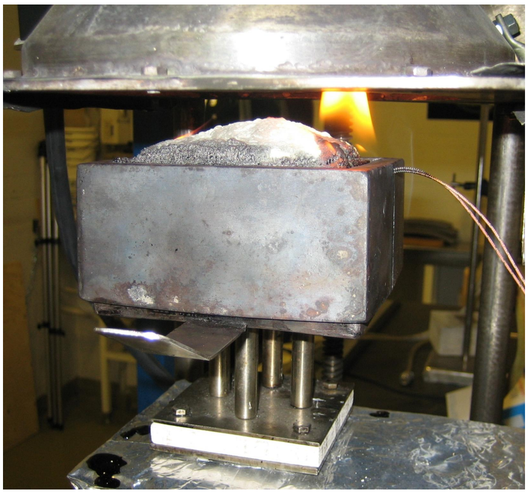
RESEARCH REPORT

VTT-R-07061-09



Thin thermal barriers for wood based products to improve fire resistance

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Summary

Fire resistance of Innovative Timber structures – FireInTimber – is a research project within the European WoodWisdom-Net framework. The key objective of the FireInTimber project is to provide new possibilities for wood products in construction by proper fire design.

This report describes the work performed in FireInTimber WP 4: Novel components and structural materials, Task 4.5: Thin thermal barriers. The basic performance requirements and potential solutions for thin thermal barriers are discussed. A fire test series for intumescent-type coatings is reported.

The main performance requirements for thin thermal barriers are the ability to influence ignition and/or charring, and the sustainability of the protection. The suitability of the thin thermal barrier for protecting wood and for end-use conditions must be considered, as well as its reliability in the long term and in fire conditions.

Thin thermal barriers considered as suitable for improving the fire performance of wooden and wood-based products include intumescent coatings and layers of non-combustible materials (e.g. metal sheets and ceramic layers), and combinations of these two methods. In the future, nanocomposite coatings might be applicable for fire protection of wood products.

The fire test series of intumescent-type coatings demonstrated that the charring behaviour of wooden or wood-based products can be significantly improved by this kind of products. Intumescent coatings can delay the onset of charring and reduce the charring rate. Further improvements can be achieved by combining a thin metal sheet acting as a gas barrier to intumescent coating.

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Contents

1 Introduction

Fire resistance of Innovative Timber structures – FireInTimber – is a research project within the European WoodWisdom-Net framework with 14 participants from 9 countries. The project started in November 2007 and will be finalised in March 2010. It is supported by industry through the European initiative BWW Building With Wood and public funding organisation. The key objective of the FireInTimber project is to provide new possibilities for wood products in construction by proper fire design. The vision is to ensure that the wider use of wood in buildings will be associated with improved fire safety.

This report describes the work performed in FireInTimber WP 4: Novel components and structural materials, Task 4.5: Thin thermal barriers. The basic performance requirements and potential solutions for thin thermal barriers are discussed. A fire test series for intumescent-type coatings is reported.

2 Basic performance requirements for thin thermal barriers

The main performance requirements for thin thermal barriers are the ability to influence ignition and/or charring, and the sustainability of the protection.

A thermal barrier can prevent or delay ignition and/or charring by its thermal insulation function or by acting as a gas barrier. A protective layer with a low thermal conductivity can insulate the underlying material from heat and thus reduce and delay its temperature rise. A gas barrier layer reduces the evaporation of pyrolysis gases from, and access of oxygen to, the surface of the protected material, with the result that ignition of the surface is prevented or delayed.

In order to provide efficient protection, the thermal barrier layer must be sustainable. First of all, it must withstand temperatures typical for fires, i.e., it must not melt, crack or otherwise lose its integrity when exposed to high temperatures. It must adhere firmly to the material beneath, so that it does not detach under heat exposure (at least not before the charring temperature of the protected surface is reached) or in the course of time. In relation to its intended end-use application, the thermal barrier system (i.e. the barrier material and its attachment) must have a sufficient long-term durability.

Further requirements can be specified for the appearance of the protective system. In some applications, it is desirable to maintain visibility of the surface features of wood, which limits the choice of thermal barriers.

When selecting a thin thermal barrier for protecting wooden or wood-based products, special attention must be paid to the suitability of the product for protecting wood, and for the intended end-use conditions. Furthermore, the method of attachment or application, and its reliability in the long term and in fire conditions must be carefully considered.

3 Potential solutions for thin thermal barriers

Thin thermal barriers considered as suitable for improving the fire performance of wooden and wood-based products include intumescent coatings and layers of non-combustible materials (e.g. metal sheets and ceramic layers). Combinations of these two methods can provide further possibilities for some applications: for example, intumescent coating can be supplemented with a metal sheet acting as an additional gas barrier.

In principle, ceramic coatings can be used for thermal protection. However, their suitability for fire protection of wood must be considered case-specifically. Thermally sprayed ceramic layers are used as thermal insulation of gas turbine components, but the method is relatively costly and its applicability to wood products is unknown. Another possibility might be ceramic materials with water of crystallisation, providing a heat sink due to the evaporation of water and thus slowing down the temperature rise. Ceramic coatings can also be used for enhancing light and moisture resistance as shown in a study of the effects of ceramic coatings on the properties of fire retardant treated wood [1]. The fire performance of the material was also slightly improved.

Intumescent coatings are commonly used for protecting steel structures. Their application on wood has been studied [2], and some commercial products intended for wood are available. At present, however, fire protection of wooden and wood-based products with intumescent coatings is not widely employed.

Intumescent coatings consist of a binding agent, a carbonising substance, a foam-producing substance, a dehydrating agent, and an esterification catalyst. A wide variety of compounds can be used for these purposes [2]. In addition to the basic constituents, other substances such as expandable graphite flakes [3, 4] can be included.

Intumescent coatings are inert at low temperatures. When exposed to high temperatures, the coating swells and produces a porous char layer of low thermal conductivity. The char layer protects the underlying material by delaying its temperature rise and hindering the transport of oxygen to and pyrolysis gases from the surface. To illustrate the process, Figure 1 shows a wooden specimen with intumescent coating during and after a fire test.

A well-selected intumescent-type coating can effectively delay the onset and propagation of charring in wooden or wood-based products as shown below in Section 4.

In the future, nanocomposite coatings might be applied to improve the fire performance of wooden and wood-based products. In this approach, nanometre-scale particles are added to a macroscopic material to produce new properties. Intumescent polymer-clay nanocomposites have been applied to protect polymers [5] and steel [6], but studies for wood products are not currently available.

a)

b)

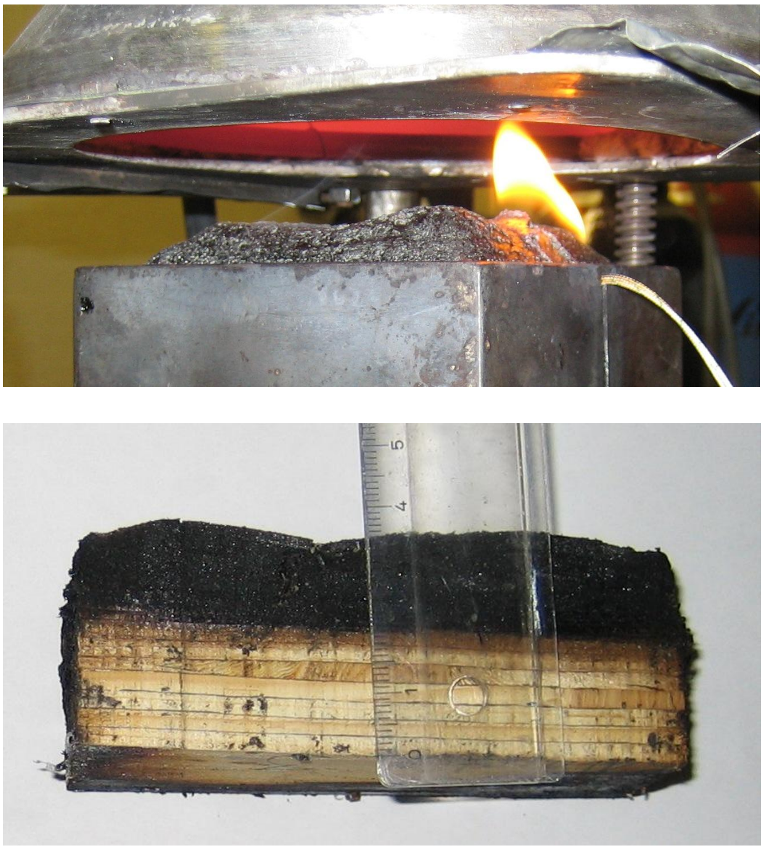

Figure 1. An LVL specimen with intumescent coating a) in fire test, and b) after fire test (cone calorimeter, 50 kW/m^2).

4 Fire tests of intumescent-type coatings

The fire tests performed in the FireInTimber project under WP4 Task 4.5 (Thin thermal barriers) at VTT are described in detail. The purpose of the tests was to evaluate the effects of various intumescent-type coatings on the charring behaviour of timber.

4.1 Test method

The cone calorimeter test [7] is a bench-scale fire test method to assess the contribution of the product tested to the rate of evolution of heat during its involvement in fire. The main parts of the apparatus are a cone-shaped radiant electrical heater with a temperature controller, a spark igniter, a weighing cell, a specimen holder, and an exhaust gas system. A schematic picture of the cone calorimeter is presented in Figure 2.

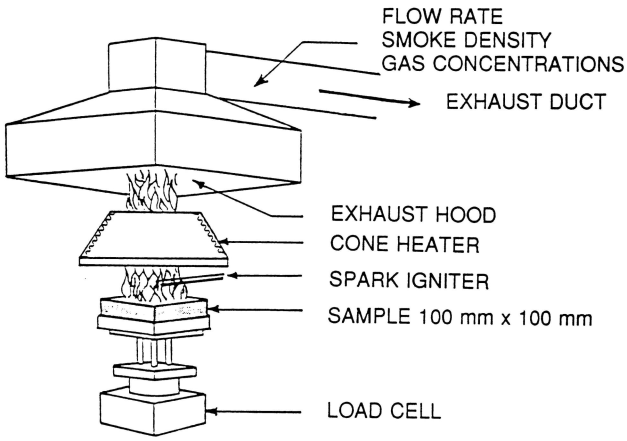

Figure 2. A schematic picture of the cone calorimeter.

The heat attack on the surface of the specimens was provided using the cone-shaped heater at the irradiance of 50 kW/m^2. The spark igniter was not used in the tests of the coated specimens.

4.2 Specimens tested

The basic material of the specimens was laminated veneer lumber (LVL) with a thickness of 38 mm and a density of ca. 480 kg/m^3. LVL was coated with different intumescent-type coatings. The specimen with a galvanized steel profile was included in the test series to examine the effect of steel parts of connections on charring. Thermocouples of type K (wire thickness 0,25 mm) were embedded in the specimens at depths of 10 and 20 mm to monitor charring. The specimens tested are summarized in Table 1 and illustrated in Figure 3.

Table 1. Description of specimens in charring tests by cone calorimeter.

Code	No. of tests	Specimen description
uncoated	1	Uncoated LVL, reference test
intum. A	3	intumescent coating, applied by brushing on LVL, ca. 200 g/m^2 (1 test) or ca. 400 g/m^2 (2 tests)
intum. B	1	intumescent coating (ca. 400 g/m^2) and topcoat (ca. 50 g/m^2), applied by brushing on LVL
intum. C	1	intumescent coating, applied by brushing on LVL, ca. 400 g/m^2
graphite-based	1	graphite-based sheet, glued on LVL using PVC glue
Al+intum.	2	A sheet consisting of aluminium foil (50 µm) and intumescent coating, glued on LVL using dispersion-based glue
galv. steel	1	A galvanized steel profile (1,2 mm) attached on LVL (partially); a sheet consisting of aluminium foil (50 µm) and intumescent coating glued on steel and LVL
nail plate	1	A galvanized steel nail plate (1,2 mm) pressed onto LVL; a sheet consisting of aluminium foil (50 µm) and intumescent coating glued on nail plate and LVL

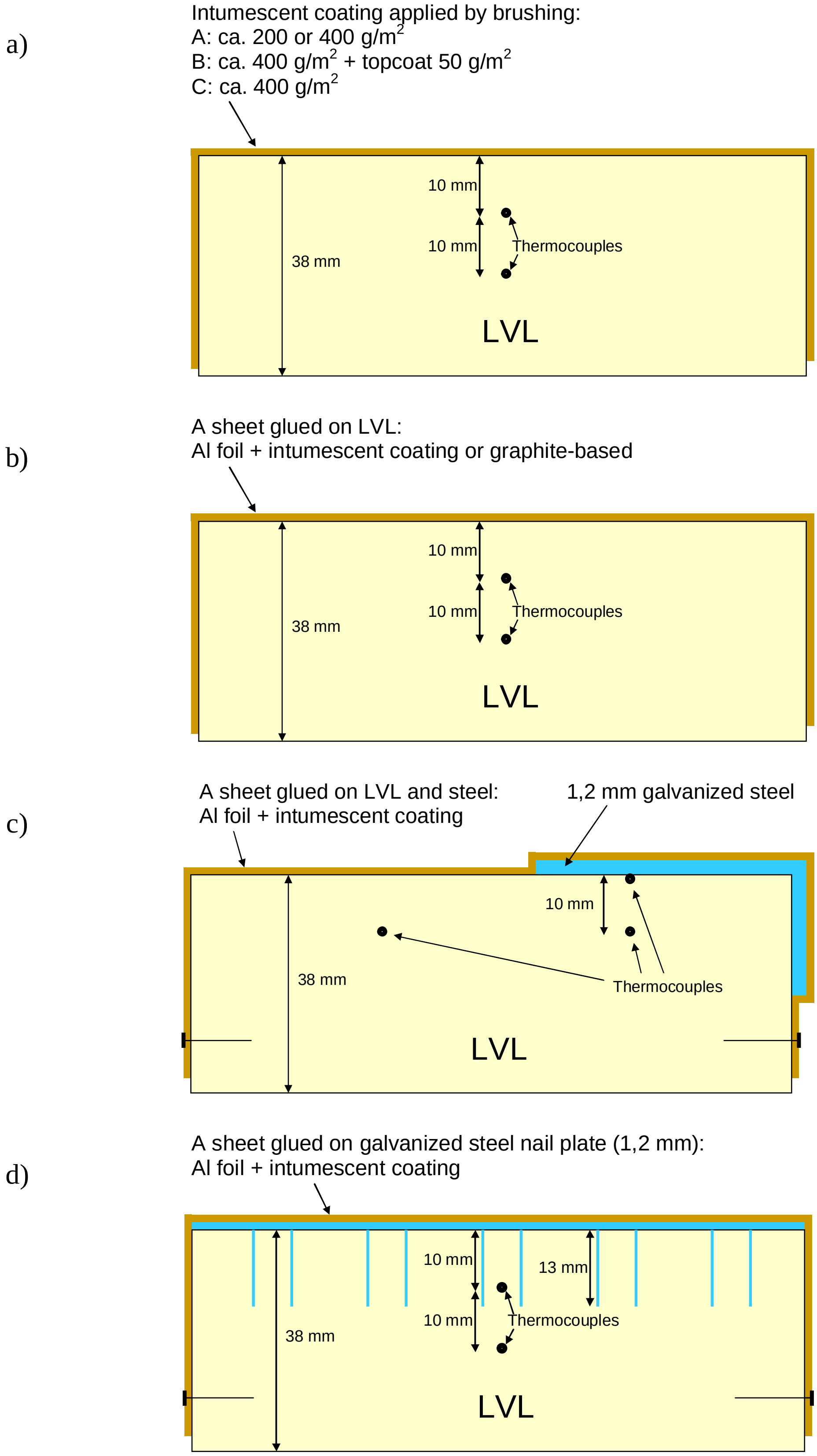

Figure 3. Structure of the coated LVL specimens: a) intumescent coatings applied by brushing, b) sheets glued on LVL, c) a sheet glued on LVL and galvanized steel profile, and d) a sheet glued on galvanized steel nail plate.

4.3 Test results

The propagation of the char front in the specimens was monitored by thermocouples. Charring was assumed to start when the temperature of wood reached 300 °C. After the tests, the specimens were cleaved to measure the total charring depth during the test. Figures 4 and 5 show the char depth as a function of time in the LVL and LVL/galvanized steel specimens, respectively.

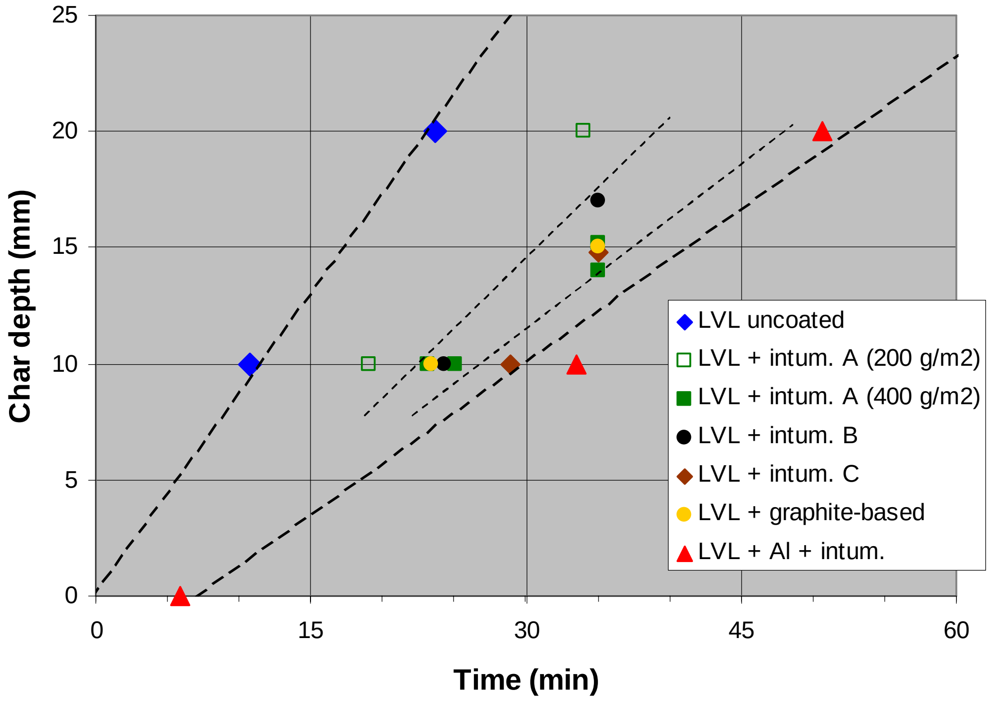

Figure 4. Propagation of charring in LVL specimens (uncoated and coated with intumescent coating or protective sheet) exposed to irradiative heat flux of 50 kW/m^2 (cone calorimeter). The measurement uncertainty of char depth at 10 and 20 mm is ± 1 mm.

The propagation of charring in LVL specimens coated with different intumescent coatings and protective sheets is presented in Figure 4, including a comparison to uncoated LVL. Charring of unprotected LVL started immediately when the specimen was exposed to heat attack, and the charring rate was about 0,85 mm/min. The intumescent coatings and protective sheets studied delayed the onset of charring approximately 6 minutes. When charring had started, the char front propagated at the rate of 0,5–0,6 mm/min in the specimens coated with different intumescent coatings, provided that the amount of application of the coating was sufficient. The results of the graphite-based sheet were of the same order as those of the intumescent coatings. The sheet consisting of intumescent coating and aluminium foil provided even more efficient protection for the underlying wood product: the measured charring rate was approximately 0,45 mm/min.

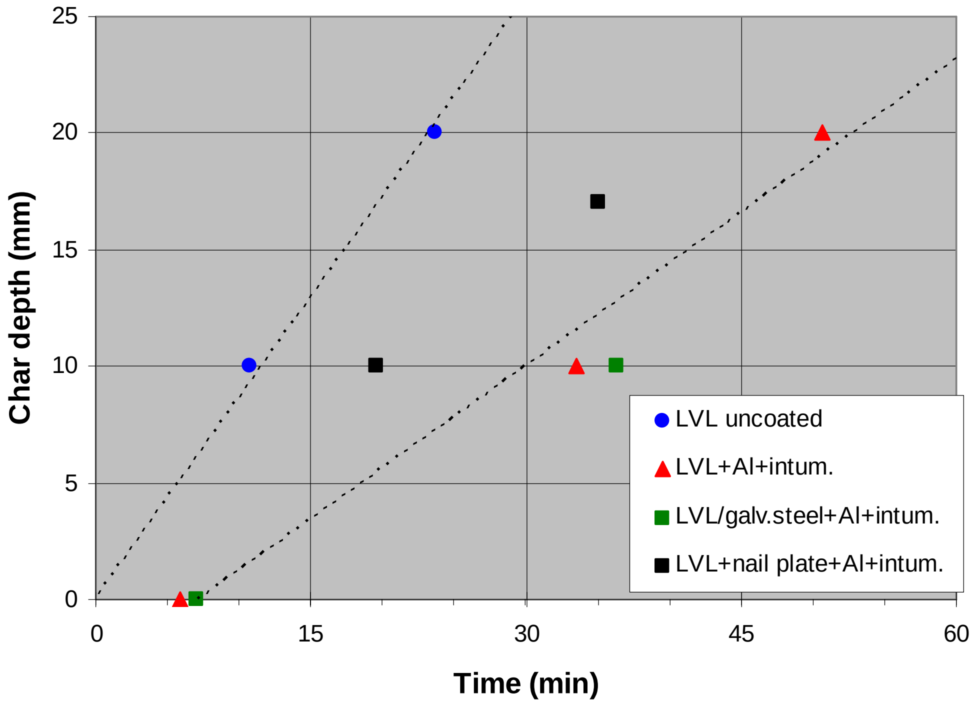

Figure 5. Propagation of charring in LVL/galvanized steel specimens coated with a protective sheet consisting of Al foil and intumescent coating exposed to irradiative heat flux of 50 kW/m^2 (cone calorimeter). The results for LVL uncoated and coated with the sheet are shown for comparison. The measurement uncertainty of char depth at 10 and 20 mm is ± 1 mm.

Figure 5 presents the charring comparison of LVL combined with galvanized steel parts and bare LVL (without any steel parts) protected by a sheet consisting of aluminium foil and intumescent coating. Also the results of uncoated LVL are shown. The charring rate of LVL for the specimen with galvanized steel profile was of the same order as that of bare LVL covered by the protective sheet. However, it was observed that the propagation of charring in LVL was faster under the steel profile than in the area not in contact with steel. For the specimen with galvanized steel nail plate, faster charring of LVL (ca. 0,6 mm/min) was observed. The nails of the nail plate apparently conduct heat deep into LVL, leading to increased charring rate.

4.4 Conclusions

Charring behaviour of wooden or wood-based products can be significantly improved by intumescent-type coatings. Intumescent coatings can delay the onset of charring and reduce the charring rate. Further improvements can be achieved by combining a thin metal sheet acting as a gas barrier to intumescent coating.

5 Summary

The main performance requirements for thin thermal barriers are the ability to influence on ignition and/or charring, and the sustainability of the protection. Ignition and charring can be prevented or delayed by heat insulation capability or by gas barrier function. Concerning sustainability, thin thermal barriers shall endure typical fire temperatures, and adhere firmly to the product to be protected.

When selecting a thin thermal barrier for protecting a wooden or wood-based product, attention must be paid to the following issues:

- suitability for protecting wood;
- suitability for specific end-use conditions;
- the method of attachment/application and its reliability in the long term and in fire conditions.

Potential thin thermal barriers for improving the fire performance of wooden and wood-based products include intumescent coatings and layers of non-combustible materials (e.g. metal sheets and ceramic layers), and combinations of these two methods. In the future, nanocomposite coatings might be applicable for fire protection of wood products.

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