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RAPPORT

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# Durability of fire retardant wood – New test methods and round robin

Nordtest-project 1527-01

Trätek
INSTITUTET FÖR TRÄTEKNISK FORSKNING

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# DURABILITY OF FIRE RETARDANT WOOD
# – NEW TEST METHODS AND ROUND ROBIN

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*service classes*
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Prediction of Euroclasses of fire retarded wood products using a one-dimensional thermal flame spread model by T Hakkarainen, VTT.

## Summary

Fire retardants may considerably improve the fire properties of wood products, but the durability e.g. in exterior applications needs to be addressed in order to form a basis for new and reliable wood products with improved fire performance.

Requirements on durability of fire retardant treatments are not mentioned in the Nordic or most other building codes. This is probably partly caused by unawareness of the problem, but may also be due to the lack of procedures. This report presents experience with a new system for service classes for fire retardant treated wood products used in interior and exterior applications.

Two cases for the durability of fire retardant treated, FRT, wood are included. One is the durability at interior use at varying and high relative humidity when increased moisture contents and salt migration to the surface of the product may occur. The other is the durability at exterior use e.g. as facade claddings when the weather exposure may leach out the fire retardant chemicals and the fire performance may be decreased or vanish.

For the interior case, seven FRT wood samples and one untreated wood panel have been included in round robin testing at four laboratories with Nordtest Method XX Version 1.0. The repeatability (in each laboratory) and the reproducibility (between laboratories) is fairly good for all samples. The repeatability evaluated as coefficient of variation for the moisture content is between 1 and 18 % with a mean value of 3,6 % for the different products at the lower relative humidity case (65 % RH at 20 °C) and between 1 and 28 % with a mean value of 5,6 % at the higher relative humidity case (90 % RH at 27 °C). The reproducibility evaluated in the same way is between 1 and 14 % with a mean value of 4,8 % at the lower relative humidity case and between 1 and 19 % with a mean value of 9,0 % for the higher relative humidity case. Parameters influencing the moisture content are mainly the amount and type of FR chemicals. The conclusion is that Draft Nordtest method XX is suitable to be used for assessment of the hygroscopic behaviour of FRT wood products.

For the exterior case, five FRT wood samples and one untreated wood panel have been included in the round robin testing at three laboratories with Nordtest Method YY Version 1.0. The repeatability (in each laboratory) and the reproducibility (between laboratories) is fairly good for all samples. The repeatability evaluated as coefficient of variation for predicted time to flashover after accelerated weathering is between 0 and 11 % with a mean value of 2,8 % for the different products. The reproducibility evaluated in the same way is between 0 and 25 % with a mean value of 11,7 %. Higher relative variations were found for low absolute values, which is quite normal. Some other durability methods have been used at one laboratory each. All durability methods included might be used as alternatives for the time being until further evidence is available. For Draft Nordtest method YY-A a first evaluation might be made already after 4 exposure cycles (instead of 12 cycles) in order to simplify the procedure. Limited mass loss during weathering exposure might be used as a first indicator of maintained fire performance after weathering.

A summary table with main data for both cases is given on next page.

***Summary table: Fire performance <u>before and after</u> accelerated weathering and Moisture content at low and high relative humidity incl. service class***

| **Wood products** | | **Fire performance** | | | | | | | | | | | | **Moisture content, %** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Before exposure** | | | | **After exposure** | | | | | | | | | | |
| | | | | | | **Draft Nordtest method YY-A** | | | **Draft Nordtest method YY-B** | | | **NT BUILD 495** | | | | |
| | FR, $kg/m^3$ | NT 2) | NT | EC | | NT | EC | ML | NT | EC | ML | NT | EC | LRH | HRH | SC |
| | | meas | pred | meas | pred | pred | pred | meas | pred | pred | meas | pred | pred | meas | meas | |
| **0 mean** | - | **III** | **III** | **(D)** | **D** | **III** | **D** | **1,5** | - | | **4,3** | - | | **12,5** | **17,9** | - |
| CoV, % | | | 9 | | | 0 | 23 | 33 | | | | | | 1 | 3 | |
| **1 mean** | 350 1) | **I** | **I** | **B** | **B** | **III** | **D** | **19,3** | **III** | **D** | **14,0** | **III** | **D** | **11,3** | **19,8** | **I** |
| CoV, % | | | | | | 13 | 17 | 7 | 0 | 19 | | 8 | 21 | 6 | 13 | |
| **2 mean** | 27? | **II-III** | **III** | **C** | **B** | **III** | **D** | **8,0** | - | **D** | **8,0** | **III** | **D** | **13,3** | **22,3** | **(I) 3)** |
| CoV, % | | | 1 | | 11 | 13 | 46 | 25 | | 7 | | 3 | 7 | 3 | 19 | |
| **3a mean** | 200 1) | **I** | **III** | **B** | **B** | **III** | **D** | **27,9** | **III** | **C** | **25,5** | **III** | **C** | **19,8** | **40,3** | - |
| CoV, % | | | 8 | | 13 | 15 | 9 | 11 | 2 | 21 | | 3 | 6 | 14 | 11 | |
| **4 mean** | 72 1) | **II** | **III** | - | **B** | **III** | **D** | **2,8** | **III** | **D** | **5,4** | **III** | **C** | **9,5** | **22,5** | **(I) 3)** |
| CoV, % | | | 34 | | 24 | 12 | 25 | 100 | 13 | 17 | | 2 | 18 | 2 | 19 | |
| **5a mean** | 260 | **II** | **II** | - | **B** | **III** | **D** | **13,5** | - | **C** | **16,0** | | | **10,8** | **24,0** | **(I) 3)** |
| CoV, % | | | 56 | | 38 | 25 | 31 | 11 | | 5 | | | | 1 | 1 | |
| ***6 mean*** | 700 $g/m^2$ | **II** | ***III*** | - | **B** | ***III*** | **D** | **3,8** | - | - | - | - | - | **13,3** | **20,7** | **(I) 3)** |
| CoV, % | | | 13 | | 0 | 4 | 9 | | | | | | | 4 | 4 | |

1) Given by producer per each delivered panel; 2) Double tests; 3) Service class I only if the fire requirements are fulfilled.

Abbreviations in table:

| | |
|---|---|
| FR | Fire retardant addition, $kg/m^3$ |
| NT | Nordic class according to NT FIRE 004, measured and predicted /11/ incl. variation for the time to flashover. |
| EC | Euroclass, measured and predicted /10/ incl. variation for the main parameter FIGRA |
| ML | Mass loss (%) during durability exposure, measured |
| LRH | Moisture content (%) at Lower Relative Humidity (65 % RH at 20 °C) |
| HRH | Moisture content (%) at Higher Relative Humidity (90 % RH at 27 °C) |
| SC | Service class (in relation to moisture content only); Higher service class depends on fire performance |
| *CoV* | *Coefficient of variation, %* |

The suitability of the proposed service classes for FRT wood has been confirmed. Proposed criteria for the service classes are:

***<u>Criteria for service classes for FRT wood products</u>***

| **Service class** | | **Existing requirements** | **New requirements 1)** | |
|---|---|---|---|---|
| | **Intended use** | **Fire performance** | **Moisture sensitivity 2)** | **Weather durability 3)** |
| - | Short term | National / European fire class | - | - |
| I | Interior – fluctuating humidity | - " - | - Moisture content < [30] %<br>- No salt at surface and no exudation of liquid | - |
| U | Exterior | - " - | - " - | Maintained fire performance after<br>- Accelerated ageing or<br>- Natural weathering |

1) to be fulfilled at the same or higher retention levels of chemicals as for the fire performance;
2) according to Nordtest Method XX /2/; 3) according to Nordtest Method YY /4/ or NT BUILD 495 /5/.

Several of the FRT wood products used in this project had an inferior initial fire performance. They also showed a marked decrease in fire performance after all durability exposure methods. There is thus a need for further product development. Until better products, better coatings or further evidence are available it is recommended that the FRT products are used only in interior applications, i e in service class I. For exterior use, appropriate protecting surface coatings are needed.

It is also recommended that the accelerated test methods used in this project are validated and compared with natural weathering.

# Svensk sammanfattning – Swedish summary

Det är relativt lätt att uppnå ett bra brandskydd för trämaterial t ex med traditionella brandskyddsmedel bestående av oorganiska salter. Svårigheten är att samtidigt bibehålla övriga goda egenskaper hos trä. Det behövs generellt sett stora tillsatsmängder, ofta 10-20 viktsprocent, för att uppnå tillräckligt brandskydd, vilket bidrar till att övriga egenskaper kan påverkas. Tillsatserna är ofta vattenlösliga och hygroskopiska och har därför en tendens till att ta upp fukt och att migrera vid varierande luftfuktigheter. Detta kan ge höga fuktkvoter i brandskyddsimpregnerat trä och saltutfällningar på träytan. Inomhus är detta främst ett estetiskt problem, men utomhus kan brandskyddseffekten snabbt försvinna genom att brandskyddsmedlet lakas ur.

För inomhusfallet, har sju olika brandskyddade träprodukter samt obehandlat trä ingått i en ringprovning vid fyra laboratorier enligt ett förslag till Nordtest-metod. Repeterbarheten (inom ett laboratorium) och reproducerbarheten (mellan laboratorier) är förhållandevis god. Fuktkvoten hos brandskyddat trä kan bli hög, vilket beror både på typ och mängd av brandskyddsmedel. Slutsatsen är att den föreslagna Nordtest-metoden är lämplig att använda (efter några smärre förtydliganden) för att bedöma risken för höga fuktkvoter i brandskyddat trä.

För utomhusfallet, har fem olika brandskyddade träprodukter samt obehandlat trä ingått i en ringprovning vid tre laboratorier genom accelererad åldring enligt ett förslag till Nordtest-metod. Produkterna har brandprovats före och efter åldringen och resultaten har utvärderats. Repeterbarheten och reproducerbarheten är förhållandevis god. Dessutom har några andra accelererade provmetoder använts vid två laboratorier. Slutsatsen är att samtliga använda metoder för accelererad åldring är likvärdiga och kan t v användas som alternativ för att bedöma om produkterna bibehåller sina brandegenskaper vid utomhusanvändning.

Huvudresultaten sammanfattas i tabell (på engelska) på föregående sida.

Resultaten ska användas som bas i ett nytt nordiskt system för kontroll av brandskyddat trä. Brandskyddsimpregnerat trä föreslås enligt det nya systemet att indelas i tre bruksklasser med hänsyn till avsedd användning. Samtliga bruksklasser ska uppfylla befintliga krav på brandegenskaper. Beroende på användning ska dessutom nya krav på beständighet vara uppfyllda. Förslaget sammanfattas i tabell (på engelska) på föregående sida.

Flera av produkterna uppfyllde inte högsta möjliga brandklass före åldringen och den försämrades ytterligare efter åldring. Det finns därför ett behov av produktutveckling. Tills vidare rekommenderas att de studerade produkterna endast används inomhus, d v s i bruksklass I. För utomhusanvändning i bruksklass U krävs ytbehandling med dokumenterad väderbeständighet.

Det rekommenderas också att de accelererade metoderna valideras och jämförs med naturlig åldring.

# 1. Background - Needs and goals

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 national fire classifications for combustible products can be reached /12/, but high retention levels of chemicals have to be used compared to preservation treatments to protect wood against rot and fungi.

On the other hand, differences between wood species may be less important for fire retardant impregnations than for impregnations against biological decay. A deep surface or envelope impregnation is often sufficient to reduce the flammability that is essentially a surface phenomenon.

However, many of the fire retardant treatments, FRT, may have adverse effects on other wood properties. FRT wood often becomes moisture sensitive, discoloured or corrosive and many FRT treatments are not durable in exterior applications. The mechanical strength of wood might also be reduced and the treatments may obstruct or interfere with glues or paints.

Adverse effects of fire retardants on other wood properties are well known in the USA and UK and some literature data are available. Other sources of information are based on industrial and laboratory experience. A literature review on the durability of FRT wood has recently been published /13/. It identifies also the lack of data and research needs.

Requirements on durability of fire retardant treatments are not mentioned in the Nordic or most other building codes. This is probably partly caused by unawareness of the problem, but may also be due to the lack of procedures, which have to be developed, in order to form a basis for new and reliable products with improved fire performance.

A new Nordic control system for the durability of FRT wood products with service classes was agreed in a Nordic Wood project during 2001 /6/. The system is based on initial testing of fire and durability properties and production control at certain time intervals. Established systems for fire performance will be used, but for the durability properties Nordic (or European) procedures need to be established.

The goal with this project is to introduce and evaluate new draft Nordtest methods for durability and moisture sensitivity of FRT wood products, mainly based on North American experience and methods. The new methods are evaluated by round robin testing and may form the basis for a new Nordic system with service classes for FRT wood.

# 2. Planned use of results

The results will be used as the basis for a new Nordic system with service classes for the durability of FRT wood products /6/. Three service classes will be used depending on expected use of the products. All service classes need to fulfil existing requirements for the fire performance. In addition, new requirements for the durability have to be fulfilled for permanent use in e g buildings. The new system is summarised in Table 2.1.

*Table 2.1 Structure of service classes for FRT wood products /6/.*

| **Service class** | | **New requirements and new test methods** | |
|---|---|---|---|
| | **Intended use** | **Moisture sensitivity** | **Weather durability** |
| - | Short term | - | - |
| I | Interior fluctuating humidity | Limited moisture content and no salt migration or exudation. | - |
| U | Exterior | - " - | Fire performance after accelerated ageing. |

# 3. Project

## 3.1 Project content - overview

Two cases for the durability of FRT wood are included. One is the durability at interior use at varying and high relative humidity when increased moisture contents and salt migration to the surface of the product may occur. The other is the durability at exterior use e.g. as facade claddings when the weather exposure may leach out the fire retardant chemicals and the fire performance may be decreased or vanish.

In order to distinguish between these two cases, two types of durability testing have been evaluated:

### *3.1.1 Interior use at varying relative humidity*

An American standard test method, ASTM D 3201 /1/, has recently been modified in order to supply more clear results and presented as draft Nordtest method XX Version 1.0 /2/.

Maximum moisture content of FRT wood, e g [30] %, at 90 % RH, 27 °C and no salt migration or exudation of liquids may be used as a criteria for interior use at varying relative humidity.

### *3.1.2 Exterior use with weather exposure*

Natural weathering is of course preferable but very time demanding. Accelerated or artificial ageing laboratory testing procedures are therefore needed for practical reasons.

There are different possibilities for accelerated testing /13/. Main experience for FRT wood comes from the USA as ASTM standards. ASTM D 2898 Method A is mostly used /3/. It includes exposure at simulated rain and drying in 12 cycles á one week, i.e. in total 12 weeks. An alternative is ASTM D 2898 Method B that includes also UV-exposure. The American standard test method has recently been modified in order to supply more clear results and presented as draft Nordtest method YY Version 1.0 /4/. There are also general weathering methods available, e g NT BUILD 495 (Four seasons carousel) /5/ that includes freezing as well.

All these methods for accelerated weathering including some modifications have been used in the project, see sections 4.1.2 and 6.

### *3.1.3 Evaluation of durability*

FRT wood products have been fire tested before and after accelerated weather exposure. The cone calorimeter, ISO 5660, has been used as the main method. Additional fire testing of non-exposed products according to Nordtest Fire 004 has been performed in order to check the present national classification. Predictions of new European classes, so called Euroclasses, have also been included, see section 4.1.3. For unexposed panels comparisons with tests for Euroclass have been included /15/.

The results of the testing at different laboratories have been evaluated and compared. Requirement levels for service classes are proposed and possible modifications of the draft Nordtest methods are suggested.

## 3.2 Project organisation - Participants

The project has been performed in cooperation between the following industries, institutes and persons:

***Industries:***

| | |
|---|---|
| BITUS, Nybro, Sweden | Kjell Kristiansson |
| Impregnum, Helsingborg, Sweden | Mats Persson |
| Ingarps Tryckimpregnering, Eksjö, Sweden | Johan Walfridsson |
| Lign Multiwood, Söderbärke, Sweden | Anna Blomberg |
| Moelven FireGuard, Moelv, Norway | Lars Grøtta |
| Presso Center, Virkala, Finland /Flame Guard, Netherlands | Bernt Hoffrén / M Janssen |
| Trysil Skog Brannimpregnering, Trysil, Norway | Vidar Baastad |

***Institutes:***

| | |
|---|---|
| NBI – Norwegian Building Research Institute, Trondheim | Tom-Nils Nilsen |
| NTI – Norwegian Institute for Wood Technology, Oslo | Fred Evans |
| Trätek – Swedish Institue for Wood Technology Research, Stockholm | Birgit Östman,<br>Lazaros Tsantaridis |
| VTT – Technical Research Center of Finland, Esbo | Esko Mikkola,<br>Tuula Hakkarainen |
| SDVU - State Forest Product Research Institute, Bratislava, Slovakia (own funding) | Ondrej Grexa |

Trätek has been project leader. The other institutes have participated in testing and evaluation of the test results.

# 4. Experimental

## 4.1 Test methods and testing

### *4.1.1 Moisture sensitivity, hygroscopicity*

A new modified test method has been used: Draft Nordtest Method XX Version 1.0: *Hygroscopic properties of fire-retardant wood and wood-based products* /2/.

The testing includes:
- Conditioning at 65 % RH and 20 °C to moisture equilibrium.
- Conditioning at 90 % RH and 27 °C to moisture equilibrium.
- Visual observations of possible salt crystallisation on the surface of the product.
- Drying at 103 °C
- Calculation of moisture contents.

Specimen size has been 100 x 100 mm with actual thickness, 6-22 mm. Five specimens have been tested for each type of panel and each test condition.

Four institutes have performed standard testing. In addition, some factors that may influence the result have been evaluated by one institute: amount of FR chemicals, presence of knots and number of exposure cycles.

### *4.1.2 Weather durability*

Three main methods for accelerated weathering have been used, two of them originating from USA and one Nordic method, see table 4.1.

- Draft Nordtest Method YY version 1.0:
*Accelerated weathering of fire-retardant wood for fire testing* /4/.

This method contains two alternative procedures, Method A and Method B. Specimen size has been 1000 mm for Method A and 470 mm for Method B. Actual panel thickness, 6-22 mm have been used in both cases. All panels have been edge sealed with a double coat, first with an alkyd primer and then with a silicone sealer. One panel of each type has been exposed for each test condition. This panel has then been cut and used for several fire tests.

For Method B, a slightly modified version of the original ASTM procedure has been employed for practical reasons in order to facilitate combination of test cycles for Method A and availability of equipment for UV exposure, see Table 4.1.

All panels were exposed with 18° to the horizontal plane during the water spray period.

Three institutes have performed standard testing according to Method A, one institute also according to Method B. In addition to the standard procedure, the influence of number of cycles and removal of primer coats have been evaluated by one institute for Method A (see section 6.1) and additional exposure conditions including freezing for Method B (see section 6.2).

- NT BUILD 495:
*Building materials and components in the vertical position: Exposure to accelerated climatic strains (similar to Danish standard DS 1127 and Norwegian Standard NS 8140)* /5/.

Specimen size has been 1000 mm (as for Method A above) and edge sealed in the same way. The specimens were exposed in the vertical orientation.

One institute has performed this testing (the equipment is available only at few institutes). The testing has been performed during 3 months. Specimen for longer exposure times are still being exposed.

***Table 4.1 Exposure conditions at accelerated test procedures for weather durability***

| | **ASTM D 2898**<br>(special method for FRT wood) | | | **NT BUILD 495**<br>(general method) |
|---|---|---|---|---|
| | Method A | Method B | | |
| | | Original procedure | Modified procedure used | |
| Water spray, h | 96 | 4 x 2 | 96 | 1[1)] |
| Freezing, h | - | - | - | 1 |
| UV radiation, h | - | 4 x 2 | 72 | 1 |
| Drying, h | 72 | (at UV exp) | (at UV exp) | (at UV exp) |
| Inspection/rest, h | - | 8 | - | 1 |
| Time per cycle | 1 week | 24 h | 1 week | 4 h |
| Number of cycles | 12 | 42 cycles<br>(1000 h) | 12 | > 180[2)] |
| Total time | 12 weeks | 6 weeks | 12 weeks | > 1 month[2)] |

1) Except 10 minutes for water drainage; 2) Not fixed, the accelerated factor is estimated to be approx. 10-15.

### *4.1.3 Fire performance*

The following methods have been used:

- ISO 5660: *Cone calorimeter* /7/.
Triple tests have been performed for each panel and test condition including unexposed panels. Samples 100 x 100 mm have been cut at least 100 mm from the edge of exposed samples (85 mm for Method B). Specimen for fire testing in the cone calorimeter after weathering exposure were cut also in the middle of the exposed pieces at laboratories A and E (in order to evaluate the possible influence of FR migration within each wood panel) and only from one end at laboratories B and C.

Calculations of time to flashover in the room/corner test ISO 9705 according to a correlation model have been performed /11/. These results have also been linked to Nordic classification.

- NT FIRE 004: *Heat release and smoke production* /9/.
Double tests have been performed for unexposed panels in order to check present national classification. Sample size is 228 x 228 mm and four samples are used for each test.

- EN 13823: *Single Burning Item Test, SBI* /8/.
Calculations according to a prediction method based on cone calorimeter data have been performed /10/. For untreated panels SBI test data are included /15/.

## 4.2 Wood products tested

The test material consists mainly of commercial products from the industrial participants, but some development products are also included.

*Table 4.2 Wood products tested*

| No | Wood specie | FR treatment | Mean FR kg/m$^3$ | Special | Thick-ness, mm | Width mm | Approx initial density kg/m3 | Estim fire class 2) | Intended use |
|---|---|---|---|---|---|---|---|---|---|
| 0 | spruce | Untreated | - |  | 20 | 120 | 400 | III 3) | Interior |
| 1 | spruce | Impregnated | 350 1) | Primer coat 5) | 22 | 130 | 540 | I 3) | Exterior |
| 2 | spruce | Impregnated | 27? | Primer coat | 19 | 130 | 490 | I 3) | Exterior |
| 3a | pine | Impregnated | 200 1) |  | 16 | 130 | 670 |  | Exterior |
| 3b | pine | -„- | 160 1) |  | 16 | 105 | 550 |  |  |
| 3c | spruce | -„- | 50 1) |  | 15 | 120 | 530 |  |  |
| 3k | pine | -„- | 190 1) |  | 16 | 105 | - |  |  |
| 4 | spruce | Impregnated | 72 1) |  | 19 | 98 | 475 | 1 4) | Exterior |
| 5a | birch | Impregnated | 260 |  | 6 | 95 | 760 |  | Exterior |
| 5b | birch | -„- | 150 |  | 8 | 100 | 730 |  | Interior |
| 6 | spruce | Surface coat | 700 g/m$^2$ |  | 15 | 100 | 490 | II 3) | Interior |

1) Given by producer per each delivered panel; 2) Given by producer; 3) According to NT Fire 004;
4) According to NEN 6065; 5) Water-based alkyd, 185-200 g/m$^2$, 50 μ.

Several precautions have been taken to ensure an even and known amount of fire retardant chemicals in each wood panel. However, for some panels only limited information (average data) on amount of FR chemicals was available.

For some of the products only a limited amount was available, while for others additional material for natural weathering are stored for possible future use.

## 4.3 Work distribution

| Institute | Hygroscopicity | Weather durability |  |  | Fire performance |  |  |
|---|---|---|---|---|---|---|---|
|  | Draft Nordtest Method XX 1.0 | Draft Nordtest Method YY-A 1.0 | Draft Nordtest Method YY-B 1.0 | NT BUILD 495 | Cone calori-meter * | NT FIRE 004 | Calcu-lations |
| NBI | - | - | - | x | - | - | - |
| NTI | x | - | - | - | - | - | - |
| Trätek | x | x | x | - | x | x | x |
| VTT | x | x | - | - | x | - | x |
| SDVU | x | x | - | - | x | - | - |

* Before and after weather exposure.

# 5. Hygroscopicity results

## 5.1 Test data

Testing according to Draft Nordtest Method XX Version 1.0 /2/ has been performed at four laboratories. The results are summarised in Table 5.1 for the lower relative humidity case and in Table 5.2 for higher relative humidity. Repeatability within each laboratory is calculated as standard deviation and coefficient of variation, CoV, based on five samples for each product. Reproducibility for all laboratories is calculated in the same way based on mean moisture content data from each laboratory and product.

***Table 5.1 Hygroscopicity Round robin results at lower relative humidity***

| **Wood products** | **Moisture content at 65 % RH, 20°C** | | | | | **Comments** |
|---|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **All labs** | |
| **0 mean** | **12,4** | **12,5** | **12,7** | **12,5** | **12,5** | |
| stdev | 0,1 | 0,2 | 0,2 | 0,1 | 0,1 | |
| CoV, % | 0,8 | 1,6 | 1,6 | 1,0 | 1,3 | |
| **1 mean** | **10,4** | **12,1** | **11,4** | **11,1** | **11,3** | |
| stdev | 1,1 | 0,2 | 0,1 | 0,4 | 0,7 | |
| CoV, % | 10,6 | 1,6 | 0,9 | 3,6 | 6,2 | |
| **2 mean** | **12,8** | **13,7** | **13,5** | **13,3** | **13,3** | |
| stdev | 0,0 | 0,1 | 0,0 | 0,1 | 0,4 | |
| CoV, % | 0,0 | 0,7 | 0,0 | 0,8 | 2,9 | |
| **3a mean** | **17,0** | **21,6** | **17,8** | **22,8** | **19,8** | |
| stdev | 0,1 | 1,7 | 0,2 | 3,0 | 2,8 | |
| CoV, % | 0,6 | 7,9 | 1,1 | 13,2 | 14,3 | |
| **3b mean** | **18,3** | **24,1** | **19,5** | **20,9** | **20,7** | |
| stdev | 0,2 | 1,7 | 0,6 | 3,7 | 2,5 | |
| CoV, % | 1,1 | 7,1 | 3,1 | 17,7 | 12,1 | |
| **3c mean** | **13,8** | - | - | - | **13,8** | |
| stdev | 0,1 | | | | 0,1 | |
| CoV, % | 0,7 | | | | 0,7 | |
| **4 mean** | **9,6** | **9,4** | **9,2** | **9,6** | **9,5** | |
| stdev | 1,5 | 0,2 | 0,4 | 0,4 | 0,2 | |
| CoV, % | 15,6 | 2,1 | 4,3 | 4,2 | 2,0 | |
| **5a mean** | - | **10,8** | - | - | **10,8** | |
| stdev | | 0,1 | | | 0,1 | |
| CoV, % | | 0,9 | | | 0,9 | |
| **5b mean** | **10,1** | **10,9** | **10,7** | **10,2** | **10,5** | |
| stdev | 0,1 | 0,1 | 0,2 | 0,1 | 0,4 | |
| CoV, % | 1,0 | 0,9 | 1,9 | 1,0 | 3,7 | |
| **6 mean** | **12,9** | **13,6** | **13,7** | **12,8** | **13,3** | |
| stdev | 0,1 | 0,6 | 1,1 | 0,1 | 0,5 | |
| CoV, % | 0,8 | 4,4 | 8,0 | 0,8 | 3,5 | |

***Table 5.2 Hygroscopicity Round robin results at <u>higher</u> relative humidity***

| **Wood products** | **Moisture content at 90 % RH, 27 °C** | | | | | **Comments** |
|---|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **All labs** | |
| **0 mean** | **18,4** | **17,4** | **17,4** | **18,3** | **17,9** | |
| stdev | 0,3 | 0,4 | 0,7 | 0,1 | 0,6 | |
| CoV, % | 1,6 | 2,3 | 4,0 | 0,6 | 3,1 | |
| **1 mean** | **23,1** | **18,8** | **17,1** | **20,0** | **19,8** | |
| stdev | 1,0 | 0,4 | 0,2 | 1,2 | 2,5 | |
| CoV, % | 4,3 | 2,1 | 1,2 | 6,0 | 12,8 | |
| **2 mean** | **28,1** | **20,8** | **18,3** | **21,9** | **22,3** | |
| stdev | 2,2 | 0,3 | 0,1 | 0,7 | 4,2 | |
| CoV, % | 7,8 | 1,4 | 0,5 | 3,2 | 18,7 | |
| **3a mean** | **42,9** 1, 2) | **41,5** 2) | **34,0** 1, 2, 3) | **42,6** 1, 2) | **40,3** | |
| stdev | 3,1 | 1,1 | 1,3 | 1,9 | 4,2 | |
| CoV, % | 7,2 | 2,7 | 3,8 | 4,5 | 10,5 | |
| **3b mean** | **44,8** 1, 2) | **51,4** 2) | **41,4** 1, 2, 3) | **48,9** 1, 2) | **46,6** | |
| stdev | 8,8 | 1,5 | 0,3 | 6,3 | 4,4 | |
| CoV, % | 19,6 | 2,9 | 0,7 | 12,9 | 9,5 | |
| **3c mean** | **27,9** | - | - | - | **27,9** | |
| stdev | 0,6 | | | | 0,6 | |
| CoV, % | 2,2 | | | | 2,2 | |
| **4 mean** | **26,3** | **17,0** | **21,6** | **25,1** | **22,5** | |
| stdev | 7,1 | 0,8 | 3,7 | 4,0 | 4,2 | |
| CoV, % | 27,7 | 4,7 | 17,1 | 15,9 | 18,6 | |
| **5a mean** | - | **24,0** | - | - | **24,0** | |
| stdev | | 1,1 | | | 1,1 | |
| CoV, % | | 4,6 | | | 4,6 | |
| **5b mean** | **25,7** 1) | **22,7** | **23,0** | **24,7** 1) | **24,0** | |
| stdev | 0,4 | 0,3 | 0,4 | 0,5 | 1,4 | |
| CoV, % | 1,6 | 1,3 | 1,7 | 2,0 | 5,9 | |
| **6 mean** | **21,7** | **19,8** | **20,5** 1) | **20,9** 1) | **20,7** | |
| stdev | 0,1 | 1,5 | 1,9 | 0,6 | 0,8 | |
| CoV, % | 0,5 | 7,6 | 9,3 | 2,9 | 3,8 | |

Observations: 1) Salt at surface; 2) Exudation of liquid; 3) Longer conditioning time.

The possible influence of some factors has been evaluated (at a slightly different lower climate) at one laboratory:

- Presence of knots
- Amount of Fire retardant chemicals
- Number of exposure cycles

The results are summarised in Table 5.3 and in Table 5.4.

***Table 5.3 Influence of some parameters on moisture content at lower relative humidity***

| **Wood products** | **Moisture content at 50 % RH, 23 °C** | | | | | | | **Comments** |
|---|---|---|---|---|---|---|---|---|
| | **Influencing factors** | | | | | | | |
| | **Knots** | | **FR amount** | | **Number of exp cycles** | | | |
| | no or few | large | low | high | 1 | 3 | 5 | |
| **0 mean** | **10,7** | **10,4** | - | - | **10,7** | **10,4** | **10,3** | |
| stdev | 0,2 | 0,1 | | | 0,2 | 0,1 | 0,1 | |
| CoV, % | 1,9 | 1,0 | | | 1,9 | 1,0 | 1,0 | |
| **1 mean** | **11,5** | **11,0** | - | - | **11,5** | **10,9** | - | |
| stdev | 0,3 | 0,2 | | | 0,3 | 0,4 | | |
| CoV, % | 2,6 | 1,8 | | | 2,6 | 3,7 | | |
| **2 mean** | **11,5** | **10,9** | - | - | **11,5** | **13,8** | - | |
| stdev | 0,1 | 0,1 | | | 0,1 | 0,1 | | |
| CoV, % | 0,9 | 0,9 | | | 0,9 | 0,7 | | |
| **3a mean** | **28,5** | - | - | **28,5** | **28,5** | **25,2** | - | |
| stdev | 2,6 | | | 2,6 | 2,6 | 3,0 | | |
| CoV, % | 9,1 | | | 9,1 | 9,9 | 11,9 | | |
| **3b mean** | **28,5** | - | - | - | **28,5** | **27,3** | - | |
| stdev | 1,3 | | | | 1,3 | 0,7 | | |
| CoV, % | 4,6 | | | | 4,6 | 2,6 | | |
| **3c mean** | **11,7** | - | **11,7** | - | **11,7** | **14,5** | - | |
| stdev | 0,1 | | 0,1 | | 0,1 | 0,1 | | |
| CoV, % | 0,9 | | 0,9 | | 0,1 | 0,1 | | |
| **4 mean** | **8,2** | - | - | - | **8,2** | **11,9** | - | |
| stdev | 0,1 | | | | 0,1 | 0,1 | | |
| CoV, % | 1,2 | | | | 0,8 | 0,8 | | |
| **5a mean** | **7,9** | - | - | - | **7,9** | **11,4** | - | |
| stdev | 0,0 | | | | 0,0 | 0,1 | | |
| CoV, % | 0,0 | | | | 0,0 | 0,8 | | |
| **5b mean** | **8,4** | - | - | - | **8,4** | - | - | |
| stdev | 0,1 | | | | 0,1 | | | |
| CoV, % | 1,2 | | | | 1,2 | | | |
| **6 mean** | **9,4** | - | - | - | **9,4** | - | - | |
| stdev | 1,1 | | | | 1,1 | | | |
| CoV, % | 11,7 | | | | 11,7 | | | |

***Table 5.4 Influence of some parameters on moisture content at higher relative humidity***

| **Wood products** | **Moisture content at 90 % RH, 27 °C** | | | | | | | **Comments** |
|---|---|---|---|---|---|---|---|---|
| | **Influencing factors** | | | | | | | |
| | **Knots** | | **FR amount** | | **Number of exp cycles** | | | |
| | no or few | large | low | high | 1 | 3 | 5 | |
| **0 mean** | **20,5** | **20,2** | - | - | **20,5** | **20,1** | **20,4** | |
| stdev | 0,1 | 0,3 | | | 0,1 | 0,1 | 0,1 | |
| CoV, % | 0,5 | 1,5 | | | 0,5 | 0,5 | 0,5 | |
| **1 mean** | **41,8** 1,2) | **40,7** 1,2) | | | **41,8** | **38,3** | | |
| stdev | 2,2 | 2,1 | | | 2,2 | 1,2 | | |
| CoV, % | 5,3 | 5,2 | | | 5,3 | 3,1 | | |
| **2 mean** | **32,0** 1) | **28,7** 1) | - | - | **32,0** 1) | **30,0** 1) | - | |
| stdev | 2,0 | 2,9 | | | 2,0 | 1,8 | | |
| CoV, % | 6,3 | 10,1 | | | 6,3 | 6,0 | | |
| **3a mean** | **84,1** 1,2) | - | - | **84,1** 1,2) | **84,1** 1,2) | **69,0** 1,2) | - | |
| stdev | 5,4 | | | 5,4 | 5,4 | 6,4 | | |
| CoV, % | 6,4 | | | 6,4 | 6,4 | 9,3 | | |
| **3b mean** | **76,6** 1,2) | - | - | - | **76,6** 1,2) | **72,4** 1,2) | - | |
| stdev | 2,1 | | | | 2,1 | 2,1 | | |
| CoV, % | 2,7 | | | | 2,7 | 2,9 | | |
| **3c mean** | **33,0** | - | **33,0** | - | **33,0** | **31,6** | - | |
| stdev | 0,9 | | 0,9 | | 0,9 | 1,2 | | |
| CoV, % | 2,7 | | 2,7 | | 2,7 | 3,8 | | |
| **4 mean** | **35,3** | - | - | - | **35,3** | **31,8** | - | |
| stdev | 2,5 | | | | 2,5 | 2,2 | | |
| CoV, % | 7,1 | | | | 7,1 | 6,9 | | |
| **5a mean** | **36,3** 1) | - | - | - | **36,3** 1) | **36,0** 1) | - | |
| stdev | 1,2 | | | | 1,2 | 0,8 | | |
| CoV, % | 3,3 | | | | 3,3 | 2,2 | | |
| **5b mean** | **33,6** 1) | - | - | - | **33,6** 1) | - | - | |
| stdev | 0,7 | | | | 0,7 | | | |
| CoV, % | 2,1 | | | | 2,1 | | | |
| **6 mean** | **27,7** | - | - | - | **27,7** | - | - | |
| stdev | 2,8 | | | | 2,8 | | | |
| CoV, % | 10,1 | | | | 10,1 | | | |

Observations: 1) Salt at surface; 2) Exudation of liquid.

The main parameter influencing the moisture content of FRT wood panels is the retention of FR chemicals, see Figure 5.1.

Other parameters as knots have a limited influence, but as the test specimens are fairly small they should contain only minor knots. Number of exposure cycles have shown some influence, but this is probably mainly due to evaporation of excuded liquid during repeated drying cycles. One cycle will give sufficient information for the service classes.

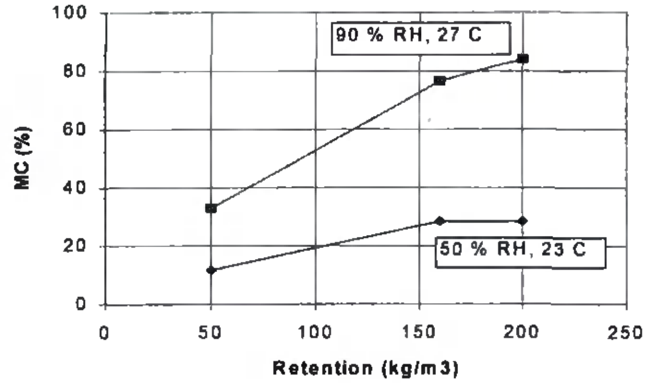

*Figure 5.1*
*Influence of amount of FR chemicals on moisture content at two different climates.*

Possible service classes for FRT wood in relation to moisture content are summarised in Table 5.5.

***Table 5.5 Possible service classes for FRT wood – Summary table***

| **Wood products** | | **Moisture content, %** | | **Service class** |
|---|---|---|---|---|
| | FR kg/m$^3$ | Low RH | High RH | |
| **0** | - | **12,5** | **17,9** | Not relevant |
| **1** | 350 1) | **11,3** | **19,8** | **I** |
| **2** | 27? | **13,3** | **22,3** | **(I)** 2) |
| **3a** | 200 1) | **19,8** | **40,3** | - |
| **3b** | 160 1) | **20,7** | **46,6** | - |
| **3c** | 50 1) | **13,8** | **27,9** | **(I)** 2) |
| **4** | 72 1) | **9,5** | **22,5** | **(I)** 2) |
| **5a** | 260 | **10,8** | **24,0** | **(I)** 2) |
| **5b** | 150 | **10,5** | **24,0** | **(I)** 2) |
| **6** | 700 g/m$^2$ | **13,3** | **20,7** | **(I)** 2) |

1) Given by producer per each delivered panel; 2) Service class I possible only if fire requirements are fulfilled.

## 5.2 Observations during hygroscopicity testing

The time to moisture equilibrium is usually much longer for FRT wood products than for untreated wood.

Exudation of liquids from the products occurred at exposure to the higher relative humidity. It was especially pronounced for products 3a and 3b, but some laboratories reported exudation also for some other products. These observations are included in Tables 5.2 and 5.4.

The weight of the exuded liquid is included in the calculation of the moisture content at high relative humidity according to the test procedure /2/. This is necessary in order to get a true value for the moisture sensitivity at high relative humidity, but special arrangements need to taken to measure all the exuded liquid correctly for each sample. Such procedures should be better specified in the test method /2/.

Salt crystallisation at the surface of panels occurred in some cases. These observations are also included in Tables 5.2 and 5.4.

# 6. Durability results

## 6.0 Initial fire performance

The initial fire performance was tested according to NT Fire 004 /9/ and the cone calorimeter /7/. The cone data have been evaluated by two calculation methods. One method /11/ results in predicted time to flashover in the room/corner test (ISO 9705), the other method /10/ in predicted FIGRA in the new European fire test SBI /8/ that determines the Euroclass. For the fire performance before weathering, the modified version of the model has been used for prediction of Euroclass, see Appendix. SBI test data from a related Nordtest project are also included /15/.

The results are presented in Table 6.0. Repeatability within each laboratory is calculated as standard deviation and coefficient of variation, CoV, based on three samples fire tested for each product. Reproducibility for all laboratories is calculated in the same way based on mean fire data from each laboratory and product.

***Table 6.0 Fire performance before weathering***

| **Wood products** | | Nordic class $^{2)}$ meas. | FIGRA (SBI) meas. W/s | **Cone calorimeter predictions** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **A** | | **B** | | **C** | | **All labs** | |
| | FR kg/m$^3$ | | | Time to f.o, pred min | FIGRA (SBI) pred $^{4)}$ W/s | Time to f.o, pred min | FIGRA (SBI), pred $^{4)}$ W/s | Time to f.o, pred min | FIGRA (SBI), pred $^{4)}$ W/s | Time to f.o, pred min | FIGRA (SBI), pred $^{4)}$ W/s |
| **0 mean** | - | **III** | - | **2,0** | **511** | - | - | **2,3** | **352** | **2,2** | **431** |
| stdev | | | | 0,1 | 5 | | | 0,2 | 78 | 0,2 | 112 |
| CoV, % | | | | 5,0 | 1 | | | 8,7 | 22 | 9,1 | 26 |
| **1 mean** | 350 $^{1)}$ | **I** | **5** | **>20** | **< 120** $^{3)}$ | **>20** | **< 120** $^{3)}$ | **>20** | **< 120** $^{3)}$ | **>20** | **< 120** $^{3)}$ |
| stdev | | | | | | | | | | | |
| CoV, % | | | | | | | | | | | |
| **2 mean** | 27? | **II?** | **202** | **6,2** | **48** | **6,5** | **38** | **5,2** | **44** | **6,0** | **43** |
| stdev | | | | 3,4 | 37 | 2,6 | 32 | 0,4 | 5 | 0,7 | 5 |
| CoV, % | | | | 54,8 | 77 | 40,0 | 84 | 7,7 | 11 | 1,2 | 11 |
| **3a mean** | 200 $^{1)}$ | **I** | **65** | **6,9** | **60** | **6,0** | **47** | **6,9** | **49** | **6,6** | **52** |
| stdev | | | | 1,1 | 27 | 0,4 | 4 | 0,5 | 9 | 0,5 | 7 |
| CoV, % | | | | 15,9 | 45 | 6,7 | 9 | 7,2 | 18 | 7,6 | 13 |
| **3b mean** | 160 $^{1)}$ | **II** | - | **4,3** | **76** | - | - | - | - | **4,3** | **76** |
| stdev | | | | 0,3 | 21 | | | | | 0,3 | 21 |
| CoV, % | | | | 7,0 | 28 | | | | | 7,0 | 28 |
| **3c mean** | 50 $^{1)}$ | **III** | - | **3,9** | **123** | - | - | - | - | **3,9** | **123** |
| stdev | | | | 0,1 | 6 | | | | | 0,1 | 6 |
| CoV, % | | | | 2,6 | 5 | | | | | 2,6 | 5 |
| **4 mean** | 72 $^{1)}$ | **II** | - | **5,3** | **83** | **2,9** | **88** | **3,3** | **127** | **3,8** | **99** |
| stdev | | | | 3,6 | 52 | 0,1 | 6 | 0,3 | 47 | 1,3 | 24 |
| CoV, % | | | | 67,9 | 63 | 3,4 | 7 | 9,1 | 37 | 34,2 | 24 |
| **5a mean** | 260 | **II** | - | **14,4** | **31** | **6,2** | **54** | - | - | **10,3** | **43** |
| stdev | | | | 6,8 | 35 | 2,0 | 39 | | | 5,8 | 16 |
| CoV, % | | | | 47,2 | 113 | 32,2 | 72 | | | 56,3 | 38 |
| **5b mean** | 150 | **II** | - | **7,5** | **29** | - | - | - | - | **7,5** | **29** |
| stdev | | | | 0,6 | 16 | | | | | 0,6 | 17 |
| CoV, % | | | | 8,0 | 21 | | | | | 8,0 | 59 |
| **6 mean** | 700 g/m$^2$ | **II** | - | **4,7** | **19** | - | - | - | - | **4,7** | **19** |
| stdev | | | | 0,6 | 0 | | | | | 0,6 | 0 |
| CoV, % | | | | 12,8 | 0 | | | | | 12,8 | 0 |

1) Given by producer per each delivered panel; 2) Double tests; 3) Max heat release < 75 kW/m$^2$ → class B;
4) FIGRA$_{0,2\ MJ}$ for class B and FIGRA$_{0,4\ MJ}$ for class C and D.

### 6.1 Nordtest Method YY-A

Durability testing according to Draft Nordtest Method YY-A Version 1.0 /4/ has been performed at three laboratories. Three pieces from each exposed panel have then been fire tested in the cone calorimeter /7/. The cone data have been evaluated by two calculation methods. One method /11/ results in predicted time to flashover in the so called room/corner test, the other method /10/ in predicted FIGRA for the new European fire test SBI /8/ that determines the Euroclasses. For the fire performance after weathering, the basic version of the model has been used for prediction of Euroclass, see Appendix. Mass loss during the durability exposure has also been included since it is a measure of how well the FR chemicals remain in the product.

The results are summarised in Table 6.1. Repeatability within each laboratory is calculated as standard deviation and coefficient of variation, CoV, based on three samples fire tested for each product. Reproducibility for all laboratories is calculated in the same way based on mean fire data from each laboratory and product. No effect of how the specimen for fire testing were cut from the exposed panels could be found.

***Table 6.1***
***Fire performance after accelerated weathering according to Draft Nordtest method YY-A - Round Robin results***

| **Wood products** | **Time to flashover, predicted minutes /11/** | | | | **FIGRA (SBI), predicted [2] W/s /10/** | | | | **Mass loss during durability exposure, %** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **A** | **B** | **C** | **All labs** | **A** | **B** | **C** | **All labs** | **A** | **B [1]** | **C** | **All labs** |
| **0 mean** | **-** | **2,6** | **2,5** | **2,6** | **-** | **285** | **396** | **340** | **0,9** | **1,7** | **1,9** | **1,5** |
| stdev | | 0,0 | 0,0 | 0,0 | | 15 | 44 | 78 | | | | 0,5 |
| CoV, % | | 0,0 | 0,0 | 0,0 | | 5 | 11 | 23 | | | | 33 |
| **1 mean** | **3,5** | **2,8** | **2,7** | **3,0** | **378** | **381** | **507** | **422** | **20,6** | **17,8** | **19,6** | **19,3** |
| stdev | 0,1 | 0,1 | 0,0 | 0,4 | 74 | 9 | 55 | 74 | | | | 1,4 |
| CoV, % | 2,9 | 3,6 | 0,0 | 13,3 | 20 | 2 | 11 | 17 | | | | 7 |
| **2 mean** | **2,7** | **2,0** | **2,5** | **2,4** | **795** | **501** | **309** | **535** | **5,2** | **11,1** | **7,6** | **8,0** |
| stdev | 0,0 | 0,1 | 0,0 | 0,3 | 23 | 32 | 22 | 245 | | | | 2,0 |
| CoV, % | 0,0 | 5,0 | 0,0 | 12,5 | 3 | 6 | 7 | 46 | | | | 25 |
| **3a mean** | **2,7** | **2,0** | **2,4** | **2,4** | **333** | **284** | **293** | **303** | **24,4** | **28,8** | **30,5** | **27,9** |
| stdev | 0,1 | 0,0 | 0,1 | 0,4 | 49 | 14 | 40 | 26 | | | | 3,1 |
| CoV, % | 3,7 | 0,0 | 4,2 | 14,6 | 15 | 5 | 14 | 9 | | | | 11 |
| **4 mean** | **2,8** | **2,2** | **2,4** | **2,5** | **533** | **371** | **336** | **413** | **1,0** | **2,9** | **5,6** | **2,8** |
| stdev | 0,3 | 0,1 | 0,1 | 0,3 | 174 | 68 | 30 | 105 | | | | 2,8 |
| CoV, % | 10,7 | 4,5 | 4,2 | 12,0 | 33 | 18 | 9 | 25 | | | | 100 |
| **5a mean** | **2,6** | **1,8** | **-** | **2,2** | **291** | **454** | **-** | **372** | **14,5** | **12,4** | **-** | **13,5** |
| stdev | 0,1 | 0,0 | | 0,6 | 17 | 45 | | 115 | | | | 1,5 |
| CoV, % | 3,8 | 0,0 | | 25,5 | 6 | 10 | | 31 | | | | 11 |
| **6 mean** | **2,4** | **-** | **-** | **2,4** | **404** | **-** | **-** | **404** | **3,8** | **-** | **-** | **3,8** |
| stdev | 0,1 | | | 0,1 | 36 | | | 36 | | | | |
| CoV, % | 4,2 | | | 4,2 | 9 | | | 9 | | | | |

1) Estimated values from different weightings; 2) $FIGRA_{0,2\ MJ}$ for class B and $FIGRA_{0,4\ MJ}$ for class C and D.

The possible influence of some parameters have been evaluated at one laboratory:

- Number of exposure cycles
- Removal of primer coat on panels

The results are summarised in Table 6.2 for the number of cycles and in Table 6.3 for primer coats.

***Table 6.2***
***Influence of number of exposure cycles at accelerated weathering according to Draft Nordtest method YY-A on the Fire performance***

| **Wood products** | **0 cycles (=unexposed)** | | | **4 cycles** | | **12 cycles (=standard exp)** | | |
|---|---|---|---|---|---|---|---|---|
| | Time to f.o, pred min | FIGRA (SBI), pred 4) W/s | Mass loss, % * | Time to f.o, pred min | Mass loss, % * | Time to f.o, pred min | FIGRA (SBI), pred 4) W/s | Mass loss, % * |
| **0 mean** | **2,0** | **511** | **0** | - | - | - | - | **0,9** |
| stdev | 0,1 | 5 | | | | | | |
| CoV, % | 5,0 | 1 | | | | | | |
| **1 mean** | **> 20** | **< 120 3)** | **0** | **5,9** | **15,9** | **3,5** | **378** | **20,6** |
| stdev | | | | 0,1 | | 0,1 | 74 | |
| CoV, % | | | | 1 | | 3 | 20 | |
| **2 mean** | **6,2** | **48** | **0** | - | **7,4** | **2,7** | **795** | **5,2** |
| stdev | 3,4 | 37 | | | | 0 | 23 | |
| CoV, % | 55 | 77 | | | | 0 | 3 | |
| **3a mean** | **6,9** | **60** | **0** | **5,8** | **23,4** | **2,7** | **333** | **24,4** |
| stdev | 1,1 | 27 | | 0,3 | | 0,1 | 49 | |
| CoV, % | 16 | 45 | | 5 | | 4 | 15 | |
| **4 mean** | **5,3** | **83** | **0** | **4,4** | **1,8** | **2,8** | **533** | **1,0** |
| stdev | 3,6 | 52 | | 0,2 | | 0,3 | 174 | |
| CoV, % | 68 | 63 | | 5 | | 11 | 33 | |

* Mass loss during durability exposure; 3) Max heat release < 75 kW/$m^2$ → class B;
4) FIGRA$_{0,2\,MJ}$ for class B and FIGRA$_{0,4\,MJ}$ for class C and D.

Much of the leaching and weathering effect on the fire performance seems to have occurred already after 4 exposure cycles in Draft Nordtest method YY-A, which can be seen also from the mass loss during weathering.

***Table 6.3***
***Influence of removed primer coat at accelerated weathering according to Draft Nordtest method YY-A on the Fire performance***
(Primer coat removed by planing of primed panel)

| **Wood products** | **With primer coat** | | | **Primer coat removed** | | |
|---|---|---|---|---|---|---|
| | Time to f.o, pred, min | FIGRA (SBI), pred $^{4)}$ W/s | Mass loss, % * | Time to f.o, pred, min | FIGRA (SBI), pred $^{4)}$ W/s | Mass loss, % * |
| **1** | | | | | | |
| Unexp | | | | | | |
| **mean** | **> 20** | **< 120 $^{3)}$** | **0** | **10.2** | **< 120 $^{3)}$** | **0** |
| stdev | | | | 1,3 | | |
| CoV, % | | | | 13 | | |
| Exposed | | | | | | |
| **mean** | **3,5** | **378** | **20,6** | **4,9** | **327** | **18,5** |
| stdev | 0,1 | 74 | | 0,5 | 65 | |
| CoV, % | 3 | 20 | | 10 | 20 | |
| | | | | | | |
| **2** | | | | | | |
| Unexp | | | | | | |
| **mean** | **6,2** | **48** | **0** | **2.8** | **112** | **0** |
| stdev | 3 | 37 | | 0,2 | 89 | |
| CoV, % | 55 | 77 | | 7 | 79 | |
| Exposed | | | | | | |
| **mean** | **2,7** | **795** | **5,2** | **3,0** | **411** | **8,8** |
| stdev | 0 | 23 | | 0,1 | 14 | |
| CoV, % | 0 | 3 | | 3 | 3 | |

* Mass loss during durability exposure.; 3) Max heat release < 75 $kW/m^2$ → class B;
4) $FIGRA_{0,2\,MJ}$ for class B and $FIGRA_{0,4\,MJ}$ for class C and D.

The removal of the primer coat from the panels decreased the fire performance for unexposed panels, apparently because some of the outer wood layer was removed simultaneously. These data show the importance of this outer layer, rather than the effect of the primer coat itself.

## 6.2 Nordtest Method YY-B and NT BUILD 495

Durability testing according to Draft Nordtest Method YY-B Version 1.0 /4/ has been performed at one laboratory and according to NT BUILD 495 /5/ at another laboratory. Three pieces from each exposed panel have then been fire tested in the cone calorimeter /7/. The cone data have been evaluated by two calculation methods. One method /11/ results in predicted time to flashover in the so called room/corner test, the other method /10/ in predicted FIGRA for the new European fire test SBI /8/ that determines the Euroclasses. For the fire performance after weathering, the basic version of the model has been used for prediction of Euroclass, see Appendix. Mass loss during the durability exposure has also been included (when available) since it is a measure of how well the FR chemicals remain in the product.

The results are summarised in Table 6.4. Repeatability within each laboratory is calculated as standard deviation and coefficient of variation, CoV, based on three samples fire tested for each product. No effect of exposure orientations could be found.

***Table 6.4***
***Fire performance after accelerated weathering according to Draft Nordtest method YY-B and NT BUILD 495***

| **Wood products** | **Draft Nordtest Method YY-B **** | | | **NT BUILD 495** (Four seasons carousel) | |
|---|---|---|---|---|---|
| | Time to f.o, pred, min | FIGRA (SBI) pred $^{1)}$ W/s | Mass loss, % * | Time to f.o, pred, min | FIGRA (SBI), pred $^{1)}$ W/s |
| **0** | | | | | |
| **mean** | - | - | **4,3** | - | - |
| stdev | | | | | |
| CoV, % | | | | | |
| **1** | | | | | |
| **mean** | **4,2** | **364** | **14,0** | **3,7** | **335** |
| stdev | 0,1 | 69 | | 0,3 | 69 |
| CoV, % | 2,4 | 19 | | 8,1 | 21 |
| **2** | | | | | |
| **mean** | **3,5** | **315** | **8,0** | **3,5** | **475** |
| stdev | 0,2 | 22 | | 0,1 | 33 |
| CoV, % | 5,7 | 7 | | 2,9 | 7 |
| **3a** | | | | | |
| **mean** | **4,0** | **201** | **25,5** | **3,4** | **179** |
| stdev | 0,5 | 43 | | 0,1 | 11 |
| CoV, % | 12,5 | 21 | | 2,9 | 6 |
| **4** | | | | | |
| **mean** | **3,9** | **259** | **5,4** | **5,9** | **115** |
| stdev | 0,7 | 43 | | 0,1 | 21 |
| CoV, % | 18 | 17 | | 1,7 | 18 |
| **5a** | | | | | |
| **mean** | **3,0** | **216** | **16,0** | **3,5** | |
| stdev | 0,1 | 10 | | 0,3 | |
| CoV, % | 3,3 | 5 | | 8,6 | |

* Mass loss during durability exposure; ** including freeze, see Table 6.5;
1) $FIGRA_{0,2\ MJ}$ for class B and $FIGRA_{0,4\ MJ}$ for class C and D.

The possible influence of some changes in the exposure cycles of Nordtest method YY-B has been evaluated at one laboratory. Freezing has been added in one case and UV has been deleted in another case. The exposure has thus been:

| | **UV (=standard)** | **Standard + freezing** | **Standard + freezing - UV** |
|---|---|---|---|
| Water spray, h | 96 | 72 | 72 |
| Freezing, h | - | 24 | 24 |
| UV radiation, h | 72 | 72 | - |
| Drying, h | (at UV exp) | (at UV exp) | 72 |
| Inspection/rest | - | - | - |
| Time per cycle | 1 week | 1 week | 1 week |
| Number of cycles | 12 | 12 | 12 |
| Total time | 12 weeks | 12 weeks | 12 weeks |

The results are summarised in Table 6.5.

***Table 6.5***
***Influence of some parameters of exposure cycles at accelerated weathering according to Draft Nordtest Method YY-B on the Fire performance***

| **Wood products** | **UV (=standard)** | | **Standard + freezing** | | | **Standard + freezing - UV** | |
|---|---|---|---|---|---|---|---|
| | Time to f.o, pred, min | Mass loss, % 2) | Time to f.o, pred, min | FIGRA (SBI) pred 1) W/s | Mass loss, % 2) | Time to f.o, pred, min | Mass loss, % 2) |
| **0 mean** | - | **3,8** | - | - | **4,3** | - | **2,8** |
| stdev | | | | | | | |
| CoV, % | | | | | | | |
| **1 mean** | **4,5** | **15,7** | **4,2** | **364** | **14,0** | **7,3** | **14,6** |
| stdev | 0,0 | | 0,1 | 69 | | 1,3 | |
| CoV, % | 0,0 | | 2,4 | 19 | | 17,8 | |
| **2 mean** | - | **10,2** | **3,5** | **315** | **8,0** | - | **6,6** |
| stdev | | | 0,2 | 22 | | | |
| CoV, % | | | 5,7 | 7 | | | |
| **3a mean** | **3,3** | **28,8** | **4,0** | **201** | **25,5** | **3,0** | **30,6** |
| stdev | 0,1 | | 0,5 | 43 | | 0,1 | |
| CoV, % | 2,1 | | 12,5 | 21 | | 4,7 | |
| **4 mean** | **3,9** | **4,9** | **3,9** | **259** | **5,4** | **3,7** | **4,5** |
| stdev | 0,5 | | 0,7 | 43 | | 0,4 | |
| CoV, % | 12,8 | | 17,9 | 17 | | 10,8 | |
| **5a mean** | - | - | **3,0** | **216** | **16,0** | - | **14,2** |
| stdev | | | 0,1 | 10 | | | |
| CoV, % | | | 3,3 | 5 | | | |

1) FIGRA$_{0,2\,MJ}$ for class B and FIGRA$_{0,4\,MJ}$ for class C and D; 2) Mass loss during durability exposure.

No significant differences were found between the three types of exposure cycles.

## 6.3 Observations and comparison between durability methods

### *6.3.1 Observations*

Considerable cracking during the exposure cycles was observed in all FRT wood panels except panels 5a and 5b. These panels were much thinner and showed instead a marked buckling.

The primer coat used for two types of FRT panels showed degradation during the initial exposure period, but had then more or less constant appearance.

Wood panels exposed to UV light cycles showed a marked colour change that did not appear for panels exposed just to moisture and drying. An example is given in Figure 6.1.

Wood resins become usually visible on the wood surface at exposure in the NT BUILD 495, but this was not the case for the FRT wood panels exposed in this project.

*Figure 6.1 Colour changes in panels exposed to UV light or not.*

### *6.3.2 Comparisons between durability methods*

Data for comparisons between durability are based on fire testing in the cone calorimeter. Some examples of results are given in Figure 6.2. These test data have also been used for predictions of Nordic fire class and Euroclass.

All data on fire performance before and after durability exposure according to all standard procedures included in the project are illustrated in Figure 6.3 and Figure 6.4 and summarised in Table 6.6. The data for Nordtest method YY-A are mean data from the round robin testing as given in Table 6.1. For Nordtest method YY-B and NT BUILD 495 mean data from Table 6.4 are used. Data for the products that have been fire tested only initially are also included. The mean amount of FR chemicals are included in the table in order to facilitate further interpretation of the results.

Data on predicted Nordic class and Euroclass are summarised in Table 6.7 and Table 6.8.

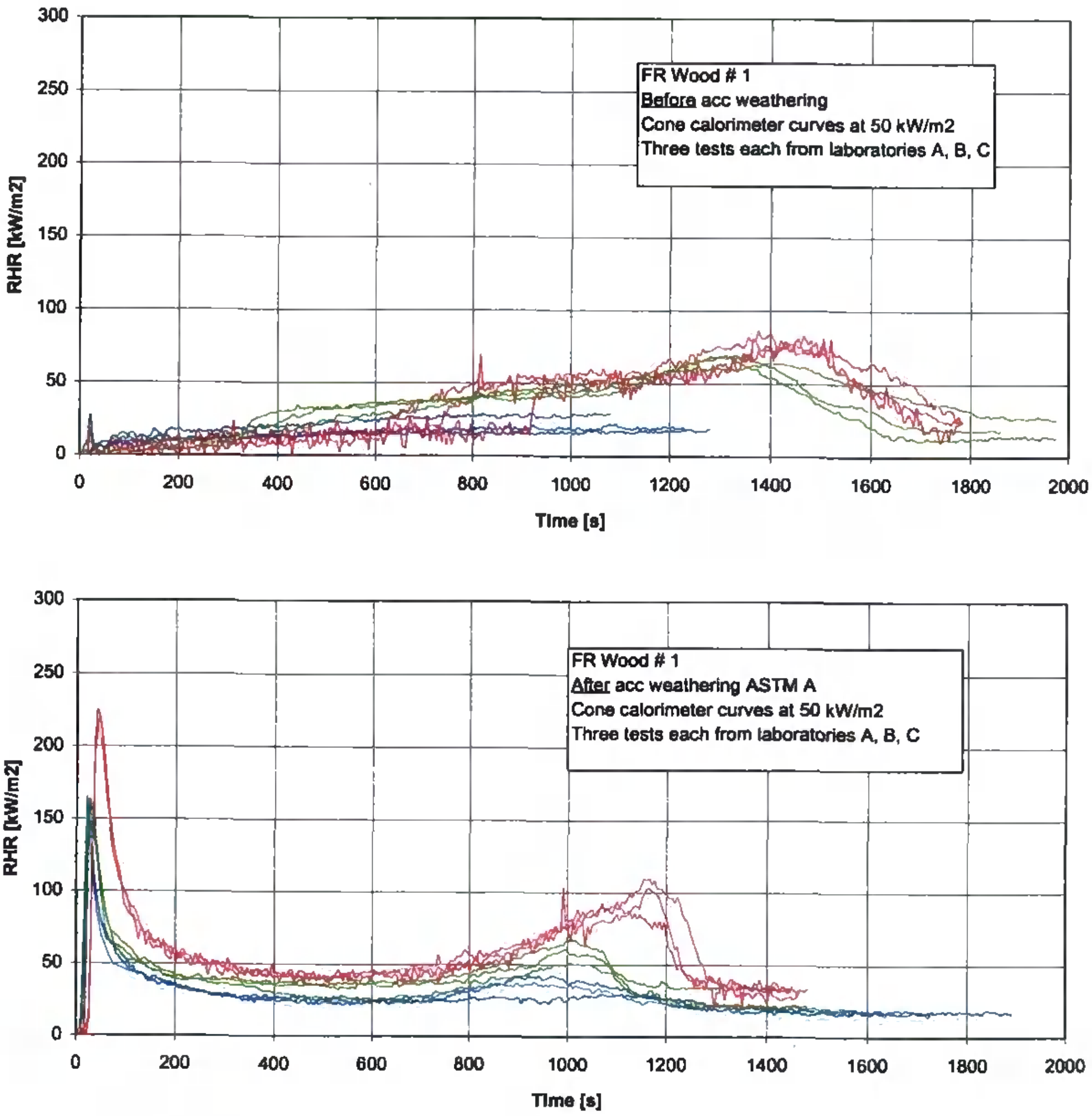

*Figure 6.2. Rate of heat release in the cone calorimeter measured before and after accelerated weathering at three laboratories.*

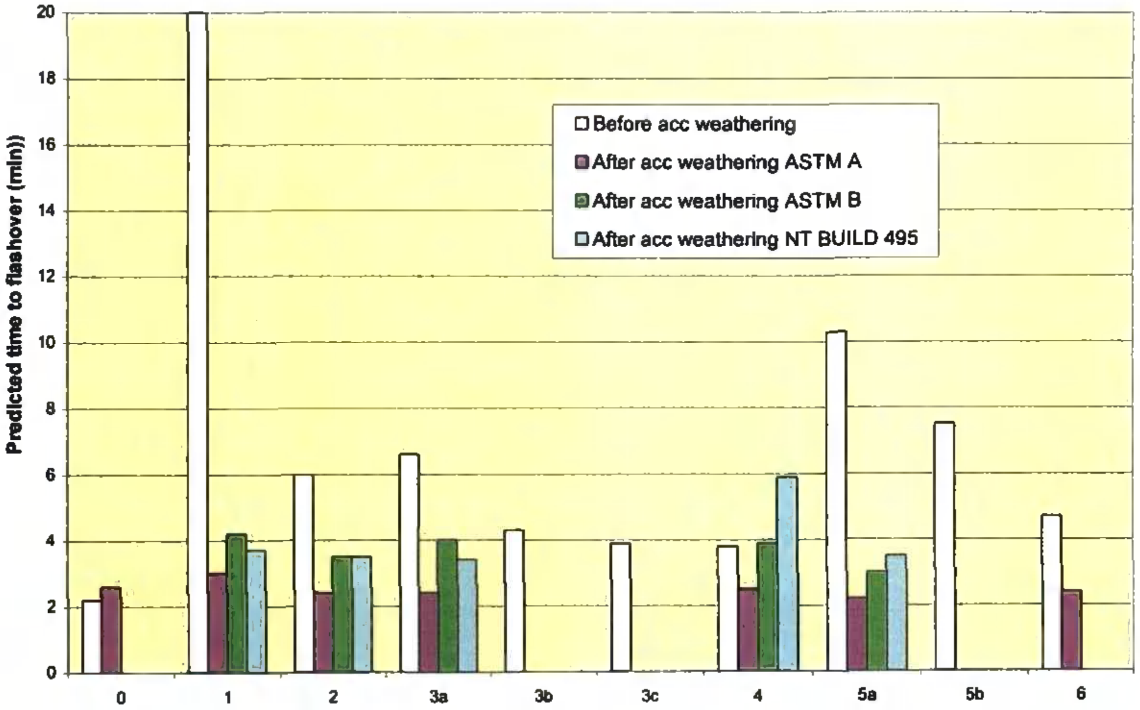

*Figure 6.3. Comparisons between durability methods for untreated wood (0) and FRT products 1 to 6 in terms of predicted time to ignition /11/.*
*OBS: Higher values mean better fire performance.*

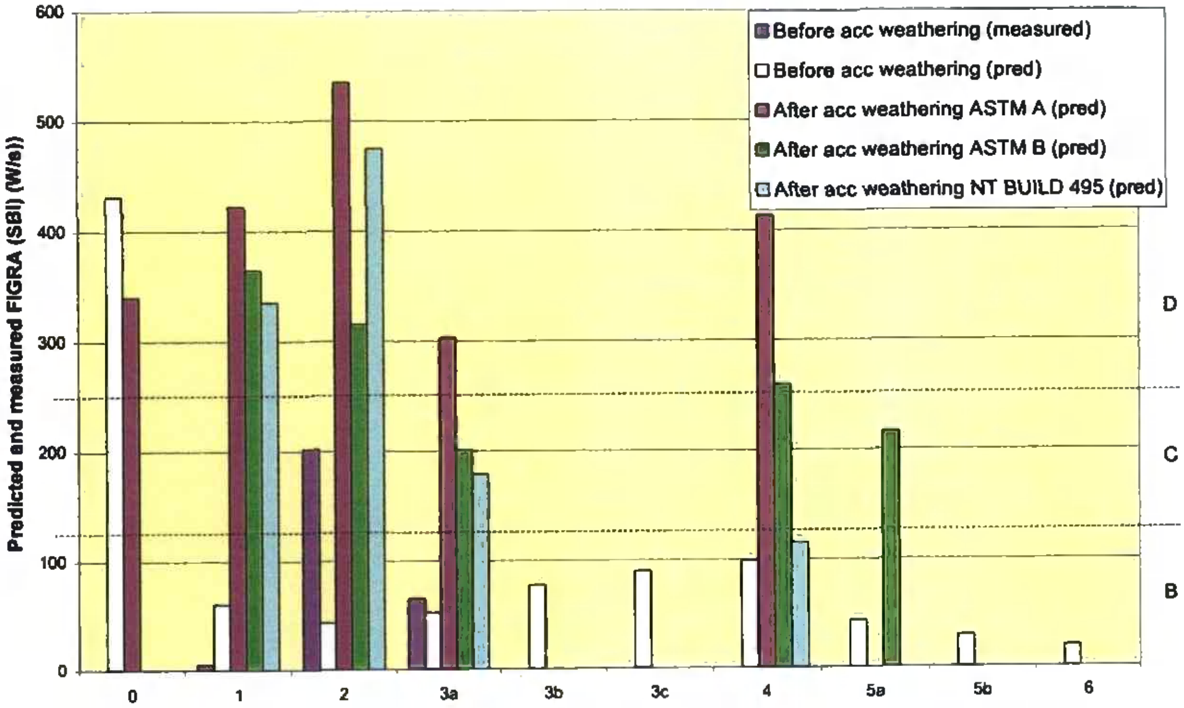

*Figure 6.4 Comparisons between durability methods for untreated wood (0) and FRT products 1 to 6 in terms of predicted FIGRA (SBI) /10/. For unexposed panels 1, 2 and 3a measured data according to SBI-testing are included /15/. Euroclass limits are indicated.*
*OBS: Lower values mean better fire performance.*

*Table 6.6 Fire performance before and after accelerated weathering – Summary table*

| **Wood products** | | **Before exposure** | | | | **Draft Nordtest method YY-A** | | | **Draft Nordtest method YY-B** | | | **NT BUILD 495** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FR $kg/m^3$ | Nordic class 2) | Time to f.o, min | FIGRA (SBI), W/s | | Time to f.o, min | FIGRA (SBI), W/s | Mass loss, % * | Time to f.o, min | FIGRA (SBI), W/s | Mass loss, % * | Time to f.o, min | FIGRA (SBI), W/s |
| | | meas | pred | meas | pred | pred | pred | meas | pred | pred | meas | pred | pred |
| **0 mean** | - | **III** | **2,2** | - | **431** | **2,6** | **340** | **1,5** | - | - | **4,3** | - | - |
| stdev | | | 0,2 | | 112 | 0,0 | 78 | 0,5 | | | | | |
| CoV, % | | | 9,1 | | 26 | 0,0 | 23 | 33 | | | | | |
| **1 mean** | 350 1) | **I** | **>20** | **5** | **< 120** 3) | **3,0** | **422** | **19,3** | **4,5** | **364** | **14,0** | **3,7** | **335** |
| stdev | | | | | | 0,4 | 74 | 1,4 | 0,0 | 69 | | 0,3 | 69 |
| CoV, % | | | | | | 13,3 | 17 | 7 | 0,0 | 19 | | 8,1 | 21 |
| **2 mean** | 27? | **II?** | **6,0** | **202** | **43** | **2,4** | **535** | **8,0** | - | **315** | **8,0** | **3,5** | **475** |
| stdev | | | 0,7 | | 5 | 0,3 | 245 | 2,0 | | 22 | | 0,1 | 33 |
| CoV, % | | | 1,2 | | 11 | 12,5 | 46 | 25 | | 7 | | 2,9 | 7 |
| **3a mean** | 200 1) | **I** | **6,6** | **65** | **52** | **2,4** | **303** | **27,9** | **3,3** | **201** | **25,5** | **3,4** | **179** |
| stdev | | | 0,5 | | 7 | 0,4 | 26 | 3,1 | 0,1 | 43 | | 0,1 | 11 |
| CoV, % | | | 7,6 | | 13 | 14,6 | 9 | 11 | 2,1 | 21 | | 2,9 | 6 |
| **3b mean** | 160 1) | **II** | **4,3** | - | **77** | - | - | - | - | - | - | - | - |
| stdev | | | 0,3 | | 20 | | | | | | | | |
| CoV, % | | | 7,0 | | 26 | | | | | | | | |
| **3c mean** | 50 1) | **III** | **3,9** | - | **90** | - | - | - | - | - | - | - | - |
| stdev | | | 0,1 | | 3 | | | | | | | | |
| CoV, % | | | 2,6 | | 3 | | | | | | | | |
| **4 mean** | 72 1) | **II** | **3,8** | - | **99** | **2,5** | **413** | **2,8** | **3,9** | **259** | **5,4** | **5,9** | **115** |
| stdev | | | 1,3 | | 24 | 0,3 | 105 | 2,8 | 0,5 | 43 | | 0,1 | 21 |
| CoV, % | | | 34 | | 24 | 12,0 | 25 | 100 | 12,8 | 17 | | 1,7 | 18 |
| **5a mean** | 260 | **II** | **10,3** | - | **43** | **2,2** | **372** | **13,5** | **3,0** | **216** | **16,0** | **3,5** | |
| stdev | | | 5,8 | | 16 | 0,6 | 115 | 1,5 | 0,1 | 10 | | 0,3 | |
| CoV, % | | | 56 | | 38 | 25,5 | 31 | 11 | 3,3 | 5 | | 8,6 | |
| **5b mean** | 150 | **II** | **7,5** | - | **29** | - | - | - | - | - | - | - | - |
| stdev | | | 0,6 | | 17 | | | | | | | | |
| CoV, % | | | 8,0 | | 59 | | | | | | | | |
| **6 mean** | 700 $g/m^2$ | **II** | **4,7** | - | **19** | **2,4** | **404** | **3,8** | - | - | - | - | - |
| stdev | | | 0,6 | | 0 | 0,1 | 36 | | | | | | |
| CoV, % | | | 12,8 | | 0 | 4,2 | 9 | | | | | | |

1) Given by producer per each delivered panel; 2) Double tests; 3) Max heat release < 75 kW/$m^2$ → class B.
* Mass loss during durability exposure.

*Table 6.7 Measured and predicted Nordic class <u>before and after</u> accelerated weathering – Summary table*

| Wood products | | Before exposure | | After exposure | | |
|---|---|---|---|---|---|---|
| | | | | **Draft Nordtest Method YY-A** | **Draft Nordtest Method YY-B** | **NT BUILD 495** |
| | FR kg/m$^3$ | Measured 2) | Predicted 3, 4) | Predicted 3, 4) | Predicted 3) | Predicted 3) |
| **0** | - | **III** | **III** | - | - | - |
| **1** | 350 1) | **I** | **I** | **III** | **III** | **III** |
| **2** | 27? | **II?** | **III** | **III** | **III** | **III** |
| **3a** | 200 1) | **I** | **III** | **III** | **III** | **III** |
| **3b** | 160 1) | **II** | **III** | - | - | - |
| **3c** | 50 1) | **III** | **III** | - | - | - |
| **4** | 72 1) | **II** | **III** | **III** | **III** | **III** |
| **5a** | 260 | **II** | **II** | **III** | **III** | **III** |
| **5b** | 150 | **II** | **III** | **III** | - | - |
| **6** | 700 g/m$^2$ | **II** | **II** | **III** | - | - |

1) Given by producer per each delivered panel; 2) Double tests; 3) Predicted data /11/; 4) Round robin data.

*Table 6.8 Measured and predicted Euroclass <u>before and after</u> accelerated weathering – Summary table*

| Wood products | | Before exposure | | After exposure | | |
|---|---|---|---|---|---|---|
| | | | | **Draft Nordtest Method YY-A** | **Draft Nordtest Method YY-B** | **NT BUILD 495** |
| | FR kg/m$^3$ | Measured | Predicted 3,4) | Predicted 3,4) | Predicted 3) | Predicted 3) |
| **0** | - | **(D)** | **D** | **D** | - | - |
| **1** | 350 1) | **B** | **B** | **D** | **D** | **D** |
| **2** | 27? | **C** | **B** | **D** | **D** | **D** |
| **3a** | 200 1) | **B** | **B** | **D** | **C** | **C** |
| **3b** | 160 1) | - | **B** | - | - | - |
| **3c** | 50 1) | - | **B** | - | - | - |
| **4** | 72 1) | - | **B** | **D** | **D** | **C** |
| **5a** | 260 | - | **B** | **D** | **C** | |
| **5b** | 150 | - | **B** | - | - | - |
| **6** | 700 g/m$^2$ | - | **(B) 2)** | **D** | - | - |

1) Given by producer per each delivered panel; 2) Not enough data for modelling; 3) Predicted data /10/;
4) Round robin data.

The Nordic class is generally low for all products, while Euroclass B is easier to achieve. This is a general trend observed for all types of products.

The fire performance is significantly decreased during the accelerated weathering for all FRT panels. No major significant differences between the three durability methods or variations of parameters have been found in this project, probably because leaching has been the dominant effect.

# 7. Conclusions and recommendations

## 7.1 Conclusions on the Hygroscopicity method

Seven FRT wood samples and one untreated wood panel have been included in the round robin testing at four laboratories with Nordtest Method XX Version 1.0 /2/. The repeatability evaluated as coefficient of variation for the moisture content is between 1 and 18 % with a mean value of 3,6 % for different products at the lower relative humidity case (65 % RH at 23 °C) and between 1 and 28 % with a mean value of 5,6 % at the higher relative humidity case (90 % RH at 27 °C). The reproducibility evaluated in the same way is between 1 and 14 % with a mean value of 4,8 % at the lower relative humidity case and between 1 and 19 % with a mean value of 9,0 % for the higher relative humidity case.

Parameters influencing the moisture content are mainly the amount and type of FR chemicals.

No major needs for revisions are foreseen. Minor revisions recommended are to change the initial climate to 50 % RH and 23 °C in order to simplify the testing and combination with fire and durability testing. However, this initial climate is not essential for the use of the test results, see 7.3. The test method should also be better specified to ensure correct handling of samples showing exudation. The testing of such samples might also be interrupted since it indicates inferior hygroscopic performance.

Draft Nordtest method XX is suitable to be used for assessment of the hygroscopic behaviour of FRT wood products.

## 7.2 Conclusions on the Durability methods

Five FRT wood samples and one untreated wood panel have been included in the round robin testing at three laboratories with Nordtest Method YY Version 1.0 /4/. The repeatability evaluated as coefficient of variation for predicted time to flashover is between 0 and 11 % with a mean value of 2,8 % for different products. The reproducibility evaluated in the same way is between 0 and 25 % with a mean value of 11,7 %. Higher relative variations were found for low absolute values, which is quite normal.

No major needs for revisions are foreseen. Minor revisions recommended are to change the initial climate to 50 % RH and 23 °C in order to simplify the determination of mass loss in combination with fire testing. It is also recommended to specify the orientation of samples at exposure and how to cut pices for fire testing from exposed panels.

All the test panels were subject to severe leaching. For this purpose all durability methods might be used as alternatives for the time being until further evidence is available. For Draft Nordtest method YY-A a first evaluation might be made already after 4 exposure cycles (instead of 12 cycles) in order to simplify the procedure.

Limited mass loss during weathering exposure might be used as a first indicator of maintained fire performance after weathering.

## 7.3 Service classes

The suitability of the proposed service classes has been confirmed. Criteria are proposed in Table 7.1

*Table 7.1 Service classes for FRT wood products*

| **Service class** | | **Existing requirements** | **New requirements** [1] | |
|---|---|---|---|---|
| | **Intended use** | **Fire performance** | **Moisture sensitivity** [2] | **Weather durability** [3] |
| - | Short term | National / European fire class | - | - |
| I | Interior – fluctuating humidity | - " - | - Moisture content < [30] %<br>- No salt at surface and no exudation of liquid | - |
| U | Exterior | - " - | - " - | Maintained fire performance after<br>- Accelerated ageing or<br>- Natural weathering |

1) to be fulfilled at the same or higher retention levels of chemicals as for the fire performance;
2) according to Nordtest XX; 3) according to Nordtest YY or NT BUILD 495.

## 7.4 Products

Several of the FRT wood products used in this project had an inferior initial fire performance. They also showed a marked decrease in fire performance after all durability exposure methods.

Earlier studies have demonstrated that the fire performance of FRT wood products might be maintained also after weathering /14/.

There is thus a need for further product development among the producers. Until better products, better coatings or further evidence are available it is recommended that the products are used in interior applications, i e in service class I. For exterior use, appropriate protecting surface coatings are needed.

## 7.5 Recommendations for further work

It is recommended that the accelerated methods used in this project are calibrated and compared with natural weathering. The products used for such an exercise must fulfil relevant fire classification initially. They should also be protected with at least primer coats. Measures should be taken to follow the mass loss of the FRT wood products carefully during the different exposure cycles in order to reduce the need for fire testing and to develop simplified procedures.

## 8. References

### Durability test methods and specifications

1. ASTM D 3201-94: Standard Test Method for Hygroscopic properties of fire-retardant treated wood and wood-based products, 1994
2. DRAFT Nordtest Method XX Version 1.0: Hygroscopic properties of fire-retardant treated wood and wood-based products, March 2001.
3. ASTM D 2898-94: Standard Methods for Accelerated weathering of fire-retardant-treated wood for fire testing, 1994
4. DRAFT Nordtest Method YY Version 1.0: Accelerated weathering of fire-retardant-treated wood for fire testing, March 2001.
5. NT BUILD 495. Building materials and components in the vertical position: Exposure to accelerated climatic strains. Nordtest Method Approved 2000-11.
6. Requirements for approval of FRT wood products used at humid conditions. In Norwegian (Kravdokument for frivillig godkjenningsordning for brannimpregnerte treprodukter brukt i fuktige miljøer). Nordic Wood project P99096. Final version, December 2001.

### Fire test methods

7. ISO 5660-1: Fire tests – Reaction to fire – Part 1: Rate of heat release from building products (Cone calorimeter method).
8. EN 13823: Reaction to fire tests for building products – Building products excluding floorings – exposed to the thermal attack by a single burning item ('SBI-test').
9. NT Fire 004: Building products: Heat release and smoke generation, Edition 2, 1985-11.

### Research papers and reports

10. Hakkarainen, T. & Kokkala, M. A. Application of a one-dimensional thermal flame spread model on predicting the rate of heat release in the SBI test. Fire and Materials, Vol. 25, No. 2, pp. 61–70, 2001.
11. Östman B, Tsantaridis L: Correlations between cone calorimeter and time to flashover in the room fire test, Fire and Materials, Vol. 18, 205-209, 1994
12. Östman B A-L, Tsantaridis L D: Heat release and classification of fire retardant wood products, Fire and Materials, vol 19, 253-258, 1995
13. Östman B, Voss A, Hughes A, Hovde P J, Grexa O: Durability of fire retardant treated wood products at humid and exterior conditions - Review of literature, Fire and Materials, vol 25, no 3, 95-104, 2001
14. Östman B, Tsantaridis L: Durability of FRT wood at exterior and humid applications – Initial studies, Proc. Interflam, 89-99, 2001.
15. Kristoffersen, B: Using the cone calorimeter for screening and control testing of fire retarded wood products. Nordtest project 1526-01, Ongoing project, 2002.

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# Prediction of Euroclasses of fire retarded wood products using a one-dimensional thermal flame spread model

## Description of the basic model

The heat release related Euroclass of a construction product in an SBI test can be predicted on the basis of cone calorimeter test data[1] using a one-dimensional thermal flame spread model.[2] The starting point of the calculation is the basic flame spread equation.[3] The flame spread can be mathematically described by solving the initial value problem

$$\frac{dx_p(t)}{dt} = \frac{x_f(t) - x_p(t)}{t_{ig}} \qquad t > 0 \qquad [1]$$

$$x_p(0) = x_{p0} \qquad t = 0$$

$$x_f(t) = k_f \left[\dot{Q}(t)\right]^n \qquad t > 0, n > 0, k_f > 0$$

where $x_p$ is the position of the pyrolysis front, $x_{p0}$ is the initial height of the pyrolysis area, $x_f$ is the flame height, $t_{ig}$ is a characteristic ignition time, and $n$ and $k_f$ are constants, specific to a test method. The heat release rate $\dot{Q}(t)$ is calculated as the sum of the contributions of the burner and the material ($\dot{Q}_0$ and $\dot{Q}_{mat}$, respectively) as follows:

$$\dot{Q}(t) = \dot{Q}_0(t) + \dot{Q}_{mat}(t) \qquad [2]$$

$$\dot{Q}_{mat}(t) = x_{p0} w \dot{q}''(t) + w \int_{\tau=0}^{\tau=t} \dot{q}''(t-\tau) \frac{x_f(\tau) - x_p(\tau)}{t_{ig}} d\tau$$

where $w$ is the width of the pyrolysis area (assumed constand in the one-dimensional model), and $\dot{q}''(t)$ and $t_{ig}$ are the heat release rate (HRR) curve and the ignition time from a cone calorimeter test, respectively. The ignition is assumed to take place at the moment when the heat release rate per unit area reaches 50 kW/m$^2$. This is an objective and traceable way to determine $t_{ig}$, and the results are in good agreement with visual observations. The origin of time in the integration is the moment when the specimen behind the burner flame is ignited. The ignition delay of the specimen is taken into account as a shift of time after the numerical calculation has been completed.

The model was originally developed for the prediction of upward flame spread on wooden facade specimens.[2] To apply the model to predicting SBI test results, the input parameters $x_{p0}$, $w$, $k_f$ and $n$ were determined and optimised by examining the features of the SBI test arrangement and based on model tuning.[1] The basic version of the SBI prediction model was developed using test data of the SBI Round Robin materials.[4] The input parameter values used in these calculations were $x_{p0}$ = 0.26 m, $w$ = 0.30 m, $k_f$ = 0.048 and $n$ = 0.77. In addition, input data from cone calorimeter tests run at the exposure level of 50 kW/m$^2$ were scaled to lower levels selected on the basis of practical experience and tuning of the model. The ignition time was scaled to 30 kW/m$^2$, and the time scale of the HRR curve to 25 kW/m$^2$. The HRR values in the basic version, however, were taken as measured at the heat exposure level of 50 kW/m$^2$ without any scaling.

The scaling of the ignition time from heat exposure level 1 to level 2 was performed as follows:

$$t_{ig2} = t_{ig1} \frac{\dot{q}_1'' - \dot{q}_{cr}''}{\dot{q}_2'' - \dot{q}_{cr}''}$$

where $t_{ig1}$ and $t_{ig2}$ are ignition times at heat exposure levels $\dot{q}_1''$ and $\dot{q}_2''$, respectively, and $\dot{q}_{cr}''$ is the critical heat flux, i.e. the minimum heat flux for ignition of a material. The typical critical heat flux of wood products, $\dot{q}_{cr}'' = 12$ kW/m$^2$, was used in the calculations due to the lack of detailed ignitability data for the majority of the products studied. Thus, the scaling of ignition times from 50 kW/m$^2$ to 30 kW/m$^2$ was equal to multiplication by 2.1.

An analytical model for the charring rate of wood[5] was used as the basis of scaling of the HRR curve. The relationship between charring rate $\beta$ (in mm/min) and an external heat flux $\dot{q}_e''$ (in kW/m$^2$) is roughly

$$\beta \propto 0.2\dot{q}_e'' + 5.$$

The heat release rate is directly proportional to the charring rate. Thus, the heat release rate at the exposure level of 25 kW/m$^2$ is approximately 2/3 of the value measured at a test with 50 kW/m$^2$. Assuming that the whole specimen burns eventually and the total amount of heat produced is constant, the burning time (i.e. the time scale of the test) should be multiplied by 3/2, respectively. In general, the scaling of the test time scale from heat exposure level 1 to level 2 can be expressed as follows:

$$t_2 = t_1 \frac{0.2\dot{q}_1'' + 5}{0.2\dot{q}_2'' + 5}$$

During the tuning of the model, it was noticed that scaling down the cone calorimeter heat release rate resulted in predictions of SBI heat release rates that were considerably lower than the measured values. Since the difference was too large to be corrected by any other input parameters, the downscaling of the HRR level was removed, which means effectively a multiplication with a constant.

In many cases, the flame front spreads on the surface of an SBI test specimen both vertically and laterally. The one-dimensional model applied takes into consideration only the vertical direction, but the effect of the lateral flame spread can be compensated to an extent adequate for most products by the selection of input parameters and the way of using the HRR curve from the cone calorimeter test. As a result of calculations according to Eqs. I–2, predicted HRR curves of SBI tests were obtained. From these curves, FIGRA values determining the product classification were calculated.

The selection of materials studied included some products that were out of the scope of the modeling calculations due to their ignition properties. The ignition was assumed to take place when the heat release rate per unit area reached 50 kW/m$^2$ in the cone calorimeter test. Some materials never crossed this limit. Only transitory flaming, or no flaming at all, was observed for these materials in the cone calorimeter tests. In addition, the behaviour of certain products could not be modeled since the ignition times scaled from exposure level of 50 kW/m$^2$ to 30 kW/m$^2$ were longer than 1200 seconds which is the duration of the SBI test. In practice, this means an ignition time longer than 570 seconds at 50 kW/m$^2$.

All these products not igniting or having very long ignition times meet the requirements of class A2/B in the SBI test. It could be concluded without any modeling calculations that if the heat release rate per unit area of a product does not exceed 50 kW/m$^2$ or its ignition time is longer than 570 seconds in the cone calorimeter test at the exposure level of 50 kW/m$^2$, the product falls into class A2/B in the SBI test. Thus, this kind of products can be included in the model as special cases.

The above-presented basic version of the one-dimensional thermal flame spread model can be used to predict the first peak of the HRR curve in the SBI test. The early phases of the test are of major importance in the determination of the FIGRA index and the classification of the product tested. Only a HRR curve from a single cone calorimeter test at 50 kW/m$^2$ is needed as input data for the model.

The basic model works reasonably well for products with minor or moderate lateral flame spread in the SBI test. For these materials, the one-dimensionality of the model can be compensated with the selection of the input parameters. In the data set studied, the classification on the basis of the FIGRA index was predicted correctly for 89 % of the products.[6]

It is emphasized that the predictive procedure developed is a non-physical model intended for engineering applications. Thus, it includes several approximations and simplifications. Since the use of the model requires only a small amount of material and data from one small-scale test, it provides a practical tool for product development and quality control.

## Application of the model to fire-retarded wood products

During the development of the basic SBI model, it was noted that the selection of input parameters is not optimal for certain groups of materials. This results in prediction inaccuracies that can be reduced by optimising the input parameters separately for these products groups. In the case of fire retarded (FR) wood products, special attention should be paid to the width of the pyrolysis area, *w*, because the lateral flame spread on FR wood specimens in the SBI test is usually negligible.

The modelling study of FR wood products (performed mostly outside this project) included about 20 different products, including impregnated or brush-applied FR wood materials, and special plywoods with FR glue. In this selection of products, different heat release behaviour patterns in cone calorimeter tests were identified. The main patterns are introduced in Figure 1. Strongly FR impregnated materials release heat at a low level showing no sustained flaming (Fig. 1a) or ignite after a long heat exposure time (Fig. 1b). A third typical behaviour for this kind of products is slowly increasing heat release at a relatively low level (Fig. 1c). Milder impregnations and brush-applied FR treatments typically result in even heat release at a moderate level (Fig. 1d), or a heat release behaviour typical of also non-FR wood products showing two maxima with an intermediate plateau (Fig. 1e). Some products exhibit a sharp peak in the very beginning, followed by even heat release level (Fig. 1f) or the "non-FR wood behaviour".

Considering the one-dimensional thermal flame spread model presented above, the cases shown in Figures 1a and 1b, and sometimes 1c, can be included to the basic model as special cases. If the heat release rate of the product does not reach 50 kW/m$^2$ (the ignition criterion) within 570 seconds from the beginning of the heat exposure, the class prediction is A2/B. In practice, however, class B is predicted because class A2 requirements in the EN ISO 1182 or EN ISO 1716 test cannot be met due to the organic substances included in all wood products.

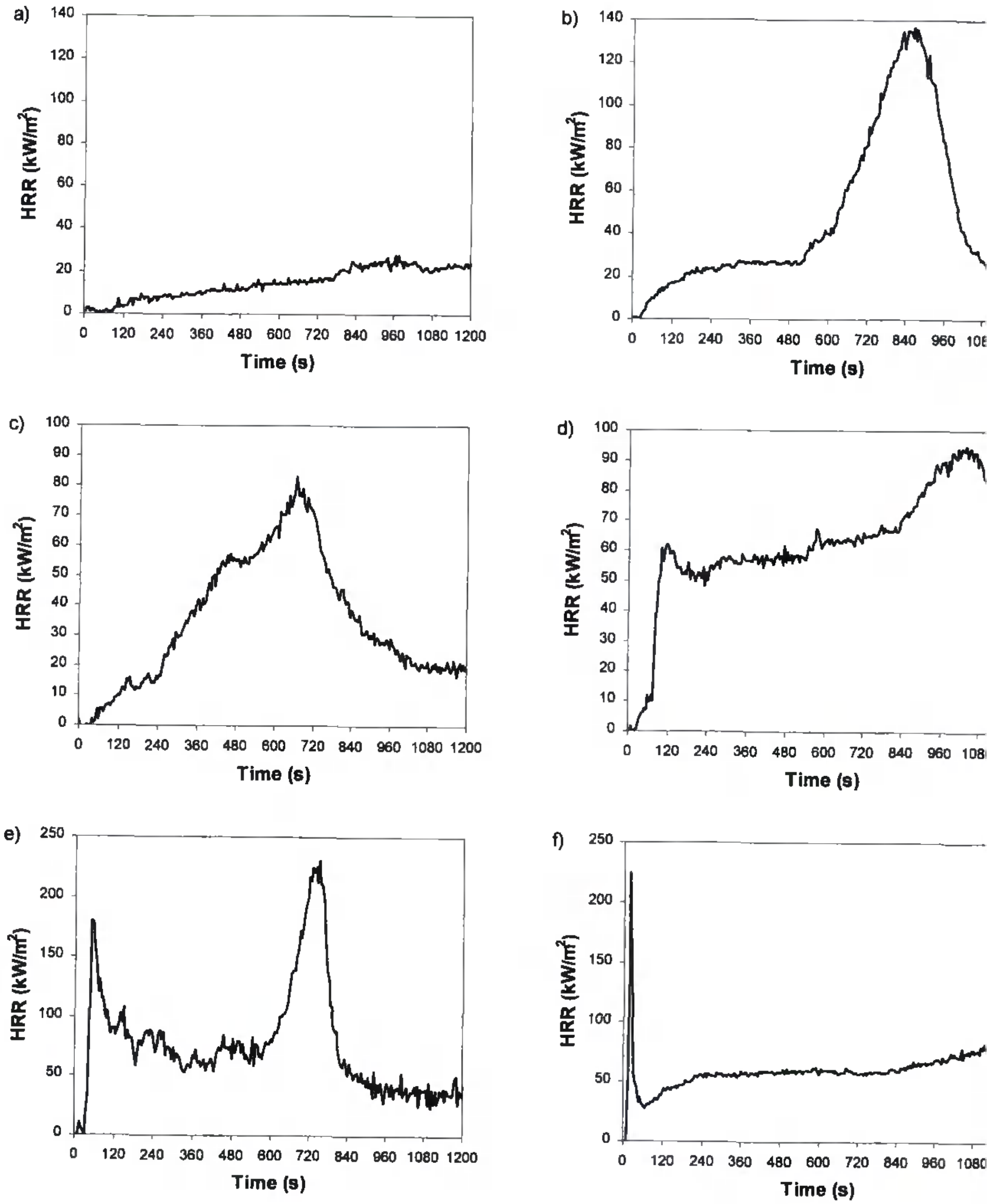

*Figure 1. Different heat release patterns of FR wood products in cone calorimeter tests at 50 kW/m$^2$: a) low heat release throughout the test, no ignition, b) low heat release in the beginning of the test, ignition after a long heat exposure, c) slowly increasing heat release at a relatively low (or moderate) level, d) even heat release at a moderate level after the ignition, e) two maxima with an intermediate plateau, also typical of non-FR wood products, and f) a sharp peak in the beginning, followed by even heat release.*

For products showing a heat release pattern of Fig. 1c, 1d, 1e or 1f, an optimisation of model input parameters was performed. It was found that the best prediction for the heat release rate is obtained using $w = 0.20$ m as the pyrolysis width, and changing the scaling of the ignition time and the heat release rate level.

In the basic model, the ignition time scaled from the exposure level of 50 $kW/m^2$ to 30 $kW/m^2$ (Eq. 3) is used both for the calculation of flame spread and heat release rate according to Eqs. 1–2, and for the ignition delay time shift after the calculation. For FR wood products, the ignition time used in the flame spread and heat release calculations is scaled to 30 $kW/m^2$, but the ignition time at 50 $kW/m^2$ is used for the ignition delay time shift.

Scaling of HRR values from the exposure level of 50 $kW/m^2$ to 25 $kW/m^2$ was introduced in the modified model for FR wood. The scaling of the heat release rate values from heat exposure level 1 to level 2 is carried out as follows:

$$HRR_2 = HRR_1 \frac{0.2\,\dot{q}''_2 + 5}{0.2\,\dot{q}''_1 + 5} \qquad [6]$$

HRR scaling from 50 $kW/m^2$ to 25 $kW/m^2$ means thus a multiplication with 2/3. Since the calculation procedure presumes that the heat release rate used as the model input reaches 50 $kW/m^2$, the original unscaled HRR measured at 50 $kW/m^2$ must reach 75 $kW/m^2$ to be applicable in the calculations. If HRR measured at 50 $kW/m^2$ is less than 75 $kW/m^2$ throughout the test, class B is predicted without calculations.

The procedure of using the one-dimensional thermal flame spread model for the prediction of Euroclasses of fire retarded wood products is presented in Table 1.

*Table 1. Phases of predicting SBI product classification of FR wood products.*

1. Perform a cone calorimeter test at the heat exposure level of 50 $kW/m^2$.
    - determine the maximum heat release rate $HRR_{max}$ (first peak for a multi-peak curve)
        - if $HRR_{max} < 75$ $kW/m^2$ → class B predicted
    - determination of the ignition time $t_{ig,50}$ as the moment when the heat release rate per unit area reaches 50 $kW/m^2$
        - if $t_{ig,50} > 570$ s → class B predicted
2. Calculate the predicted HRR curve of the SBI test according to Eqs. 1–2 using the following input parameter values and data scalings:
    - $x_{p0} = 0.26$ m
    - $w = 0.20$ m
    - $k_f = 0.048$
    - $n = 0.77$
    - ignition time scaled to 30 $kW/m^2$ (Eq. 3), use $\dot{q}''_{cr} = 12$ $kW/m^2$ or a value known for the product studied
    - time scale scaled to 25 $kW/m^2$ (Eq. 5)
    - HRR values scaled to 25 $kW/m^2$ (Eq. 6)
3. Shift the resulting SBI HRR curve with $t_{ig,50}$ taking into account the ignition delay.
4. Calculate FIGRA indices (and $THR_{600s}$) and determine the predicted "SBI class".

## References

[1] Hakkarainen, T. & Kokkala, M. A. Application of a one-dimensional thermal flame spread model on predicting the rate of heat release in the SBI test. Fire and Materials, 2001. Vol. 25, No. 2, pp. 61–70.

[2] Kokkala, M., Baroudi, D. & Parker, W. J. Upward flame spread on wooden surface products: Experiments and numerical modelling. In: Hasemi, Y. (ed.). Fire Safety Science – Proceedings of the 5th International Symposium. Melbourne, Australia, 3–7 March 1997. International Association for Fire Safety Science, 1997. Pp. 309–320. ISBN 4-9900625-5-5

[3] Saito, K., Quintiere, J. G. & Williams, F. A. Upward turbulent flame spread. In: Grant, C. E. & Pagni, P. J. (eds.). Fire Safety Science – Proceedings of the 1st International Symposium. Gaithersburg, USA, 7–11 October 1985. Washington: Hemisphere, 1986. Pp. 75–86. ISBN 0-89116-456-1

[4] Van Mierlo, R. J. M. Development of the SBI test method. Delft: TNO Building and Construction Research, 1998. 11 p. + app. 43. p. (TNO-report 98-CVB-R1067.)

[5] Mikkola, E. Charring of wood. Espoo: Technical Research Center of Finland, 1990. 35 p. (VTT Research Reports 689.) ISBN 951-38-3711-4

[6] Hakkarainen, T. Correlation studies of SBI and cone calorimeter test results. In: Interflam 2001 – Proceedings of the 9th International Conference (Vol. 1). Edinburgh, UK, 17–19 September 2001. London: Interscience Communications, 2001. Pp. 519–530. ISBN 0-9532312-8-3

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