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Advancing Timber for the Future Built Environment

FIRE AND CLT: LINEAR JOINTS

Paola Brugnara[1], Speranza Alice[2], Luca Sestigiani[3]

ABSTRACT: The topic of fire safety in multi-story buildings has become increasingly important in the field of wood engineering. As wood construction continues to push the boundaries of height and design, it is essential to ensure that buildings are protected from the risks associated with fire. When exposed to fire, wood can release heat, produce smoke, and spread flames quickly, making it critical to design and construct buildings considering fire safety. One key aspect is the sealing of linear joints, which can be vulnerable to heat transfer and ignition. The effectiveness of these seals depends on several factors, including the quality of the sealant material, the thickness of the wooden elements, and the width of the joint. This study aims to investigate the insulation and fire resistance of linear joints in CLT slabs and walls. By characterizing the performance of these joints under various conditions, it would be easier to design and construct buildings that meet the demands of modern architecture.

KEYWORDS: timber, liner joints, fire, sealants, tests

1 – INTRODUCTION

The objective of this research project is to investigate the performance of cross-laminated timber (CLT) in different thicknesses, joint types, and sealing methods. To achieve this goal, three experimental campaigns were conducted. The first campaign tested two CLT slabs with a thickness of 200 mm, employing simple joints, half lapped joints and spline boards and different kind of sealant. In the second campaign, CLT with a thickness of 100 mm in vertical wall configuration was used while also incorporating a wider gaps and different solutions to facilitate prefabrication and simplify installation. The last campaign featured CLT with a thickness of 120 mm, combining the experience of the two previous campaigns. The results of these experiments provide valuable insights into the optimal configuration for CLT construction in various applications.

1.1 REQUIREMENTS

Fire resistance indicates the ability of a building element to maintain its structural stability and integrity during a fire condition for a given period of time, while retaining the ability to compartmentalize smoke and hot gases generated by combustion. In this work, the R factor was omitted and the results are expressed as EI.

The integrity (E) is the time in minutes for which the test specimen continues to maintain its separating function during the test without:

- Causing the ignition of a cotton pad
- Resulting in sustained flaming

The insulation (I) is the time in minutes for which the test specimen continues to mantain its separating function during the test without developing temperatures on its unexposed surface with:

- increase at any location (including the roving thermocouple) above the initial average temperature by more than 180 K.

The increments refer to the initial average temperature measured on the non-exposed side of the specimen being tested.

Although not mandated by regulations, internal thermocouples have been incorporated into the joint in certain configurations to monitor temperature variations within it.

2 – TEST CAMPAIGNS

In order to enhance know-how and provide feasible solutions, three test campaigns were conducted, each incorporating insights from previous tests.

2.1 CLT SLAB (200mm)

The initial test campaign focused on understanding the behavior of CLT joints during a fire event. In this phase,

[1] Paola Brugnara, Product Engineer, Rotho Blaas srl, Bolzano, Italy, paola.brugnara@rothoblaas.com

[2] Alice Speranza, Product Line Manager, Rotho Blaas srl, Bolzano, Italy, alice.speranza@rothoblaas.com

[3] Luca Sestigiani, Technical Director, Rotho Blaas srl, Bolzano, Italy, luca.sestigiani@rothoblaas.com

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three types of joints were evaluated: simple, with cover plate and half lap.

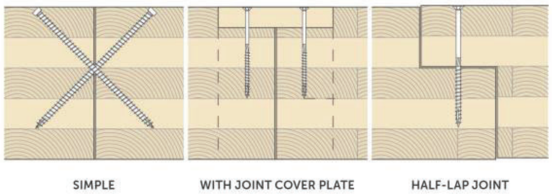

Figure 1. Types of jonts

More than fifteen joints with a 2mm gap and one joint with a 10mm gap were tested.

Figure 2. CLT slab (200mm) ready for testing

Each joint was equipped with two thermocouples, allowing the measurement of the temperature variations within the joints.

Figure 3. Thermocouples inside the joint

2.2 CLT WALL (100mm)

Thanks to the insights gained and the expertise accumulated, it was possible to test more challenging configurations, including a thinner panel and larger gaps.

A total of eight simple joints and one joint with cover plate were evaluated, characterized by gaps of 2mm, 3mm, 5mm, and 20mm, depending on the sealant used.

For this second testing campaign, a vertical wall was tested to expand the number of case studies and assess the relevance of panel orientation.

Figure 4. CLT wall (100mm) ready for testing

Internal thermocouples were installed exclusively in cases where sealant was applied also on the exposed side to evaluate the effectiveness of the sealant as a protective component for the fastening systems.

2.3 CLT SLAB (120mm)

The latest test campaign was conducted to validate the results from earlier testing phases and to incorporate additional configurations that had not been evaluated previously.

A total of thirteen configurations were evaluated, comprising eight that resemble those tested on the wall for comparative analysis of different orientations, alongside five designed to explore new applications and potential future developments in the field.

Figure 5. CLT slab (120mm) ready for testing

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3 – MATERIAL AND METHODS

The fire resistance of joints between timber elements is influenced not only by the properties of the sealing material but also by the supporting structure. Since wood is a combustible material, the effectiveness of the sealant depends on the charring rate of the timber and the position where the sealant is applied.

In the first test campaign (CLT slab 200mm), a strategy akin to that employed for traditional structures was implemented, with the sealant applied to the fire-exposed side to inhibit flame penetration into the joint. However, this method proved to be not particularly effective for timber structures; thus, in subsequent campaigns, an alternative approach was pursued.

To explore various solutions and approaches, each test campaign utilize a CLT panel featuring different joints, varying both the gap size and the type of sealant applied. While this approach allows for a wider range of results, it also requires to ensure that solutions have similar expected performances, because testing has to stop immediately if a flame breaches a joint, for safety reasons. As a result, the outcome reported at the end of each campaign reflects the performance of the first joint that failed, rather than the performance of each individual joint. This approach does not allow for a ranking of joints based on performance, but rather indicates the minimum fire resistance of them. This methodology was deemed valid, as the CLT panel itself establishes a limit due to its defined fire resistance.

4 – OUTPUT METHODS

Due to space constraints, it is not feasible to present all configurations and graphs; therefore only some of the most intriguing results obtained from these experimental campaigns will be highlighted.

4.1 CLT SLAB (200mm)

The initial test campaign was particularly insightful for determining the optimal placement of the sealant and understanding its role based on its installation position. A sealant applied to the side exposed to fire serves as a protective layer, functioning effectively as long as the timber does not burn. While this solution is effective for protecting fastening systems and/or other components, it does not fully utilize the structural integrity of the entire CLT element (Fig. 6).

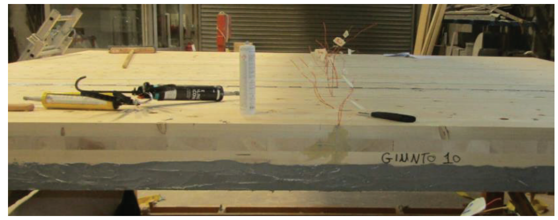

Figure 6. Fire sealing silicone applied on the exposed side

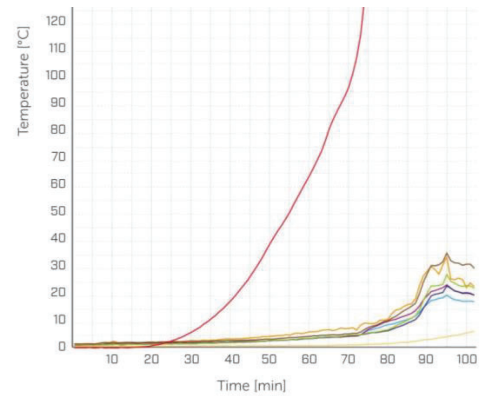

Figure 7. Temperature trend inside the joint (red curve) and on the non-exposed side

Fig. 7 shows that none of the thermocouples record an increase in temperature during the first 20 minutes. After 60 minutes, the thermocouple located 60mm on the exposed side (red curve) still measures a temperature of less than 100°C.

It is noteworthy to compare this solution with an alternative that utilized a sealing tape (Flexi Band) applied to the upper surface (Fig. 8).

Figure 8. Flexi Band tape applied on the upper side

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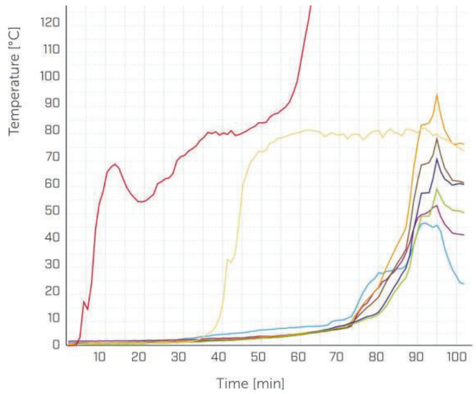

Figure 9. Temperature trend inside the joint (red curve) and on the non-exposed side

As shown in Fig. 9, the solution with the sealant applied to the upper side also achieved EI90 performance. However, the internal thermocouple (red curve) exhibits an almost instantaneous temperature increase. In this scenario, the function of the tape is to prevent the chimney effect, but it does not influence the temperature dynamics within the joint.

This initial test campaign demonstrated that for 2mm gaps, air-tight solutions are sufficient to ensure the fire resistance of the joint. Preventing the chimney effect is adequate to stop the propagation of flames and smoke along the gap. Specific fire-resistant products are not necessary for 2mm gap unless they are intended for use on the exposed side as protective elements for fasteners or other components.

The tests conducted were found to be excessively conservative and not very applicable to real-world scenarios, where larger gaps and thinner CLT panels are often required. Additionally, the tested solutions were not designed for symmetrical installation, making this initial test campaign difficult to generalize.

4.2 CLT WALL (100mm)

The second test campaign thus begins with the intention of testing a much thinner wooden panel and joints that can be easily constructed even when the direction of the flame is unknown.

For this test campaign, three main categories of joints are distinguished:

- joints less than 3mm, which can be sealed with simple air-tight products, are intended to ensure smoke tightness and prevent the chimney effect within the joint.

- joints of 5mm, which must be sealed with flame-resistant products to prevent flames from penetrating through the joint.

- joints of 20mm, which must be completely sealed with fire-resistant foam. In this case, it is crucial to prevent flame penetration into the joint to avoid accelerating the wood's charring rate.

In the case of standard products, butyl sealant (Supra Band) proves to be an excellent material not only for durability and elasticity but also as smoketight sealant (Fig. 11).

Figure 10. Supra Band, butyl sealant

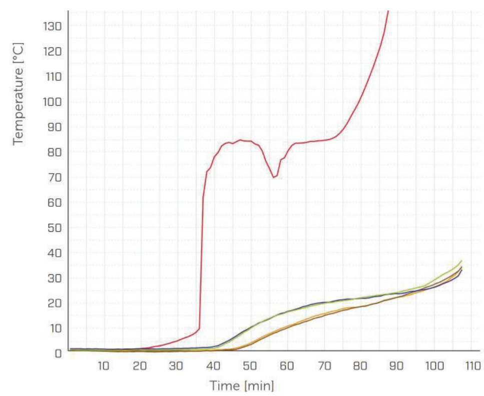

Figure 11. Temperature trend inside the joint (red curve) and on the non-exposed side

An interesting solution tested involved a 1.5mm thick intumescent gasket (Fire Stripe Graphite) within a 5mm gap. This solution is particularly noteworthy for prefabrication, as it allows for pre-installation of the gasket with assembly tolerance during the construction phase. Since the intumescent gasket requires heat to expand, it was necessary to use a sealing tape (Flexi Band) to ensure the tightness against cold smokes during the initial phase of the fire (Fig. 12).

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Figure 12. Fire stripe graphite and Flexi Band installed

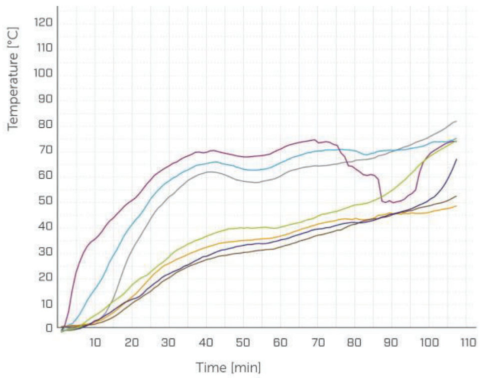

Figure 13. Temperature trend on the non-exposed side

As shown in Fig. 13, in this case, the temperatures increase more during the initial phase, but then stabilize once the gasket begins to expand and to function as a fire barrier.

4.3 CLT SLAB (120mm)

Particularly noteworthy in the third test campaign was the test with Fire Stripe Graphite, a 1.5mm thick intumescent gasket in an 8mm joint. In this case, it was necessary to apply a strip of the product on the underside as well to prevent flame penetration into the joints (Fig. 14). Due to the width of the joint, air-tightness was achieved using a butyl tape (Manica Plaster), as butyl exhibited excellent fire-resistant properties.

Figure 14. Fire stripe graphite installed in 8mmm gap

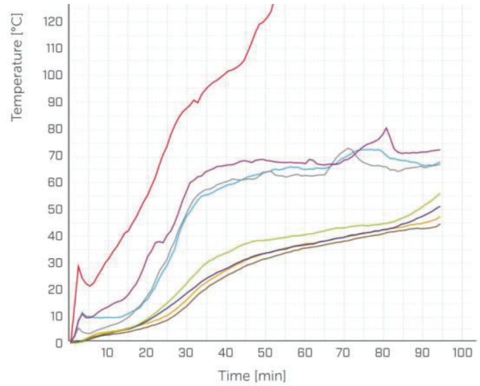

Figure 15. Temperature trend inside the joint (red curve) and on the non-exposed side

As illustrated in Fig. 15, despite the increased gap, the joint maintains performance exceeding EI90. This solution is validated by its ease of symmetry, the feasibility of preinstalling the gasket, and the assembly tolerance of the CLT panels in the construction site.

This test campaign also served to evaluate a specific fastening system (RING60T), which penetrates the wood to a depth of 45mm. The fastening system and the 3mm joint were sealed with an adhesive membrane (Defence Adhesive).

Figure 16. Installation of RING60T

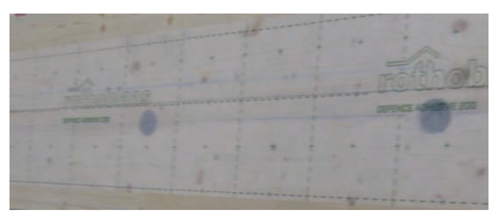

Figure 17. Installation of Defence Adhesive as sealing layer

Given the narrow width of the gap (3mm), ensuring air-tightness with Defence Adhesive was sufficient to achieve EI90 fire performance in this case as well.

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5 – FURTHER COMPARISONS AND COMMENTS

In addition to the immediate analyses, useful for determining how to proceed in subsequent steps of the research, a second phase of analysis was conducted to compare the results of the various test campaigns.

In all test campaigns, a joint with a width of 10mm or 20mm, completely filled with fire-resistant foam (Fire Foam), was tested. The presence of internal thermocouples allows the comparison of the results.

In first test campaign (CLT slab, 200mm) a 10mm wide joint was completely filled with Fire Foam. There are a thermocouple placed at a depth of 60mm (red curve) and another at a depth of 140mm (yellow curve).).

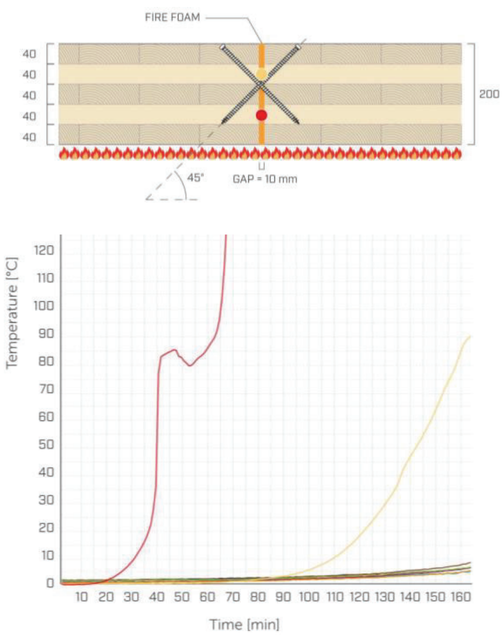

Figure 18. Temperature trend inside the joint (60mm red curve, 140mm yellow curve) and on the non-exposed side

Fig. 18 shows that the temperature measured at a depth of 60 mm remains below 180°C for over 60 minutes, and the thermocouple placed at a depth of 140 mm maintained the temperature below 180°C for more than 160 minutes.

Comparing this measurement with the one conducted on the 120mm CLT slab, it can be observed that the increase in gap width (20mm) tends to reduce resistance of the foam. Fig. 19 shows that the thermocouple positioned at a depth of 60mm exceeds 180°C in less than 60 minutes.

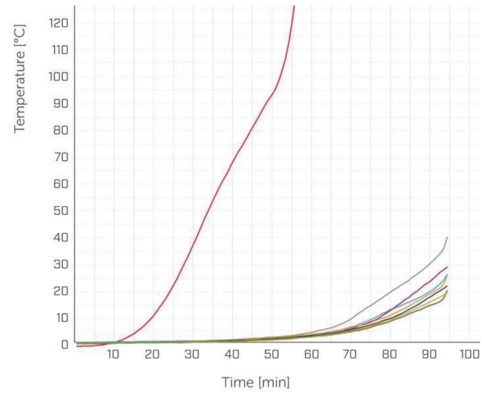

Figure 19. Temperature trend inside the joint (60mm red curve) and on the non-exposed side

The comparison with the vertical joint on the CLT wall 100mm is also noteworthy. In this case, the gap is 200mm wide, but the thermocouple was placed 50mm from the edge. Although the thermocouple is closer to the exposed side, Fig. 20 shows that the measured temperature remains below 180°C for over 60 minutes. This behavior could be attributed to the influence of gravity, which causes the lamellae to fall more quickly in slabs.

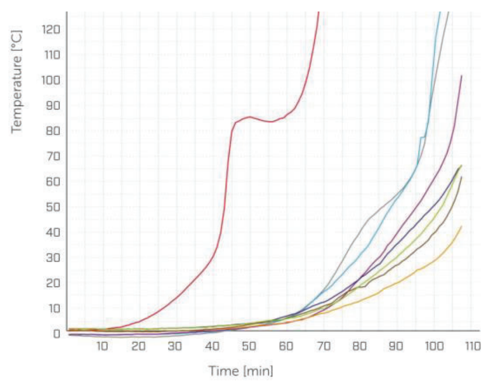

Figure 20. Temperature trend inside the joint (50mm red curve) and on the non-exposed side

The better performance of the vertical joints on wall compared to the horizontal joints on floor can also be observed in other measurements, thanks to the internal thermocouple.

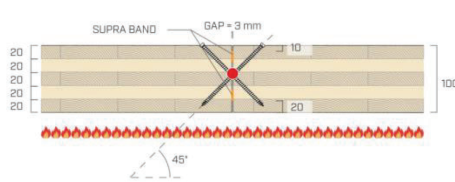

Figure 21. Simple joint on wall, 3mm gap and Supra Band

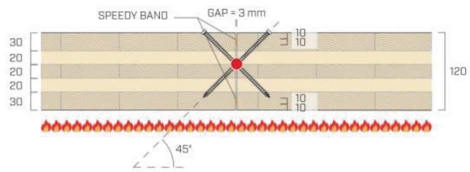

Figure 22. Simple joint on slab, 3mm gap and Supra Band

For instance, compare the joint in Fig. 21 with the joint in Fig. 22.

In Fig. 23 it can be observed that, in the case of the wall, the temperature measured by the thermocouple placed 50mm from the exposed side remains below 180°C for more than 60 minutes.

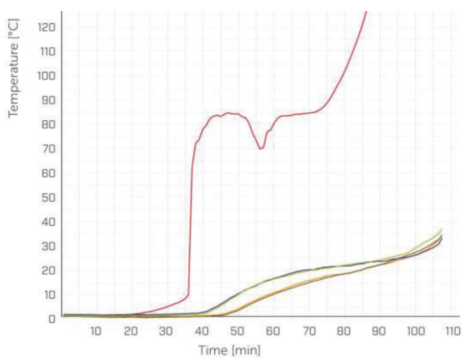

Figure 23. Temperature trend inside the joint (50mm red curve) and on the non-exposed side

In the case of the floor, the temperature measured by the thermocouple placed 60mm from the exposed side exceeds 180°C within 60 minutes (Fig. 24).

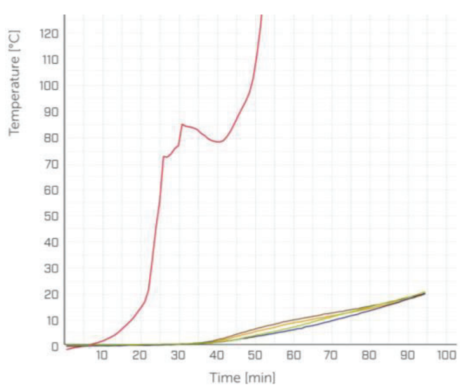

Figure 24. Temperature trend inside the joint (60mm red curve) and on the non-exposed side

6 – REFERENCES

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