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COMPARISON OF PERFORMANCES OF BOND LINES IN DIFFERENT SMALL-SCALE TESTS

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ABSTRACT: The evolution of fire testing methodologies for engineered wood products is transitioning from traditional large-scale timber fire tests to more efficient and cost-effective small-scale testing techniques. So far, large-scale fire tests have been essential for evaluating the fire behavior of timber. However, these tests are resource-intensive, time-consuming, and complex. To address these challenges, alternative approaches like tension and shear tests at elevated temperatures or cone heater tests are being investigated. This study investigates these small-scale testing methods, utilizing different adhesive families for comparison. A classification system for structural wood adhesives based on temperature resistance has been previously proposed by CEN TC193 as FprEN 18070, grounded in tests conducted at elevated temperatures. These tests demonstrated a reasonable correlation with those conducted under the cone heater and in the furnace when conducted at 200°C or higher, depending on the specific method used. While the classification system may underestimate the performance of one or two adhesives, it generally aligns with the results from the fire tests.

KEYWORDS: timber, cone heater testing, shear testing, elevated temperatures, fire performance

1 INTRODUCTION

The fire performance of engineered wood products is crucial to ensure the safety and structural integrity of buildings in the event of a fire. The fire testing of engineered wood products is a critical aspect of ensuring their safety and performance in real-world fire scenarios. Fire performance testing involves exposing these products to flames, allowing for the observation of pyrolysis and the formation of a char layer. Engineered wood products such as cross-laminated timber (CLT), glued laminated timber (GLT), and I-joists primarily rely on adhesives to bond multiple layers of wood together. While the performance of adhesives under ambient conditions has been extensively studied, their influence on the fire performance of engineered wood products remains an area requiring further research. Studies have demonstrated that different adhesives can significantly impact fire behaviour, with variations observed even among adhesives from the same chemical family [1].

Studies have shown that (phenol-)resorcinol-formaldehyde (PR/PRF) adhesives exhibit high thermal stability at elevated temperatures [1] - [3]. According to EN 1995-1-2:2004 [4], the behaviour of adhesive bond lines can be disregarded for PR/PRF adhesives and other aminoplastic type I adhesives, as specified in EN 301 [5]. Over the past decades, various other adhesives have been introduced to the market, including polyurethane adhesives (PU/PUR), melamine adhesives (MF/MUF), emulsion-polymer isocyanate adhesives (EPI), and polyvinyl acetate adhesives (PVA).

The forthcoming revision of FprEN 1995-1-2:2024 [6] aims to introduce different design scenarios and parameters based on the behaviour of adhesive bond lines at elevated temperatures. Depending on whether the bond line can prevent or fails to prevent the detachment of the charred layer, either a linear or stepped charring model is applied.

Traditionally, large-scale fire tests have been required to assess the performance of adhesive bond lines in fire conditions. However, these tests are inherently complex, time-consuming, and costly. In response to these challenges, the field of fire testing for engineered wood products has been shifting towards more efficient model-scale and small-scale testing methods. Researchers worldwide have been working to develop small-scale testing techniques capable of providing comparable insights while significantly reducing material usage and time requirements.

1.1 FIRENWOOD

FIRENWOOD was a transnational research, development and innovation project jointly funded by

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The project consortium comprised leading research institutions in this field: RISE Fire Research, MPA University of Stuttgart, Tallinn University of Technology, Technical University of Munich, and ETH Zurich. Additionally, industrial partners Moelven, Splitkon, and Masonite Beams contributed to the research and development efforts.

The project involved testing 11 different adhesives—PRF, PUR, MUF, MF, and EPI—sourced from five adhesive manufacturers under elevated temperatures and fire conditions, using a range of configurations and specimen sizes. Each individual adhesive has a unique number (1 – 12) throughout the paper. Spruce (Picea abies) timber with a strength class of T22 was utilized, with a density ranging from 430 to 480 kg/m³. The primary objective of the project was to compare testing methodologies across different scales. Tests were conducted at small-scale [7], model-scale [8] - [9], and large-scale levels [10].

1.2 AIMS AND OBJECTIVES

This paper examines the comparison of small-scale testing methods under elevated temperatures and fire exposure, as well as their correlation with model-scale fire tests on glued laminated timber (GLT) beams and cross-laminated timber (CLT) slabs.

2 METHODS

The objective of all used methods was to record the temperature-, time-, and load-dependent thermo-mechanical behaviour of different adhesive products.

2.1 MODEL-SCALE TESTS WITH GLULAM BEAMS AND CLT SLABS

The aim of the model-scale tests was to measure the mass loss and the charring depth of CLT and GLT with different types of adhesives when exposed to fire from below. It is known that heat induced delamination can occur when these products are exposed to heat or fire due to the adhesive’s inability to retain its properties at higher temperatures.

The CLT specimens were composed of seven wood lamellae, each with a thickness of 30 mm. The upper and lower lamellae were oriented in the lengthwise direction of the specimen. The overall dimensions of the specimens were 2000 mm × 600 mm (length × width). The CLT specimens were subjected to 120 minutes of fire exposure in a model-scale furnace, following the standard fire curve. The weight of each specimen was recorded before and after the fire test. Upon cooling, charring depths were measured at six points on each specimen. One test was conducted using almost all adhesives, except for adhesives no. 4, 7, and 8.

The GLT specimens consisted of ten wood lamellae, nine of which had a thickness of 28 mm, while one, positioned at the top of the beam, had a thickness of 23 mm. The final cross-section of the specimens measured 230 mm × 275 mm. The beams were exposed to fire for 90 minutes in a model-scale furnace, following the standard fire curve, with exposure on three sides (bottom and sides). The weight of each specimen was recorded before and after the fire test. After cooling, charring depths were measured at five points on each beam. One test was conducted with each of the 11 adhesives.

2.2 TESTS AT ELEVATED TEMPERATURES

Three different specimen/test configurations were considered:

1) Laboratory made scarf joints under tension
2) Industrially manufactured finger joints under tension
3) Single-lap compression shear block specimens

Laboratory made scarf joints under tension

Scarf jointed specimens were manufactured in a controlled laboratory environment to ensure consistent wood properties among specimens sourced from the same wooden plank. A wooden plank with a cross-section of 50 mm x 70 mm and a length of 725 mm was diagonally cut into two wedge-shaped segments. The segments were subsequently planed and prepared for adhesive application. The adhesive bonding parameters and quantities were provided by the adhesive manufacturers. Each test specimen had a cross-section of 20 mm x 8 mm and a length of 185 mm. The test specimen geometry and dimensions are presented in Fig. 1.

Ramp load reference tests were conducted to evaluate the tensile strength at an ambient temperature of 20°C. For each of the 11 adhesives, eight test specimens were examined. The tests were performed at displacement-controlled conditions with a constant crosshead speed of 2.5 mm/min. The maximum load was achieved within

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approximately 60 seconds, depending on the load-bearing capacity of the adhesive joint.

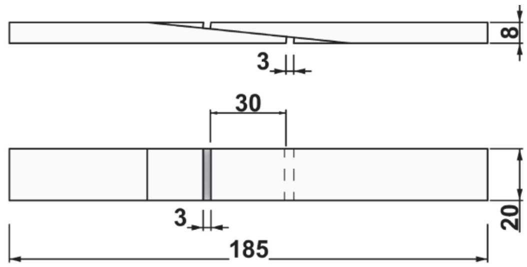

Figure 1. Scarf joint specimen.

The tests at elevated temperatures (160°C, 180°C, 200°C, 232°C, and 250°C) were set up as quasi duration of load experiments. These were conducted using a tensile testing machine equipped with a heat chamber. Specimens, initially stored at 20°C, were introduced into the preheated heat chamber set to the target temperature. Based on preliminary tests conducted for various target temperatures, an 8 mm thick specimen required approximately 7 to 12 minutes to reach thermal equilibrium. The target load level for the specimens was defined as 30% of the average short-term tensile strength determined in the reference tests at 20°C. The target load was applied at a test speed of 5 N/s, reaching the specified level within approximately 100 seconds, depending on the maximum load-bearing capacity of the respective adhesive. Once the target load level was attained, it was maintained for over 40 minutes. If the test specimen did not fail within this period, the tensile force was subsequently increased at a monotonic loading rate until the maximum load was reached. Depending on the test results, i.e. whether the sample survived the applied temperature level or not the next temperature was chosen higher or lower than 200°C.

Industrially manufactured finger joints under tension

The test specimens with a thickness of 5 mm were cut from finger-jointed boards with a cross-section of 155 mm × 50 mm with the joint profile visible at the wide board face. From each board segment with a mid-length finger joint, ten test specimens were extracted, each with a cross-section of 5 mm × 39 mm and a length of 300 mm. For each adhesive, a total of 30 test specimens (3 × 10) were produced from three finger jointed board segments. The geometry and dimensions of the specimen is shown in Fig. 2.

The testing procedure is analogous to the procedure described for the laboratory made scarf joints under tension. For each adhesive, nine reference tests were conducted at 20°C. The tests at elevated temperatures (160°C, 180°C, 200°C, 232°C) were conducted in a heat chamber.

It should be mentioned that the finger joint specimens as well as the above-described scarf joints were not primarily intended as an alternative to fibre parallel bonded lap joints [11] or block shear specimens [12]. Both, scarf and finger joints show bond lines inclined to fibre direction and hence differently accentuated stress concentrations at the overlap ends. These build-up characteristics should affect the bond line resistance to high temperatures and charring quantitatively different as in case of fibre parallel bonds in more stout specimens.

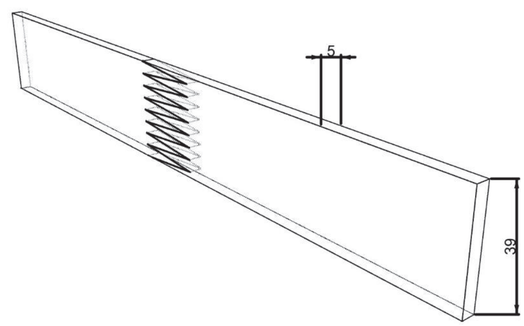

Figure 2. Small scale finger joint specimen cut from industrially manufactured full scale lamination joint.

Single-lap compression shear block specimens

The shear test specimens were manufactured in accordance with EN 17224 [13]. Two types of test specimens were produced: adhesive bonded specimens and unglued solid wood specimens. The specimen geometry and dimensions are shown in Fig. 3.

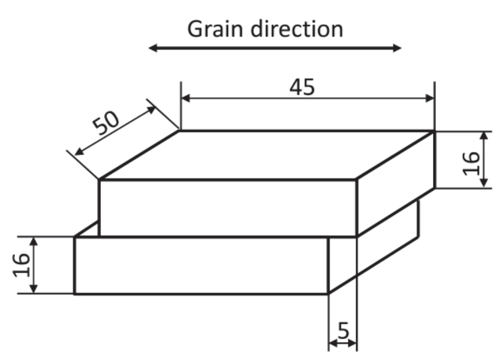

Figure 3. Block shear specimen according to FprEN 18070 [14].

The heating process required to elevate the specimen to a higher temperature was complex. To regulate the temperature increase, the chamber temperature had to be adjusted multiple times throughout the process. The temperature of the test specimen was monitored using a thermal wire inserted into a drilled hole on one side of the specimen.

All samples were first tempered at 60°C for a period of 48 hours and then stored in a container at 20°C to prevent further moisture absorption until the actual temperature tests began. Before tempering the average moisture content of the samples was 11.8 ± 0.5%. After the heat treatment, the average wood moisture content was around 1.4%. No abnormalities were found in any sample after the temperature treatment. The solid wood reference samples and the glued samples were then stored unloaded in a temperature cabinet at the respective elevated temperature (70 to 270°C). After reaching the target temperature, the test specimens were left at the respective target temperature for 15 minutes. The time from placing the test specimen in the preheated temperature cabinet until reaching the target temperature was approximately 25 – 45 minutes, depending on the target temperature. At the end of the temperature storage period, the samples were removed from the temperature cabinet, weighed and tested in the block shear test within a maximum of 60 seconds. The room temperature during the shear test was around 20 - 23°C.

2.3 CONE HEATER TEST

Two small-scale methods were considered for the cone heater tests: 1) Tests for finger jointed specimens loaded in tension; 2) Shear tests for unloaded CLT and GLT specimens.

Finger joints under tension

Knot-free spruce timber with cross-section dimensions of 50 mm x 150 mm was used for the manufacturing of finger joints. The boards had a moisture content of 12%. Finger joints were produced industrially on the Masonite Beams production line. Adhesive application was performed manually, following the specified amounts by adhesive manufacturers.

The boards, initially sized at 45 mm x 100 mm x 300 mm, were cut into strips measuring 45 mm x 10 mm x 300 mm. Holes with a 12 mm diameter were drilled into the ends of the specimen, and plywood reinforcements were glued to the ends to prevent tensile fractures at the attachment points. Bolts with a 10 mm diameter were used to apply the force. The geometry of the specimen is shown in Fig. 4. The finger joint geometry is shown in Fig. 5.

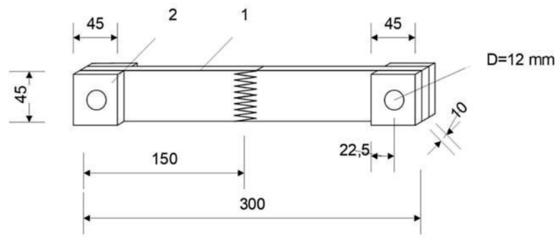

Figure 4. Finger jointed test specimen. Number 1 marks the raw specimen and number 2 marks the reinforcing plywood pieces.

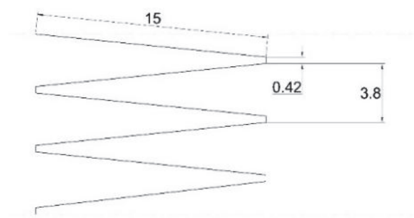

Figure 5. Finger joint geometry.

The lateral sides of the specimens were insulated with stone wool to ensure one-dimensional charring. A stainless-steel casing was used to keep the wool in place during the test as shown in Fig. 6. The chosen heat flux 25 mm from the cone (the top of the specimen) was 50 kW/m^2.

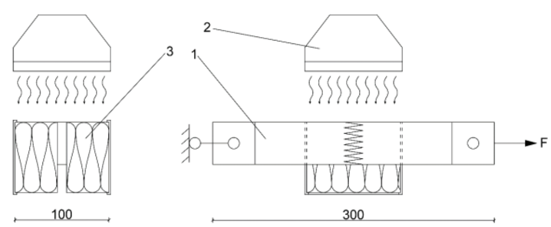

Figure 6. Specimen setup under the cone heater, where 1 marks the specimen, 2 marks the cone heater, and 3 marks the protective stone wool.

The test started when the shutter was removed from between the specimen and the cone heater. Ignition occurred within a second of plate removal. The specimen burned until rupture, after which it was removed from the cone heater and submerged in cold water to extinguish the flames and prevent further charring. Failure time and failure mode were recorded for each specimen.

The test series included a total of 61 specimens, each loaded with 100 kg, corresponding to approximately 5% of the average tensile strength of the wood. The tensile strengths were determined through tensile testing at ambient temperatures.

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Shear tests on small-scale CLT and GLT specimens

CLT and GLT blocks with a size of 240 mm x 160 mm were produced by manufacturers. Fire test specimens with a size of 100 x 100 x 80 mm were subsequently prepared from these blocks. The specimens consisted of three layers, with a lamella setup of 20 + 40 + 20 mm, and were bonded using the 11 adhesives. To define the tested bond line surface, a notch was cut on all sides using a thin band saw, reducing the surface area to 50 mm x 50 mm as shown in Fig. 7.

During specimen preparation, two thermocouples were inserted into the notch on opposite sides to measure the temperature at the bond line. The notch was then filled with ceramic wool insulation to minimize the influence of air on temperature measurements. The lateral sides of the specimen were covered with 15 mm thick gypsum plasterboard pieces (Type F), while the edges of the top surface were covered with 25 mm wide gypsum board strips. This setup ensured a consistent fire-exposed surface area of 80 mm x 80 mm for all specimens. The gypsum boards were secured using aluminium tape.

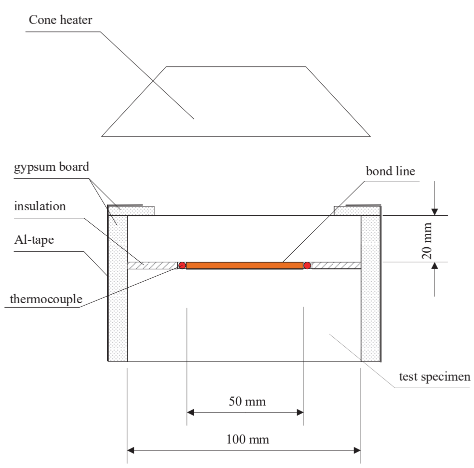

Figure 7. GLT and CLT test specimen setup under the cone heater. The thermocouples are indicated by red circles, while the bond line is highlighted with a bold black line.

The chosen heat flux for the tests was 50 kW/m^2 at a distance of 25 mm from the surface of the specimen. The thermocouples were used for temperature monitoring during the cone heater test. The specimen was heated until the average temperature at the bond line reached 290°C. The specimen was then removed from the cone, the protective gypsum casing was gently removed, and the specimen was loaded in shear until failure. The failure load and mode were recorded for all specimens. Shear capacity testing was always carried out along the grain direction of the second lamella.

The GLT test series included testing 24 specimens and the CLT test series included testing 46 specimens.

3 ANALYSIS

A classification system for structural wood adhesives based on temperature resistance has been proposed in FprEN 18070, as shown in Table 1. This table is derived from single-lap compression shear block tests conducted at elevated temperatures. The classification follows the test principles of EN 17224 and ASTM D 7247 [15], with a key deviation: the mean residual shear strength ratio of bonded samples is compared to 85% of the mean residual shear strength ratio of solid wood samples. The system consists of four adhesive classes, where higher classes (e.g. T270) fully encompass the lower classes (e.g. T232).

Table 1: Adhesive classification system

Temperature resistance class	Temperature limit [°C]	Verification criteria	Adhesive number	Adhesive families
T270	270	$R_{bW,Tref180,270} \geq 0,85$	2, 3, 6, 8, 11	PRF, MUF/MF
T232	232	$R_{bW,Tref180,232} \geq 0,85$	1	1KPUR
T220	220	$R_{bW,Tref180,220} \geq 0,85$	7	1KPUR
T200	200	$R_{bW,Tref180,200} \geq 0,85$	4, 12, 9	1KPUR, MUF

To assess the reliability of this classification system, the elevated temperature tests will be compared with small-scale cone heater tests and model-scale fire tests.

3.1 Comparison of small-scale tests

The following graphs will investigate the correlations between the small-scale cone heater test methods and the small-scale elevated temperature test methods.

The results of cone heater shear tests with CLT and GLT are compared in Fig. 8. The shear capacities of the GLT specimens ranged from 0 N to 539 N, while the shear capacities of the CLT specimens ranged from 0 N to 251 N. The findings indicate that bond lines with the same parallel grain direction exhibit approximately 1.5 times higher capacity than those with a crosswise grain direction. The results also reveal a clear distinction between two adhesive groups, highlighting significant differences in fire performance. Some adhesives demonstrate lower effectiveness in fire due to softening at high temperatures, leading to premature failure at reduced strength. The group with lower shear capacities consistently exhibited adhesive failure modes, whereas adhesives in the higher-performing group predominantly showed char failure modes or a combination of char and adhesive failure.

The average time to failure of the finger-jointed specimens tested under the cone heater is compared with the load-bearing capacities of the small-scale GLT specimens, also tested under the cone heater, as shown in Fig. 9. The adhesives can mostly be grouped into similar categories as in Fig. 8.

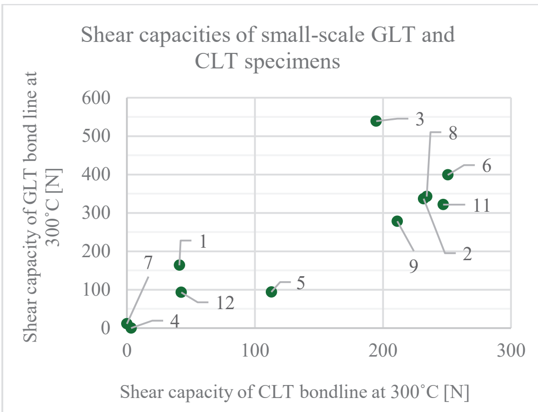

Figure 8. Comparison of shear capacities of small-scale CLT specimens and GLT specimens.

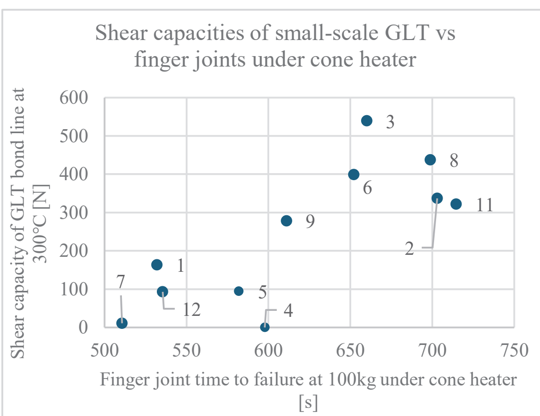

Figure 9. Load-bearing capacities of small-scale GLT specimens under the cone heater compared to the time to failure of small-scale finger jointed specimens under the cone heater.

Fig. 10 presents a comparison between the average eccentric tensile strengths of finger-jointed specimens tested under the cone heater and the mean tensile strengths of finger-jointed specimens tested at 200°C. The tests conducted at temperatures below 200°C did not exhibit consistent correlations with the results obtained under the cone heater. However, for the finger-jointed specimens tested at elevated temperatures, those tested at 200℃ or temperatures higher than 200°C demonstrated a good correlation with the cone heater tests. The temperature of 200°C was selected in this paper to enable visual comparison, as it is the only elevated temperature at which all adhesives were tested. The adhesives are categorized into two distinct groups: the group exhibiting lower strengths primarily shows adhesive failure modes under the cone heater, while the higher-strength group displays a combination of adhesive/wood failure modes and wood failure modes. The adhesive groups match the groups described beforehand.

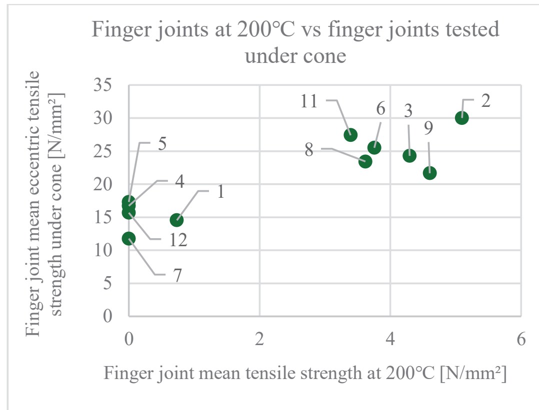

Figure 10. The mean tensile strength of finger jointed specimens tested at 200℃ compared to the mean eccentric tensile strength of finger jointed specimens tested under cone heater.

In Fig. 11, the mean shear strength of the block shear specimens tested at 270°C is compared to the mean eccentric tensile strength of the finger-jointed specimens tested under the cone heater. As observed in previous comparisons, the adhesives can be categorized into two distinct groups. Tests conducted at lower temperatures showed no clear correlations between the block shear tests and the small-scale cone heater test methods.

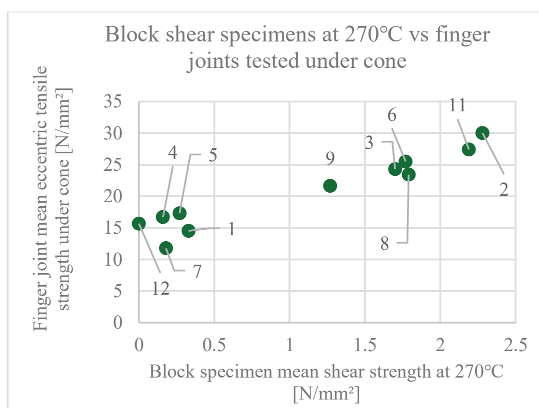

Figure 11. The block shear specimen mean shear strength at 270℃ compared to the mean eccentric tensile strength of finger jointed specimens tested under cone heater.

Building on the previous elevated temperature test methods, Fig. 12 compares the mean tensile strengths of scarf joints tested at 200°C with the mean eccentric

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strength of finger-jointed specimens tested under the cone heater. Like the results for finger-jointed specimens at elevated temperatures, the correlations with cone heater tests at temperatures lower than 200°C were not well-defined. The key observation from these results is that, for the scarf-jointed specimens, the adhesive groups are still somewhat distinguishable; however, adhesives 1 and 9 do not align with the same groups as observed in the other test methods.

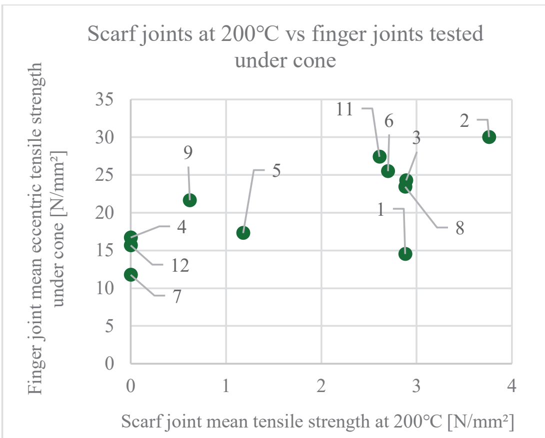

Figure 12. The mean tensile strength of scarf jointed specimens at 200°C copmared to the mean eccentric tensile strength of finger jointed specimens tested under cone heater.

In Fig. 13, the mean shear strength of the block shear specimens tested at 270°C is compared to the shear capacities of the CLT specimens tested under the cone heater.

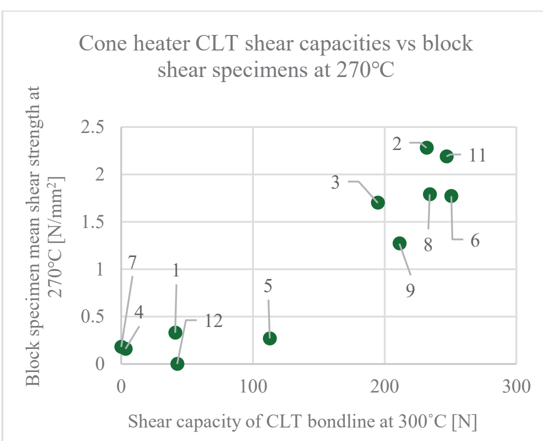

Figure 13. The block shear specimen mean shear strength at 270°C compared to the shear capacities of small-scale CLT specimens under cone heater.

In Fig. 14, the mean shear strength of the block shear specimens tested at 270°C is compared to the shear capacities of the GLT specimens tested under the cone heater.

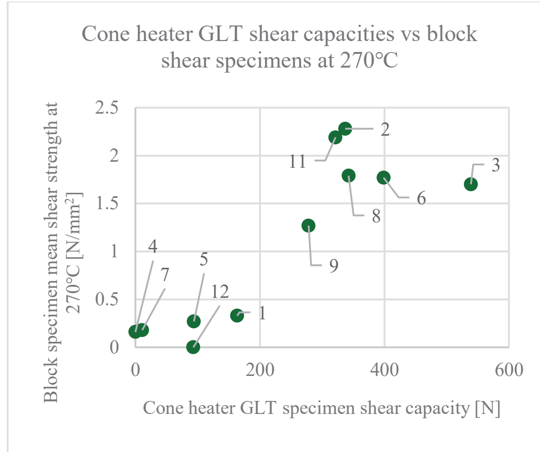

Figure 14. The block shear specimen mean shear strength at 270°C compared to the shear capacities of small-scale GLT specimens under cone heater.

The small-scale test methods generally show strong correlations when compared to one another, with some notable deviations observed in the scarf-jointed specimen method.

3.2 Small-scale tests compared to model-scale furnace tests

The following graphs will investigate the correlations between the small-scale methods and the model-scale furnace tests. It will be examined how the char depth of GLT beams and CLT slabs correlate with the previously proposed classification method.

Fig. 15 presents a comparison between the average charring depths of model-scale glulam beams tested in the furnace and the mean tensile strengths of finger-jointed specimens tested at 200°C. Adhesive no. 1 exhibited relatively low charring depths in the glulam beam furnace tests, suggesting that it may also belong to the 'stronger' group of adhesives based on this observation. It is important to note that each data point in the graph represents a single glulam beam test.

Fig. 16 presents a comparison between the average charring depths of model-scale CLT slabs tested in the furnace and the mean tensile strengths of finger-jointed specimens tested at 200°C. Adhesive no. 1 shows a larger charring depth in case of CLT than it does for GLT. It is important to note that each data point in the graph represents a single CLT slab test.

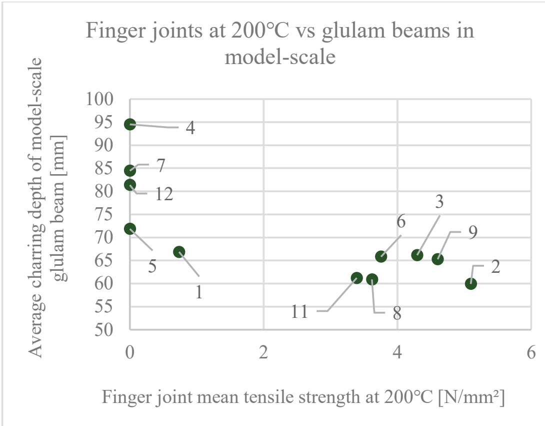

Figure 15. The mean tensile strength of finger jointed specimens tested at 200℃ compared to the average charring depth of model-scale glulam beams.

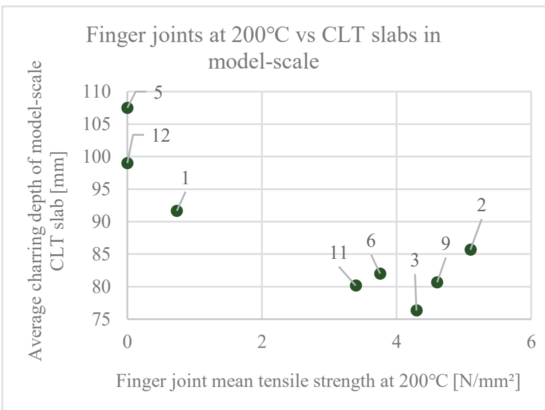

Figure 16. The mean tensile strength of finger jointed specimens tested at 200℃ compared to the average charring depth of model-scale CLT slabs.

In contrast to the two previous graphs, the notional charring depth for the notional charring rate of 0.65 mm/min according to the FprEN 1995-1-2:2024 is 58.5 mm. Considering the effect of corner rounding for the beams, the notional charring rate is 0.7 mm/min and the respective charring depth results in 63 mm. While many of adhesives for the beams manage to stay around that charring depth, there are quite a few that exceed this fairly. In case of CLT slabs it can be seen that charring depths for all specimens exceed the notional value.

Fig. 17 presents a comparison between the average charring depths of model-scale glulam beams tested in the furnace and the mean eccentric tensile strength of finger-jointed specimens tested under the cone heater. The groupings observed are like those formed in the comparison between finger-jointed specimens tested at 200°C and the charring depths of the glulam beams tested in the furnace.

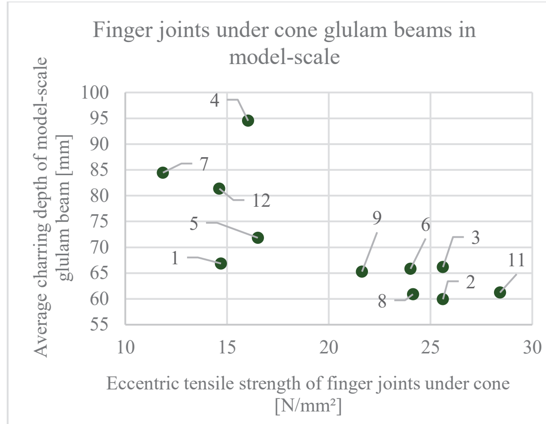

Figure 17. The mean eccentric tensile strength of finger jointed specimens tested under cone heater compared to the average charring depth of model-scale glulam beams.

In Fig. 18, a comparison of the average charring depth of model-scale glulam beams and the shear capacities of small-scale GLT specimens tested under cone heater is shown. This comparison is mainly shown to confirm the correlation between the two scales of fire testing.

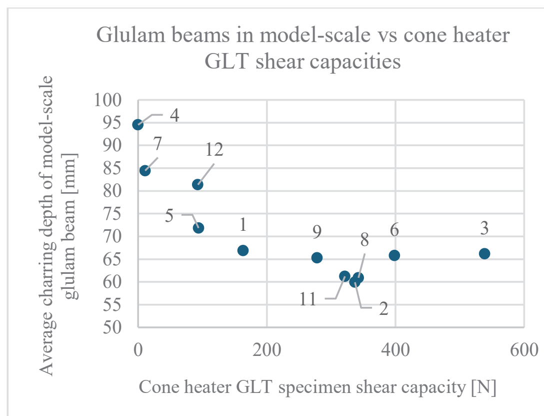

Figure 18. The average charring depths of model-scale glulam beams compared to the shear capacities of small-scale GLT specimens under cone heater.

Finally, Fig. 19 and Fig. 20 use the charring depths of the glulam beams and CLT slabs to assess their correlation with the proposed classification system. This classification system, developed through tests conducted at elevated temperatures, aims to replace the currently used larger-scale test methods. While the classification system does not invalidate the results, it tends to be somewhat conservative for certain adhesives. For instance, adhesive no. 9 has been placed in the lowest temperature class; however, both model-scale and small-scale tests suggest it may belong in a higher temperature class. Adhesive no. 1, which exhibits variability between glulam and CLT specimens, is appropriately classified in the T232 class. While small-scale methods generally

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categorize adhesive no. 1 in the weaker adhesive group, model-scale tests indicate that the small-scale methods may not be the most reliable for estimating the performance of this adhesive.

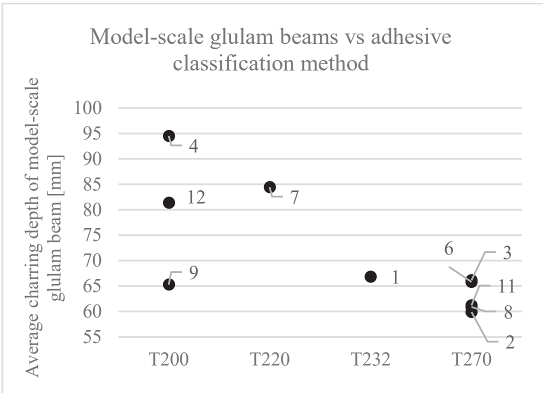

Figure 19. Charring depths of model-scale glulam beams classified according to the classification method.

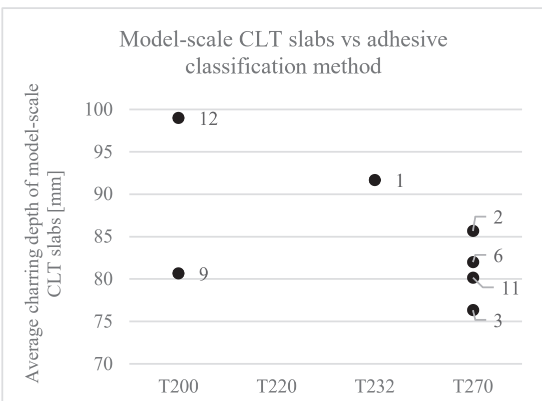

Figure 20. Charring depths of model-scale CLT slabs classified according to the classification method.

4 CONCLUSIONS

This study investigated the performance of bond lines of engineered wood by comparing small-scale and model-scale fire testing methods. The primary objective was to evaluate the correlation between different test methods and assess the classification system for structural wood adhesives based on temperature resistance. The findings demonstrate that while small-scale test methods provide valuable insights, their ability to predict large-scale fire performance varies depending on the adhesive type and testing conditions.

In general, tests conducted at elevated temperatures yield results comparable to other fire testing methods when performed at temperatures exceeding 200°C for finger-jointed and scarf-jointed specimens and 270°C for single-lap compression shear block specimens. However, the test method using scarf joints exhibits certain inconsistencies that are not observed in other methods. A classification system for structural wood adhesives based on temperature resistance, as outlined in FprEN 18070, was developed using the single-lap compression shear block method. In this study, we compared this classification system to model-scale tests conducted in a furnace. In general, the classification system provides a reasonable prediction of an adhesive's fire performance and does not overestimate the performance of any adhesives. However, it underestimates the performance of one adhesive (No. 9), which, according to fire tests without load, demonstrates better fire resistance in terms of charring depth than the classification system suggests.

In the new generation of FprEN 1995-1-2, a stepped charring model has been introduced alongside the traditional linear model to account for the behaviour of adhesive bond lines in fire conditions. Based on the proposed classification system and the fire tests conducted, it is recommended that adhesives assigned to temperature class T270 follow the linear charring model, while the remaining classes (T232, T220, and T200) adhere to the stepped charring model. Additionally, given that adhesive no. 7 exhibited consistently poor performance across nearly all testing methods, a separate temperature class for this adhesive is unnecessary, as it should be categorized under temperature class T200. This adjustment would also simplify the classification system by reducing the number of temperature classes from four to three.

Adhering to the classification system for structural wood adhesives based on temperature resistance can provide sufficiently conservative results, as is the case with all small-scale testing methods. The advantages of the single-lap compression shear block method include its cost-effectiveness and high repeatability. However, for more precise or application-specific assessments, model-scale or large-scale fire tests may be necessary.

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