Recent developments and regulations in fire resistance of wood and wood-based composites

Nadir Ayrilmis
Department of Wood Mechanics and Technology, Forestry Faculty, Istanbul University-Cerrahpasa, Bahcekoy, Sariyer, 34473, Istanbul, Turkey
nadiray@istanbul.edu.tr

Abstract: This study focused on the fire-retardant treatment of wood and wood-based composites using various methods. The recent developments in the fire-retardant standards and classification of wood and wood-based composites were reviewed. Most commonly used fire-retardants and commercial application methods of fire retardants such as boron compounds and phosphates to improve fire resistance of wood and wood based composites were explained. Furthermore, fire-retardant mechanism was informed. Novel nanomaterials used in the fire resistance of wood and wood-based composites were introduced. Significant criteria in choosing of the suitable fire retardants for wood and wood-based composites were explained.
KEYWORDS: *FIRE, FLAME RETARDANCY, WOOD, FIRE RETARDANTS, COMBUSTION, WOOD-BASED COMPOSI T*

1. Introduction

Fire resistance is one of the main obstacles to use wood and wood-based composites in structural applications in most countries. In figures, fires in dwellings cause in Europe over 4.000 deaths and 80.000 diverse injuries per year. The cause of death is suffocation due to smoke in about two thirds of the cases, while burns result only in about one third of the fatalities [1].

Fire retardants protect wood against to the fire in different ways [2]:

Promotion of char formation,
- Conversion of volatile gases to inert gases such as water vapour and carbon dioxide,
- Dilution of pyrolysis gases,
- Inhibiting chain reactions of burning in the gas phase,
- Protecting the surface by an insulating/intumescent layer.

Significant criteria in choosing of the suitable fire retardants are as follows:

Low-toxicity to human health
Minimal risk to atmosphere, climate and environment
Flame spread of 25 or less or «Class B»
Self extinguishing
Won't spread fire
Reduced heat release rate
Disrupts volatile gases
Suitable with manufacturing process conditions (resin blending and hot pressing) during production of wood based-composites
Minimum effect on mechanical properties of wood and wood based materials
Easy-suppy
Low-cost
Easy preparation and application to wood and wood-based panels
Type of wood based substrate
Regulatory requirement to be satisfied
New build or maintenance/upgrade
Service life conditions/environment
Installation conditions
Maintenance requirements

2. Fire-retardant treatment methods of wood and wood-based composites

Fire retardants, if correctly applied, provide added value to wood materials extend the market potential of the world's most natural building material.

Commercial applications of fire retardants to wood can be divided to three classes:

1) Impregnation of wood with a fire retardant using vacuum and over pressure.
2) Addition of a fire retardant as a surface application.
3) Addition of a fire retardant to wood during its manufacturing process (in particular adhesive with fire retardant). Compatibility between resin and fire retardant (in terms of acidity of the fire retardant) and hot pressing conditions is significant factor.

Other techniques to improve fire resistance of wood and wood based composites are as follows:

a) Chemical modification

The most common fire retarding chemicals used for wood and wood-based panels are inorganic salts, such as ammonium polyphosphate, monoammonium phosphate, diammonium phosphate, ammonium sulfate, melamine phosphate, guanyl phosphate, ammonium sulphate; aluminum trihydrate (the most widely used fire retardant in the U.S.), magnesium hydroxide, and boron compounds, such as borax, boric acid, borax pentahydrate, disodium octaborate tetrahydrate, ammonium pentaborate, zinc-borate, and zinc chloride [3,4]. Waterborne inorganic salts may be hygroscopic and cause to the corrosion metal fixtures in treated wood.

Chemical mechanisms are often accompanied by one or several physical mechanisms, most commonly endothermic dissociation or dilution of fuel. Charring is the most common condensed phase mechanism (Fig. 1).

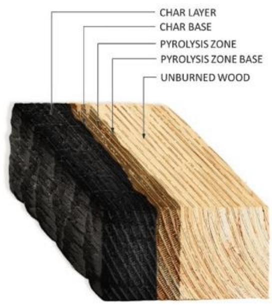

Figure 1. *Superficial carbonization structure of wood exposed to the fire [5].*

b) Physical modification

The physical modifications can include, for instance, combinations of different wood species, methods for higher surface densities, and composites [2]. If the top layer of a wood material consists of a specific species of wood with a relatively low heat release, the heat release peak is smaller, offering possibilities to improve the reaction-to-fire class of the wood material. Alternatively, fire-retardant treated lamellas can be included in wood as surface layers. Using this method, the consumption of fire retardant is reduced compared to wood materials that are fire-retardant treated as a whole. Ignition can be delayed by introducing a high-density surface layer on a wood material. High pressure laminate, for example, might be used for this purpose [2].

c) Nanocomposites

Fire performance of wood and wood-based composites can be improved by using nanocomposites made of layered silicates and organic polymers. The mechanism of fire retardancy of nanocomposites is generally considered to be due to the structure of the char formed during combustion, which enables the char to thermally insulate the polymer and inhibit the formation and escape of volatiles. Nanoscale fire retardants, such as SiO_2, TiO_2 and ZrO_2, nanoclay, nano-wollastonite, carbon nanotube, nano-silica, have a high ratio of surface area to weight; the smaller the particle size is, the bigger the ratio of surface area to weight. These adavantages improve fire resistance of nanoscale fire retardant chemicals. In addition, nanoscale fire retardants, for example zinc borate, can adsorb more smoke and dust per unit weight than regular sizes during wood combustion.

The most commonly used test methods and guidance documents for the reaction to fire testing of wood materials are as follows:
1. Non-combustibility test EN ISO 1182
2. Gross calorific potential test EN ISO 1716
3. Single Burning Item test EN 13823
4. Ignitability test EN ISO 11925-2
5. Radiant panel test EN ISO 9239-1

3. Fire protection classes of wood materials

Fire protection classes of the materials according to EN 13501-2 and DIN 4102 is given in Table 1. According to Table 1, for example, F90 means that escape routes beneath the fire are protected for up to 90 minutes.

Table 1. *Fire protection classes of the materials.*

Test designation type	Fire protection class		Fire protection in min.
	EN 13501-2	DIN 4102	
fire retarding	REI 30	F 30	30
highly retardent	REI 60	F 60	60
fire resisting	REI 90	F 90	90
fire resisting	REI 120	F 120	120
high fire resistance	REI 180	F 180	180

The relevant classification system is based on the EN 13501-1. In the Euroclass system, building materials are divided to seven classes on the basis of their reaction-to-fire properties. The performance description and the fire scenario for each class are presented in Table 2 according to the main principles used in the development of the Euroclass system [2].

Table 2. Indicative performance descriptions and fire scenarios for Euro-classes.

Class	Performance description	Fire scenario and heat attack		Examples of products
A1	No contribution to fire	Fully developed fire in a room	At least 60 kW/m²	Products of natural stone, concrete, bricks, ceramic, glass, steel and many metallic products
A2	"	"	"	Products similar to those of class A1, including small amounts of organic compounds
B	Very limited contribution to fire	Single burning item in a room	40 kW/m² on a limited area	Gypsum boards with different (thin) surface linings Fire retardant wood products
C	Limited contribution to fire	"	"	Phenolic foam, gypsum boards with different surface linings (thicker than in class B)
D	Acceptable contribution to fire	"	"	Wood products with thickness ≥ about 10 mm and density ≥ about 400 kg/m³ (depending on end use)
E	"	Small flame attack	Flame height of 20 mm	Low density fibreboard, plastic based insulation products
F	No performance requirements	–	–	Products not tested (no requirements)

The highest possible European class for fire retardant wood materials is class B. Untreated wood usually fulfils class D. The main parameters influencing the reaction to fire characteristics of all wood are product thickness, density and end use conditions such as substrates or air gaps behind the wood material [6].

Table 3. *Classification of wood and wood-based composites according to EN 13986 standard.*

Wood-based panel products2)	EN product grade reference	Minimum density (kg/m³)	Minimum thickness (mm)	Class3) (excluding floorings)	Class4) Floorings
Particleboards	EN 312	600	9	D-s2, d0	D_{FL}-s1
Fibreboards, Hard	EN 622-2	900	6	D-s2, d0	D_{FL}-s1
Fibreboards,	EN 622-3	600	9	D-s2, d0	D_{FL}-s1
Medium		400	9	E, pass	E_{FL}
Fibreboards, Soft	EN 622-4	250	9	E, pass	E_{FL}
Fibreboards, MDF5)	EN 622-5	600	9	D-s2, d0	D_{FL}-s1
Cement-bonded particleboard6)	EN 634-2	1000	10	B-s1, d0	B_{FL}-s1
OSB board7)	EN 300	600	9	D-s2, d2	D_{FL}-s1
Plywood	EN 636	400	9	D-s2, d0	D_{FL}-s1
Solid wood panels	EN 13353	400	12	D-s2, d0	D_{FL}-s1

1) EN 13986
2) Wood-based panels mounted without an air gap directly against class A1 or A2-s1,d0 products with minimum density 10 kg/m³ or at least class D-s2,d0 products with minimum density 400 kg/m³
3) Class as provided for in Table 1 of the Annex to Commission Decision 2000/147/EC
4) Class as provided for in Table 2 of the Annex to Commission Decision 2000/147/EC
5) Dry process fibreboard
6) Cement content at least 75% by mass
7) Oriented strand board

Structural timber with minimum mean density of 350 kg/m³ and minimum thickness and width of 22 mm may, based on the evidence presented, be classified without further testing as class D-s2, d0. Glued laminated timber (Glulam) with minimum mean density of 380 kg/m³ and minimum thickness and width of 40 mm can be classified without further testing as class D-s2, d0 [6]. Classes of reaction to fire performance for construction materials excluding floorings are given in Table 4 [2]. The significant parameters affecting the reaction to fire behavior of wood material are its density and thickness, and final use conditions such as substrates or air gaps behind the wood material. For wood materials except floorings the relevant main classes are B, C, D, and E. The relevant additional classes for smoke development are s1, s2 and s3, and for burning droplets d0, d1 and d2 (Table 4).

Table 4. *Euroclass of reaction to fire performance for construction materials excluding floorings [2].*

Class	Test method(s)	Classification criteria	Additional classification
A1	EN ISO 1182 (1); *and*	ΔT ≤ 30°C; *and* Δm ≤ 50%; *and* t_f = 0 (i.e. no sustained flaming)	-
	EN ISO 1716	PCS ≤ 2.0 MJ.kg⁻¹ (1); *and* PCS ≤ 2.0 MJ.kg⁻¹ (2) (2a); *and* PCS ≤ 1.4 MJ.m⁻² (3); *and* PCS ≤ 2.0 MJ.kg⁻¹ (4)	
A2	EN ISO 1182 (1); *or*	ΔT ≤ 50°C; *and* Δm ≤ 50%; *and* t_f ≤ 20s	
	EN ISO 1716; *and*	PCS ≤ 3.0 MJ.kg⁻¹ (1); *and* PCS ≤ 4.0 MJ.m⁻² (2); *and* PCS ≤ 4.0 MJ.m⁻² (3); *and* PCS ≤ 3.0 MJ.kg⁻¹ (4)	
	EN 13823 (SBI)	FIGRA ≤ 120 W.s⁻¹; *and* LFS < edge of specimen; *and* THR_{600s} ≤ 7.5 MJ	Smoke production(5); *and* Flaming droplets/ particles (6)
B	EN 13823 (SBI); *and*	FIGRA ≤ 120 W.s⁻¹; *and* LFS < edge of specimen; *and* THR_{600s} ≤ 7.5 MJ	Smoke production(5); *and* Flaming droplets/ particles (6)
	EN ISO 11925-2(8): *Exposure = 30s*	Fs ≤ 150mm within 60s	
C	EN 13823 (SBI); *and*	FIGRA ≤ 250 W.s⁻¹; *and* LFS < edge of specimen; *and* THR_{600s} ≤ 15 MJ	Smoke production(5); *and* Flaming droplets/ particles (6)
	EN ISO 11925-2(8): *Exposure = 30s*	Fs ≤ 150mm within 60s	
D	EN 13823 (SBI); *and*	FIGRA ≤ 750 W.s⁻¹	Smoke production(5); *and* Flaming droplets/ particles (6)
	EN ISO 11925-2(8): *Exposure = 30s*	Fs ≤ 150mm within 60s	
E	EN ISO 11925-2(8): *Exposure = 15s*	Fs ≤ 150mm within 20s	Flaming droplets/ particles (7)
F	No performance determined		

(1) For homogeneous products and substantial components of non-homogeneous products.
(2) For any external non-substantial component of non-homogeneous products.
(2a) Alternatively, any external non-substantial component having a PCS ≤ 2.0 MJ/m², provided that the product satisfies the following criteria of EN xxxx(SBI) : FIGRA ≤ 20 W.s⁻¹; *and* LFS < edge of specimen; *and* THR_{600s} ≤ 4.0 MJ; *and* s1; *and* d0.
(3) For any internal non-substantial component of non-homogeneous products.
(4) For the product as a whole.
(5) **s1** = SMOGRA ≤ 30m².s⁻² *and* TSP_{600s} ≤ 50m² ; **s2** = SMOGRA ≤ 180m².s⁻² *and* TSP_{600s} ≤ 200m²; **s3** = not s1 or s2.
(6) **d0** = No flaming droplets/ particles in ENxxxx (SBI) within 600s; **d1** = No flaming droplets/ particles persisting longer than 10s in ENxxxx (SBI) within 600s; **d2** = not d0 or d1; Ignition of the paper in EN ISO 11925-2 results in a d2 classification.
(7) Pass = no ignition of the paper (no classification); Fail = ignition of the paper (**d2** classification).
(8) Under conditions of surface flame attack and, if appropriate to the end–use application of the product, edge flame attack.

4. Conclusions

When the wood is heated, it burns by producing flammable volatiles that can ignite. To reduce combustion, wood is treated with fire retardants which significantly decrease the rate at which flames travel across the wood surface. Nevertheless, some fire-retardant treatments may produce unwanted secondary side effects, for example, increased moisture content, reduced strength and increased potential to corrode metal connectors. To decrease these negative effects, fire retardant treatments may improve the fire performance of wood and wood-based composites considerably through reducing ignitability, rate of heat release and flame spread. This study summarized the fire-retardant treatment mechanism, national and international fire testing standards, and commonly used fire retardants in wood industry. When the wood is protected against to the fire using fire-retardants, its use will increase in construction industry, especially for structural timbers as well as home furniture, doors, window frames, and other applications.

5. References

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