90 % RH at 27°C. In addition, possible salt crystallisation at the wood surface and exudation of liquid in the wet climate is observed. The testing is illustrated in Figure 1.

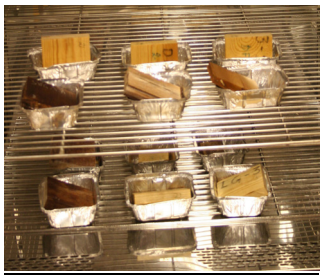

***Figure 1: Hygroscopicity tests according to NT Build 504***

### *Fire performance at exterior end use*

Reaction to fire performance before and after the ageing has been tested in the Cone Calorimeter, see Figure 2.

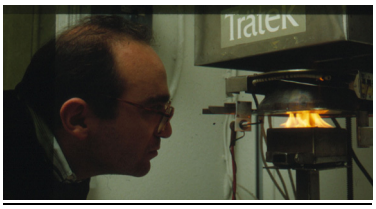

***Figure 2 : Cone calorimeter, ISO 5660, sample size 100 x 100 mm***

<u>Accelerated and natural ageing</u>

The durability of the fire performance in exterior applications has been studied by accelerated ageing according to NT Fire 053 Method A. Natural field exposure is being performed with wood panels facing south, both vertically and at 45° slope at a test field is in the Stockholm area, see Figure 3 and 4.

***Figure 3: Accelerated ageing of FRT wood panels according to NT FIRE 053***

***Figure 4: Natural field weathering of FRT wood panels exposed both vertically and at 45° slope***

## WOOD PRODUCTS AND TREATMENTS

Two sets of wood products have been studied, one set of commercial products, intended for exterior application, and another set of development products. Several types of chemicals were chosen among those with indications of superior fire performance based on literature studies, earlier experience and new innovative ideas. The basic principle has been to choose chemicals with an environmentally safe profile. Halogenated compounds have been completely avoided. The chemicals have been applied by vacuum pressure impregnation of pine sapwood and at three different retention levels in order to study the influence of amount of chemicals added.

Paint systems are usually needed to maintain the fire performance properties of FRT wood products for exterior applications. Four different paint systems have been used. Further details are available in (Östman and Tsantaridis *et al*. 2006, 2007). Among the FT treatments, furfurylated wood (Kebony pine) and thermally modified wood (ThermoWood D) were impregnated with three fire retardant chemicals denoted BSM, BH and DQ, respectively. The opposite route was also applied, i e pine sapwood specimens treated with the three chemicals were then furfurylated by Kebony ASA, in some cases also by impregnating with furfuryl alcohol solution without added catalysts. The intention was that the FR chemicals would act as *in situ* catalysts during the curing of the furfuryl alcohol in the wood.

## INITIAL REACTION TO FIRE PERFORMANCE

As an example of the initial reaction to fire properties, data for FRT furfurylated wood in the cone calorimeter at 50 kW/m$^2$ are presented in Figure 5. The FR treatment has been performed both before and after the furfurylation process. It is obvious that fire retardant impregnation before the furfurfylation process gave much higher retentions and was generally most successful, especially for the treatment with DQ.

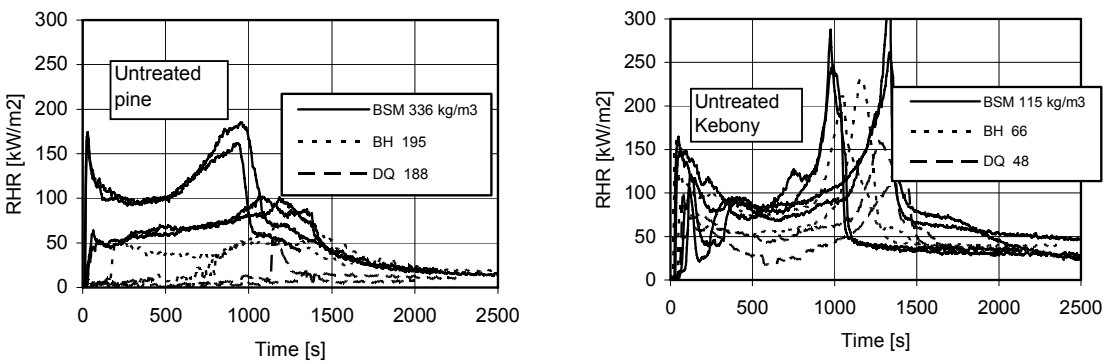


***Figure 5: Examples of reaction to fire performance in the Cone Calorimeter, 50 kW/m$^2$. Rate of Heat Release, RHR, vs time. Left: FR impregnated pine sapwood, then furfurylated; Right: Furfurylated pine sapwood, then FR impregnated***

Another example of the initial reaction to fire properties is FR treatment of thermally modified wood (thermowood) in the cone calorimeter at 50 kW/m$^2$, see Figure 6. The FRT resulted in a substantial reduction in the Rate of Heat Release (RHR) during the first 1000 seconds of the test.

The FR treatment could be performed only after the thermal modification, since the thermal modification of FR treated samples resulted in severe charring and degradation.

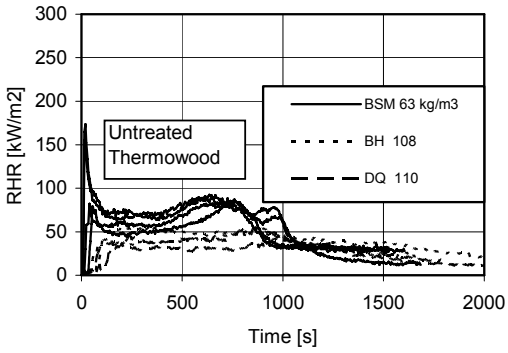


***Figure 6: Examples of reaction to fire performance in the Cone Calorimeter, 50 kW/m$^2$. Rate of Heat Release, RHR, vs time. Thermowood, spruce, FR impregnated***

## HYGROSCOPIC PROPERTIES

The hygroscopic properties of some of the FR treatments as a function of the retention level are illustrated in Figure 7. The moisture content is unchanged compared to untreated wood for several FRT wood products.

It is evident that the moisture content may increase with increased amount of fire retardant chemical added. It is thus important to optimise the FR content not only from an economical point of view, but also to reach the intended fire performance with a safety margin to maintain the fire performance during service life of the product but not jeopardizing the moisture resistance.

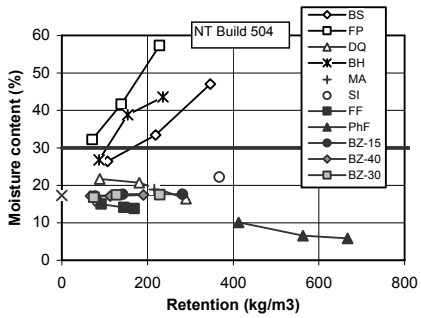


***Figure 7: Moisture content at high RH vs retention for FR chemicals and for untreated pine sapwood***

## REACTION TO FIRE PERFORMANCE BEFORE AND AFTER AGEING

The reaction to fire performance after the accelerated and natural ageing has been determined for the most promising treatments. Examples of data from the in the cone calorimeter at 50 kW/m$^2$ are summarised in Figures 8 and 9. It is obvious that the FR effect is at least somewhat decreased in all cases, but still sufficient in many cases. It is also obvious that a paint coat is necessary for to maintain the reaction to fire performance.

### *Comparisons of reaction to fire performance*

All results for the initial reaction of fire performance and after accelerated ageing and natural weathering are summarised and compared in Figure 10. The comparison is based on predicted time to flashover (Östman, Tsantaridis 1994). Several products exhibit high initial reaction to fire performance, but it may be reduced over time during accelerated and natural weathering.

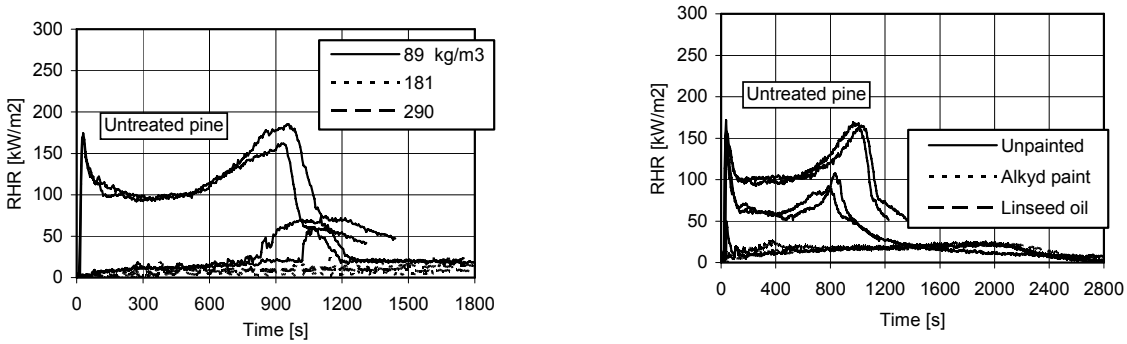


***Figure 8: Examples of reaction to fire performance in the Cone Calorimeter, 50 kW/m$^2$ for DQ . Rate of Heat Release, RHR, vs time. To the left: Initial fire performance, three retentions; To the right: DQ with retention 286 kg/m$^3$ after accelerated weathering, with and without paint coats, according to NT Fire 053***

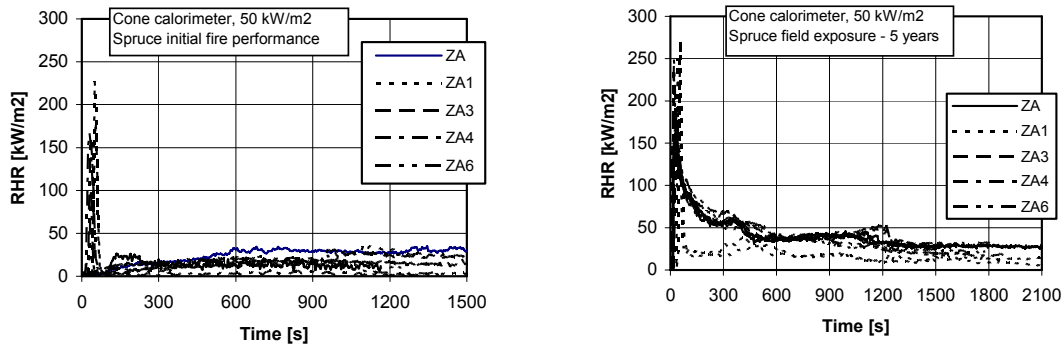


***Figure 9: Examples of reaction to fire performance. Rate of Heat Release, RHR, vs time To the left: Initial fire performance; To the right: After natural weathering during five years***

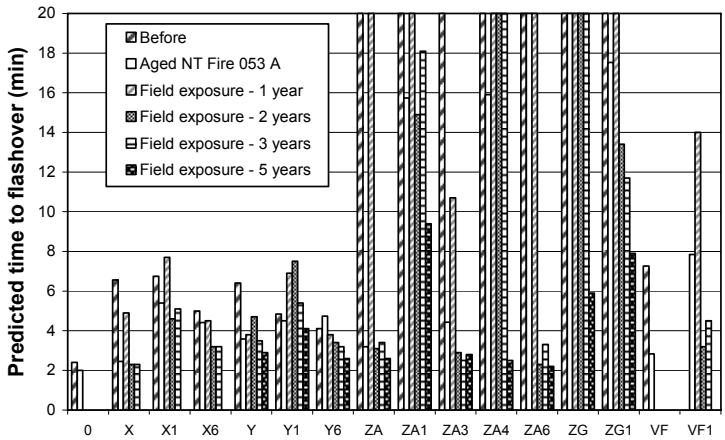


***Figure 10:***

***Reaction to fire performance before and after accelerated ageing according to NT FIRE 053 Method A and after natural weathering at 45º slope during up to 5 years. Untreated spruce (0) and FR treated (X, Y, ZA, ZG and VF) spruce. Surface coatings with paints nr 1, 3, 4 and 6 are included***

## CONCLUSIONS

Main conclusions are:

- The fire properties of FRT wood may be maintained after accelerated ageing and natural weathering if the retention levels are high enough.
- Paint systems contribute considerably to maintain of the fire performance at exterior applications.

- The hygroscopicity of sufficiently durable FRT wood is about the same as for untreated wood, but much higher for simple inorganic salts.
- More experience with correlation of natural field testing and accelerated ageing methods is needed.
- Furfurylation of FRT wood resulted in some cases in excellent initial reaction to fire performance, while the opposite route, post treatment with fire retardant chemicals of furfurylated and thermally modified wood resulted in only moderately improved reaction to fire performance.
- Further work with furfurylated and thermally modified FRT wood is thus needed.
- A system with Durability of Reaction to Fire performance (DRF) classes to evaluate the fire performance of FRT wood over time at humid and exterior conditions has been developed. It provides a supplement to requirements on the fire performance in national building codes and enables to guide potential users to find suitable FRT wood products.

## ACKNOWLEDGEMENTS

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