

Reaction-to-Fire Performance of Coated Cross-Laminated Timber Assessed by the Single Burning Item Test, Including the Cooling Phase [†]

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Abstract

The reaction-to-fire performance of cross-laminated timber (CLT) was investigated using the Single Burning Item (SBI) test in accordance with EN 13823, with emphasis on the influence of surface coatings on fire behaviour during both the heating and cooling phases. Five CLT configurations were examined, including an uncoated reference specimen, specimens treated with hydrophobic UV, insecticide, and combined fire-retardant and insecticide coatings, as well as a configuration incorporating an additional thin timber layer. In addition to the standard SBI measurements used for classification according to EN 13501-1, in-depth temperatures were recorded at selected positions, heights and depths within the CLT. The results show that all coated and modified configurations exhibit higher near-surface in-depth temperatures compared to the uncoated reference during heating, with the insecticide coating producing differences exceeding 150 °C at shallow depths, while differences decrease with increasing depth and during the cooling phase. Despite these differences, all configurations exhibited equal or reduced FIGRA values, with reductions of up to 13% relative to the uncoated reference, and were all classified as Euroclass D-s2,d0. The study demonstrates that consideration of both heating and cooling behaviour provides complementary insight into CLT fire response without altering the reaction-to-fire classification outcome.

Keywords: Single Burning Item (SBI); reaction to fire; cross-laminated timber (CLT); surface treatments; in-depth temperature measurements; EN 13823; cooling phase

1. Introduction

The use of cross-laminated timber (CLT) in buildings has increased steadily in recent years, driven by sustainability considerations and the growing acceptance of timber-based structural systems. As a combustible construction product, CLT must be assessed within the framework of reaction-to-fire testing in order to demonstrate compliance with regulatory requirements and to support its classification for use in buildings.

The fire performance of CLT has been extensively studied in the context of fire resistance, with research focusing on charring rates, structural behaviour under standard fire exposure and compartment fire dynamics [1,2]. These studies have established a solid understanding of CLT thermal response under severe fire conditions. However, the reaction-to-fire performance of CLT, which governs its contribution to fire growth in the early stages



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of a fire, has received comparatively less attention in the research literature. While the SBI is recognised as one of the principal reaction-to-fire test methods for CLT in Europe [3], published experimental SBI data for CLT configurations remain limited.

Within the European regulatory system, the Single Burning Item (SBI) test, defined in EN 13823 [4], constitutes the reference experimental method for evaluating the contribution of construction products to fire growth. The test provides quantitative indices, including FIGRA, THR600, SMOGRA and TSP600, which form the basis for classification according to EN 13501-1 [5]. For timber products, and in particular for CLT, these indices capture the combined response of surface ignition, flame spread and heat release under a standardised fire exposure.

Surface treatments and coatings are widely used in timber construction for protective and aesthetic purposes; their influence on reaction-to-fire performance has been studied for solid wood and wood-based products, predominantly using cone calorimetry and smaller-scale test methods [6,7]. However, the effect of such treatments on the SBI performance of CLT specifically and on the in-depth thermal response of CLT under SBI exposure has not been systematically examined.

Supplementary temperature measurements can offer additional insight into the behaviour of CLT during SBI testing, particularly with respect to spatial and temporal variations in temperature within the material. When implemented without altering the standard test procedure, such measurements remain fully compatible with the intent of the SBI method while providing additional information. SBI testing is primarily used to assess fire growth during the heating phase, whereas the cooling phase is not included in the test procedure and is rarely examined in relation to the in-depth temperature response of timber products.

The present study addresses this gap by conducting a series of SBI tests on CLT specimens with different surface treatments and configurations, including coatings and an additional thin timber layer. In addition to the standard SBI measurements required for Euroclass classification, in-depth temperatures were recorded at multiple positions, heights and depths within the CLT. The objective is to examine how these modifications influence both the SBI fire growth indices and the in-depth temperature development of CLT, including the cooling phase, while remaining strictly within the framework of standardised reaction-to-fire testing.

2. Materials and Methods

2.1. Test Method and Specimens

The experimental programme was based on the Single Burning Item (SBI) test conducted in accordance with EN 13823 [4]. All tests followed the standard procedure, using the prescribed burner configuration and test duration, and were performed under identical conditions to ensure direct comparability between test cases. For testing the CLT specimens, EN 16351 [8] provides additional information regarding the mounting of the specimen. Based on this, the long and short wings are butt-joined (edge to edge) and are supported by 50 × 80 mm battens (two in the short wing and four in the long wing), which are connected to the backing boards (c.f. Figure 1c). Five CLT configurations were examined: an uncoated reference specimen ("Ref"), a specimen treated with a hydrophobic UV coating ("UV"), a specimen treated with an insecticide coating ("Ins"), a specimen where a combined fire-retardant and insecticide coating was used ("FR+Ins"), and a CLT configuration incorporating an additional 6 mm thick timber layer applied to the exposed surface (" +6 mm"). The additional layer is added to the exposed surface and consists of a high-quality, usually more expensive timber, for aesthetic purposes. All specimens were

mounted in the standard SBI corner arrangement, forming a long and a short wing, as defined in the test method.

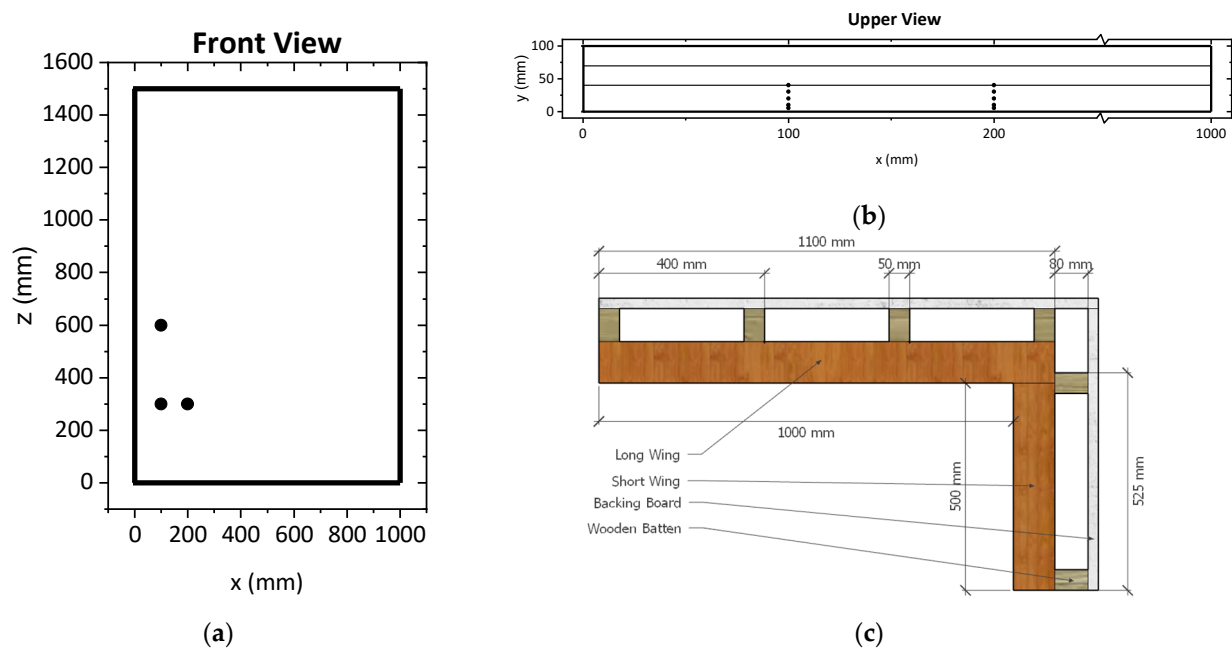


Figure 1. Front view (a) and side view (b) of the specimen with the installed thermocouples and detailed schematic (c) of the configuration according to EN 16351 [8].

2.2. Instrumentation and Temperature Measurements

In addition to the standard SBI instrumentation required for the determination of the standard reaction-to-fire indices (FIGRA, THR_{600} , SMOGRA and TSP_{600}) according to EN 13823, supplementary temperature measurements were implemented in order to record and analyse the increase in the temperature of the CLT specimen during the test. Thermocouples were installed at multiple positions, heights and depths within the long wing of the CLT specimen. In total, 15 thermocouples were installed, and their positioning is summarised in Table 1, considering $(x,z,d) = (0,0,0)$ for the exposed, bottom corner of the long wing. The instrumentation layout was designed to allow temperature development to be monitored both along the height of the specimen and through the thickness of the CLT, rather than at a single representative location. This arrangement enables the identification of spatial variations in temperature that arise due to differences in local fire exposure and material configuration (Figure 1a,b). In-depth temperature measurements were recorded throughout the entire duration of the SBI test (20 min); in addition, temperatures were recorded for 35 min after that, aiming to capture the characteristics of the post-flaming cooling phase following flame extinction.

Table 1. Coordinates of thermocouple locations.

TC	x [mm]	z [mm]	d [mm]	TC	x [mm]	z [mm]	d [mm]	TC	x [mm]	z [mm]	d [mm]
TC01	100	300	5	TC06	100	600	5	TC11	200	300	5
TC02	100	300	10	TC07	100	600	10	TC12	200	300	10
TC03	100	300	20	TC08	100	600	20	TC13	200	300	20
TC04	100	300	30	TC09	100	600	30	TC14	200	300	30
TC05	100	300	40	TC10	100	600	40	TC15	200	300	40

Importantly, the installation of the additional thermocouples did not alter the SBI test procedure or boundary conditions, and all standard SBI measurements were conducted as specified in EN 13823. The supplementary temperature measurements were therefore implemented solely for observational purposes and did not affect the determination of the SBI reaction-to-fire indices or the resulting Euroclass classification.

2.3. Test Matrix

Each CLT configuration was tested once under the same SBI exposure conditions. The uncoated specimen (“Ref”) served as the reference configuration, against which all coated and modified specimens were compared. This approach allows the influence of surface treatments and the additional timber layer on both the SBI indices and the in-depth temperature development to be assessed consistently. It is acknowledged that each configuration was tested once; the results should therefore be interpreted as indicative and comparative rather than statistically representative, which is consistent with common practice in large-scale fire testing research.

3. Results

3.1. Temperature Development Within the CLT Specimens

Figures 2–5 present the in-depth temperature–time histories recorded by thermocouples installed at different positions, heights and depths within the CLT specimens. In each Figure, the temperature curves of the uncoated reference specimen are included. Owing to space limitations, the figures show indicative measurements obtained in selected thermocouple locations; the selected curves capture the most representative near-surface behaviour. All thermocouple positions listed in Table 1 were monitored throughout the test; curves not shown exhibited trends consistent with those presented.

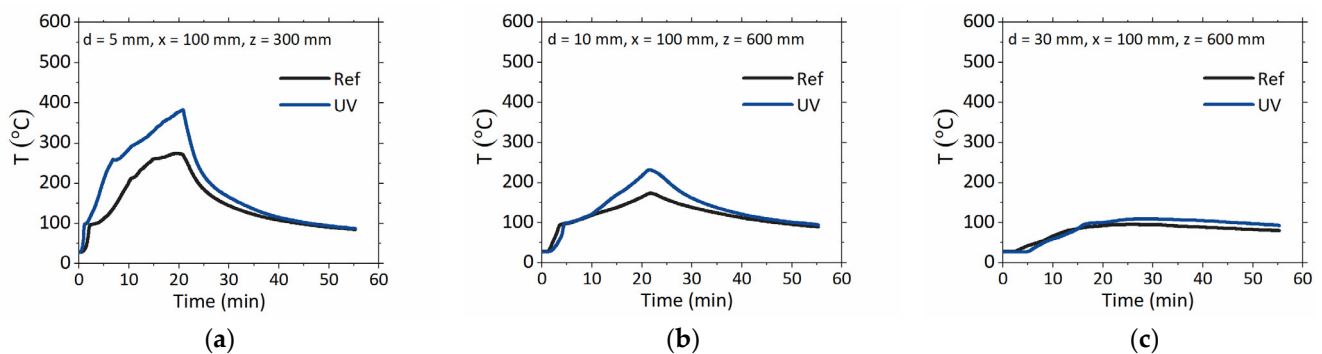


Figure 2. CLT temperatures 100 mm from the corner at a 5 mm depth and 300 mm height (a), at 10 mm depth and 600 mm height (b), and at 30 mm depth and 600 mm height (c).

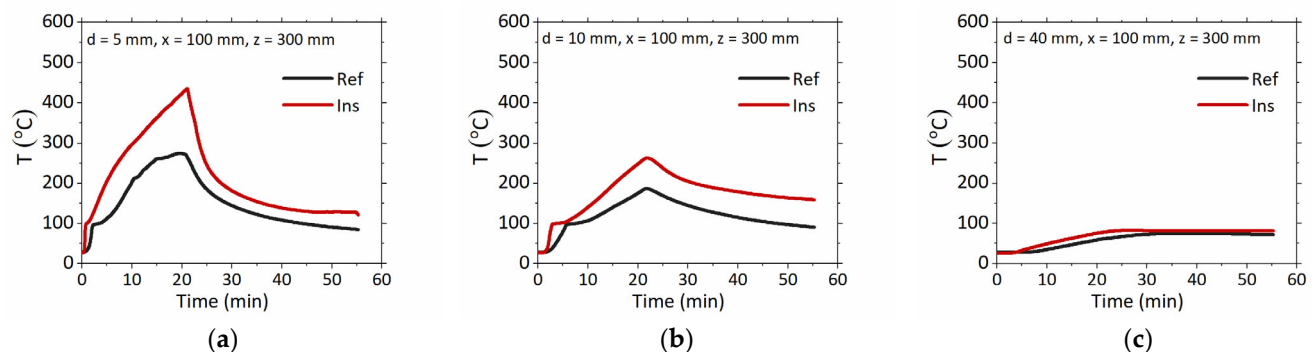


Figure 3. CLT temperatures 100 mm from the corner at a 5 mm depth and 300 mm height (a), at 10 mm depth and 300 mm height (b), and at 40 mm depth and 300 mm height (c).

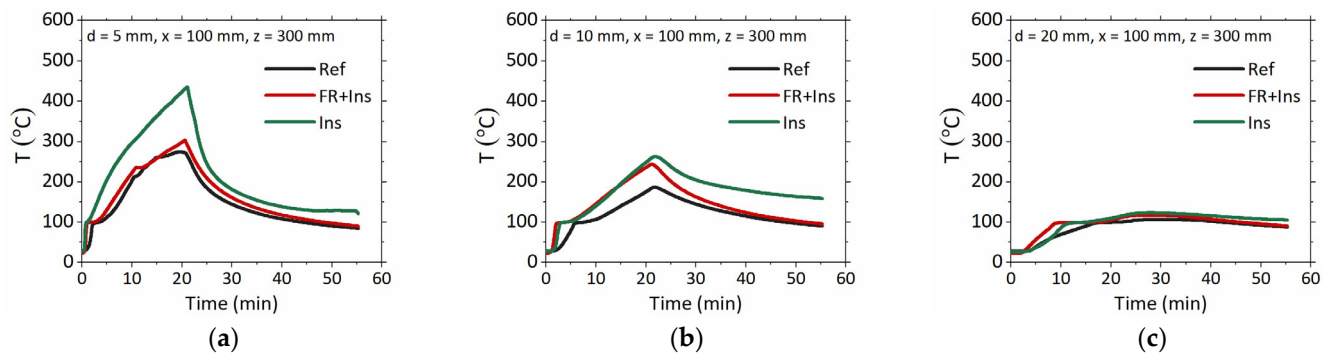


Figure 4. CLT temperatures 100 mm from the corner at 5 mm depth and 300 mm height (a), at 10 mm depth and 300 mm height (b), and at 20 mm depth and 300 mm height (c).

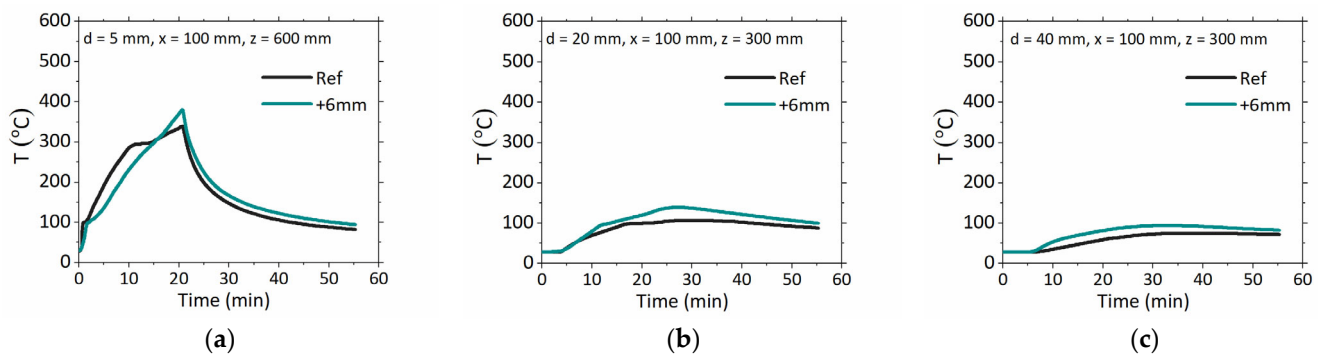


Figure 5. CLT temperatures 100 mm from the corner at a 5 mm depth and 600 mm height (a), at 20 mm depth and 300 mm height (b), and at 40 mm depth and 300 mm height (c).

As shown in Figure 2, the hydrophobic UV-coating-treated specimen exhibits higher near-surface in-depth temperatures compared to the uncoated reference, with peak differences of approximately +100 °C at shallow depths. At greater depths and higher positions, the temperature differences decrease substantially and are typically limited to 10–20 °C. During the cooling phase, near-surface temperatures of the coated specimen decrease below 300 °C at approximately 1300 s, while the uncoated reference remains above this threshold throughout the test. The temperature of the coated specimen drops below 100 °C at approximately 2800 s, slightly later than the uncoated reference, which reaches this level at around 2400 s.

Figure 3 shows that the insecticide-coated specimen exhibits the most pronounced increase in near-surface in-depth temperatures relative to the uncoated reference, with differences exceeding +150 °C at shallow depths. At intermediate depths, the differences remain positive, while at greater depths they are reduced to approximately 10–20 °C. During cooling, near-surface temperatures fall below 300 °C at approximately 1450 s. However, within the recorded time window, the temperature of the insecticide-treated specimen does not fall below 100 °C, whereas the uncoated reference reaches this level at approximately 2400 s, indicating a more persistent near-surface thermal response for the insecticide-coated configuration.

The temperature development for the specimen treated with a combined fire-retardant and insecticide coating is presented in Figure 4; the Ins configuration is also included in Figure 4 to allow direct comparison with the FR+Ins specimen, thereby isolating the contribution of the fire-retardant component to the reduction in the temperatures. Compared to the uncoated reference, near-surface in-depth temperatures are higher, with differences of up to +100 °C, while deeper locations show only minor deviations. A direct comparison with the insecticide-only configuration highlights the influence of the fire-retardant com-

ponent, resulting in a reduction in near-surface temperatures by up to 130 °C relative to the insecticide alone. During the cooling phase, near-surface temperatures decrease below 300 °C at approximately 1320 s and fall below 100 °C at approximately 3000 s, with only small differences relative to the uncoated reference.

Figure 5 shows the temperature–time histories for the configuration incorporating an additional 6 mm thick timber layer. Near-surface temperatures are moderately higher than those of the uncoated reference, with differences of approximately +50 °C increasing to around +80 °C at shallow in-depth locations. At greater depths, the deviations are smaller, typically 15–30 °C. During cooling, near-surface temperatures fall below 300 °C at approximately 1400 s and below 100 °C at approximately 2800 s, compared to 1350 s and 2400 s, respectively, for the uncoated reference. These differences are limited and do not indicate a clear beneficial or adverse effect of the additional timber layer on in-depth temperature development.

Overall, the results show that all coated and modified configurations exhibit higher near-surface in-depth temperatures than the uncoated reference during the heating phase. Differences decrease with increasing depth and height, and during the cooling phase, the relative trends observed during heating are largely preserved close to the surface, while deviations at greater depths diminish rapidly. Table 2 presents the near-surface cooling times, determined from the 5 mm thermocouple measurements, as shown in Figures 2–5. “Not reached” indicates that the temperature remained above 100 °C within the recorded time window. Reported times refer to the selected thermocouple position and are intended as comparative indicators between the investigated configurations.

Table 2. Near-surface cooling times (5 mm) for selected temperature thresholds.

Specimen	Time to T < 300 °C (s)	Time to T < 100 °C (s)
Ref	–	2400
UV	1300	2800
Ins	1450	Not reached
FR+Ins	1320	3000
+6 mm	1400	2800

3.2. Reaction-to-Fire Classification

The reaction-to-fire performance of the tested CLT configurations was evaluated using the standard SBI indices FIGRA, THR_{600s}, SMOGRA and TSP_{600s}, which form the basis for classification according to EN 13501-1 [5]. The results for all configurations are summarised in Table 3.

Table 3. Summary of the SBI indices and the corresponding Euroclass classification.

Specimen	FIGRA [W/s]	THR _{600s} [MJ]	SMOGRA [m ² /s ²]	TSP _{600s} [m ²]	Classification
Ref	512.36	16.09	4.07	61.16	D-s2,d0
UV	503.46	18.64	3.82	57.82	D-s2,d0
Ins	497.01	18.53	3.63	62.93	D-s2,d0
FR+Ins	450.64	17.75	3.32	60.00	D-s2,d0
+6 mm	447.20	12.98	3.85	62.96	D-s2,d0

The uncoated reference specimen provides the baseline for comparison and results in a D-s2,d0 classification. All coated and modified configurations exhibited equal or reduced

FIGRA values relative to the uncoated reference, indicating a reduced contribution to fire growth under SBI exposure. Among the examined surface treatments, the combined fire-retardant and insecticide coating showed the most pronounced reduction in FIGRA compared to both the uncoated reference and the insecticide-only configuration. The configuration incorporating an additional 6 mm thick timber layer also resulted in a clear reduction in FIGRA relative to the uncoated specimen. This reduction can be attributed to the fact that the exposed timber is of higher quality, meaning it has fewer imperfections such as knots, holes and cracks. Although the thickness is small, it results in better performance in the early stage of the experiment, which is the most crucial for the FIGRA. Variations in THR_{600s} , $SMOGR$ and TSP_{600s} were observed between configurations; however, these differences did not affect the resulting Euroclass classification. Despite the observed differences in individual SBI indices, all tested configurations were classified as Euroclass D-s2,d0. A detailed quantitative comparison of the reaction-to-fire parameters for each configuration is provided in Table 3.

3.3. Relationship Between In-Depth Temperature Development and SBI Indices

A combined assessment of the results presented in Sections 3.1 and 3.2 shows that the in-depth temperature development and the SBI reaction-to-fire indices do not exhibit a direct correspondence. All coated and modified configurations displayed higher near-surface in-depth temperatures than the uncoated reference during heating and, in several cases, during the cooling phase, while at the same time exhibiting equal or reduced FIGRA values. This indicates that elevated near-surface temperatures measured within the CLT do not necessarily translate into an increased contribution to fire growth as captured by the SBI indices. The results therefore demonstrate that in-depth temperature measurements provide complementary information to the standard SBI parameters, supporting a more comprehensive interpretation of SBI test outcomes without altering their regulatory classification.

The observed decoupling between in-depth temperature development and SBI indices suggests that these quantities are governed by different physical phenomena; while FIGRA is primarily driven by surface combustion and spread of flames in the early stages of the test, in-depth temperatures reflect heat conduction in the bulk material, which is governed by the thermal properties of the CLT and is not directly linked to surface fire growth. Further testing involving multiple specimens per configuration would be needed to draw more definitive conclusions.

4. Conclusions

In this study, the reaction-to-fire performance of cross-laminated timber (CLT) was investigated using the Single Burning Item (SBI) test in accordance with the EN 13823 standard. A series of five SBI tests was conducted, including an uncoated reference specimen, specimens with different surface coatings, and a configuration incorporating an additional thin timber layer. In addition to the standard SBI indices used for classification, in-depth temperature measurements were recorded at selected positions, heights and depths within the CLT throughout the entire test duration, including both the heating and cooling phases.

The experimental results allowed a combined assessment of standard reaction-to-fire performance and in-depth thermal response. Differences between configurations were consistently observed close to the exposed surface, while temperature differences decreased with increasing depth and height. The analysis of the cooling phase provided additional insight into the persistence of elevated near-surface temperatures after flame extinction, complementing the observations made during the heating phase.

Based on the experimental results, the following main conclusions can be drawn:

- All coated and modified CLT configurations exhibited higher near-surface in-depth temperatures than the uncoated reference during the heating phase, with differences diminishing at greater depths.
- During the cooling phase, near-surface temperature differences between configurations persisted after flame extinction, whereas differences at greater depths rapidly decreased.
- Among the examined surface treatments, the insecticide coating resulted in the highest near-surface temperatures, while the addition of a fire-retardant component reduced near-surface temperatures relative to the insecticide-only configuration.
- The configuration incorporating an additional 6 mm timber layer showed only limited deviations from the uncoated reference during both heating and cooling phases, indicating no clear beneficial or adverse effect on in-depth temperature development.
- Despite the observed differences in in-depth temperature development and cooling behaviour, all tested configurations exhibited equal or reduced FIGRA values compared to the uncoated reference.
- All specimens were classified as Euroclass D-s2,d0, confirming that the observed variations in in-depth temperature response occur within the same reaction-to-fire classification boundary.

Overall, the results demonstrate that in-depth temperature development, including cooling behaviour, provides valuable complementary information for the interpretation of SBI test results, while the reaction-to-fire classification remains governed by the standard SBI performance criteria.

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