WORLD CONFERENCE ON TIMBER ENGINEERING 2025
BRISBANE, AUSTRALIA
Advancing Timber for the Future Built Environment

POST-FIRE STRUCTURAL REHABILITATION OF MASS TIMBER ELEMENTS

Samuel Cuerrier Auclair[1], Christian Dagenais[2]

ABSTRACT: Post-fire rehabilitation of modern mass timber buildings has seen little research attention. Developing clear methodologies to rehabilitate char-damaged mass timber elements is crucial since mass timber buildings are becoming considerably more common and as such, the risk of having fire-damaged mass timber buildings is increasing. Preliminary investigation was performed in 2023 to quantify the amount of wood that needs to be removed beyond the char layer. Following this study, full-scale bending test of char-damaged mass timber glue-laminated timber decking elements reinforced with laminated veneer lumber were evaluated. The main objective of this study is to quantify the effect of different reinforcing methodologies and to validate calculation methodologies. From the test campaign, it is found that the mechanically jointed beam theory (gamma method) predicts well the level of composite action when fully threaded screws are used. When partially threaded screws are used, the friction between timber elements is sufficient to create an almost perfect composite action under low loading conditions.

KEYWORDS: mass timber, fire rehabilitation, timber-timber composite (TTC), self-tapping screws (STS)

1 – INTRODUCTION

How a fire might impact structural elements depends on the size of the fire, duration and intensity, but is also dependent on whether they are protected with gypsum board or other protection/encapsulation materials. Depending on the extent of damage, mass timber elements may be replaced which would most likely be either very challenging and/or very costly. Therefore, doing an on-site repair appears to be the easiest, although still challenging based on various aspects. The limited research done so far lacks a clear step-by-step procedure. Moreover, it is unclear whether the repaired elements should be reinforced to regain their initial capacity or to provide sufficient capacity to meet the actual service conditions [1].

For this project, char-damaged mass timber elements were dismantled from the Canadian Wood Council Mass Timber Demonstration Fire Test Program (MTDFTP) completed in 2022. In a preliminary study [2], char depth evaluation was done through the use of a drilling resistance measurement during the MTDFTP as well as manual measurements and compared to the predicted char depth from an analytical calculation method. The measured char depths and calculated char depths were consistent with those obtained by the drilling resistance measurement.

In attempt to evaluate how much wood needs to be removed beyond the charred layer, two methods were used in this preliminary study: 1) block shear tests per ASTM D905 and 2) surface bond strength tests per ASTM D5651. The latter small-scale test method was judged as a practical method and easily feasible on-site, with minor modifications in the setup.

As expected, the results from the block shear tests showed a reduction in the shear resistance as the bond line was closer to the charred layer. While the shear stress test results showed lots of variability, a closer evaluation of the wood failure provided valuable insight on the bonding performance. The results from the surface bond strength showed a similar pattern, where specimens with the bond line at least 15 mm beyond the charred layer were able to resist a similar withdrawal force as those from the control and Douglas fir specimens.

The results and visual observations suggest that a depth of 15 mm beyond the char layer should be removed in attempt to provide adequate and undamaged wood fibers suitable for bonding. However, given the variability in the results, a larger sampling size should be tested to better assess the accuracy and repeatability of the proposed 2 small-scale test methods.

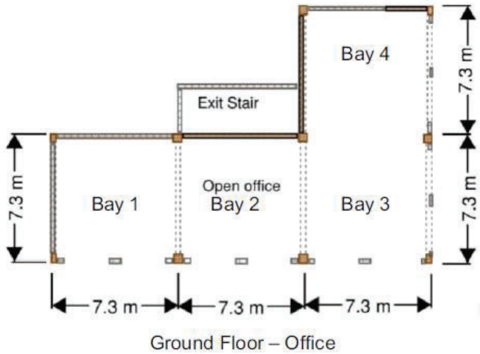
2 – OBJECTIVES

This project is the 2nd phase of a larger initiative aiming at identifying and evaluating post-fire structural rehabilitation methods for mass timber construction. This 2nd phase is intended to validate the analytical method proposed in Phase 1 [2] through a series of full-scale bending tests of reinforced char-damaged glue-laminated timber elements.

[1] Samuel Cuerrier Auclair, Building System Group, FPInnovations, Québec, Canada, samuel.cuerrier-auclair@fpinnovations.ca

[2] Christian Dagenais, Building System Group, FPInnovations, Québec, Canada, christian.dagenais@fpinnovations.ca

https://doi.org/10.52202/080513-0283



a) Floor plan of the MTDFTP

b) View of the glulam decking (ceiling)

c) Fire test 5 (open-space office)

d) Char-damaged elements at FPInnovations

Figure 1: Char-damaged elements from Test 5 of the MTDFTP

It is noted that the aesthetic aspects of the reinforcing materials were not considered in this study. The practicality of the solutions for preparing the char-damaged surface in an actual building, i.e., ceiling orientation, was also not considered.

3 – METHODOLOGY

Fundamental concepts for reinforcing timber elements were presented in the Phase 1 report [2]. Charring behavior, composite action between structural elements, connection stiffness and the reinforcing materials were described, along with a rehabilitation methodology – which has been followed herein.

Char-damaged mass timber elements were dismantled from the Canadian Wood Council Mass Timber Demonstration Fire Test Program (MTDFTP) completed in 2022. Glulam decking panels forming the ceiling in Bay 4 of the MTDFTP Test 5 were used for this rehabilitation methodology (Figure 1).

3.1 CHAR-DAMAGED GLULAM ELEMENTS

The glulam decking panels consisted of 215 mm (8½") thick glulam decking made of visually-graded lumber No.2 or better of the Spruce-Pine (SP) species group. Each decking panel was 603 mm (23⅝") wide and spanning about 7.3 m (24'). According to CSA O86 [3], such glulam decking made of vertically glued laminations of the SPF No.2 species group has a specified bending strength (f_b) of 11.8 MPa and a modulus of elasticity (MOE) of 9 500 MPa. The factored bending resistance under normal conditions is calculated as 27.0 kN·m, assuming a resistance factor (ϕ) of 0.9, a load sharing factor for built-up beams (K_h) of 1.10 and a cross-section of 300 mm wide by 215 mm deep. The mean bending resistance is estimated as 46.6 kN·m when following the fire-resistance design method in Annex B of CSA O86. The bending stiffness (EI) is calculated as 2 360 kN·m².

The panels were simply butt-jointed and covered with a plywood sheathing. Panel-to-panel joints were sealed using a fire stop caulking. After receiving the char-damaged elements, the char was first manually removed using a hand scrapper to facilitate the following evaluations. The glulam decking was then cut into 2 specimens of equivalent width of ±305 mm (1-ft), as shown in Figure 2, with total length varying between 8.5 and 9 m (18 and 19-ft). A total of 8 glulam specimens were obtained for conducting this Phase 2 study.

Most of the glulam elements had a residual thickness of approximately 190 mm, resulting in a char depth of 25 mm after such design fire, which is 3 times less than the calculated value of 78 mm using Annex B of CSA O86 for a 2-hrs standard fire exposure. As suggested in the Phase 1 report [2], an additional layer of 15 mm should be removed to provide adequate wood bonding, assuming

https://doi.org/10.52202/080513-0283

that bonding is the chosen connecting method. Four of the eight char-damaged glulam elements were therefore reduced to a thickness of 175 mm to follow the proposed methodology, while the remaining four were reduced to 180 mm in attempt to evaluate whether the 15 mm is too severe.

As indicated in the project objectives, the methodology for preparing the surface of the char-damaged elements was not intended to simulate actual building conditions after a fire incident. For the benefit of this study, a portable WoodMizer bandsaw was used to shave down the 8 specimens to the desired thickness indicated in Table 1

Figure 2: Glulam decking to be cut into two pieces of 305 mm (1 ft) wide panels

Figure 3: WoodMizer used to reduce the thickness of the char-damaged glulam elements

Table 1: Preparation of char damaged glulam elements

GLT ID	Residual Thickness (removed thickness) mm	Comments
1	190 (0)	Used as control specimen
2	190 (0)	
3	175 (15)	Per recommendations in [1]
4	175 (15)	
5	175 (15)	
6	180 (10)	Less than recommendations in [1]
7	180 (10)	
8	180 (10)	

3.2 REINFORCING MATERIALS

Laminated Veneer lumber (LVL)

Laminated veneer lumber (LVL) conforming to ASTM D5456 [4] were purchased from a local supplier and used as reinforcing tension lamination (Figure 4). The LVL were initially 38 mm x 140 mm x 6.1 m (1½" x 5½" x 20') with the specified strengths of 30.6 MPa in bending, 17.2 MPa in axial tension and an apparent and true modulus of elasticity of 11 721 and 12 411 MPa, respectively, for use in limit states design following CSA O86-19 [3,5]. They were all cut down to a length of 4.42 m (14.5') and one face was sanded to remove the protective wax coating, down to a thickness of approximately 35 mm.

Figure 4: LVL used as reinforcing tension lamination

While the LVL is an engineered wood product with relatively constant and uniform mechanical properties, all pieces have been characterized using transverse vibration modulus of elasticity with an E-computer model E340 manufactured by Metriguard, following the principles of ASTM D6874 [6]. The E-computer is an easy and economical non-destructive technique that can predict the MOE of a lumber board. Based on their MOE, the LVL elements with similar MOE were combined as reinforcements to the glulam.

Self-Tapping screws

Self-tapping screws were used to attach the reinforcing LVL to the char-damaged glulam elements. Two types of structural self-tapping screws were used to assess their respective composite performance. A fully threaded screw with a cylindrical head VGZ 7 x 160 mm [7] and a partially threaded screw with a washer head SK 8 x 160/80 mm [8] were used, as shown in Figure 5.

Figure 5: STS used to fasten the elements

VGZ screws were installed at a staggered spacing of 150 mm (6") on center, at an angle of 45° from the surface of the reinforced elements, with the assumption that the fully threaded screws would allow to maintain a close

https://doi.org/10.52202/080513-0283

contact between the elements during the bending tests, but not necessarily to press the elements together during the adhesive curing period. Screws were positioned at either +45° or -45°, depending on their position relative to mid-span. The SK screws were also installed at a staggered spacing of 150 mm (6") on center, driven perpendicularly (90°) to the surface with only the threaded portion being in the glulam and not in the reinforcing element for which, with the washer head, may provide some level of pressure between the elements during both the adhesive curing period and bending tests. Figure 6 illustrate the installation pattern for both the SK and VGZ screws.

Figure 6: Installation of SK (left) and VGZ (right) screws

Structural adhesive

In addition to the self-tapping screws, a phenol-resorcinol gap-filling structural adhesive complying to ANSI A190.1 [9] and CSA O112.7 [10] was used to increase the composite action between the LVL and char-damaged glulam elements. The gap-filling adhesive is approved for use in Canada through its CCMC evaluation report 13050-L [11].

The adhesive was prepared by mixing 100 parts (by weight) of liquid resin with 30 parts (by weight) of powdered hardener for 5 minutes. The application was per the supplier specifications using a paint roller at a spread rate of 418 pounds of adhesive per 1 000 ft² for gap sizes of 1/16" (100 lbs/1000 ft² per gap of 1/64"). When inserting the self-tapping screws, adhesive squeeze-outs were observed through the screw holes and along the sides of the LVLs (Figure 7) which is an indication that sufficient adhesive was spread and that some pressure was applied by the screws. The glued specimens were left in the conditioned structural laboratory for 7 days to allow for room-curing of the adhesive prior to full-scale bending testing.

Figure 7: Squeeze-outs of the adhesive

3.3 FULL-SCALE BENDING TESTS

In attempt to characterize the mechanical properties of the char-damaged glulam elements, full-scale bending tests were performed following ASTM D4761 [12], shown in Figure 8.

Table 2 summarizes the test matrix. All of the 8 char-damaged glulam specimens were first evaluated for their MOE by conducting 3 times non-destructive testing for all specimens.

Bending tests were then performed on the reinforced specimens following the same procedure; that is characterizing the MOE by limiting the mid-span deflection to 8 mm for the first few specimens (GLT-1, 2 and 6), and to 12 mm for the subsequent specimens. Specimens reinforced using both screws and adhesive were also evaluated for their bending stiffness by removing half of the screws (removing one every other screw – thus a 300 mm (12") staggered spacing). Once the maximum deflection criterion was reached after the 3rd replicate, the displacement sensors, lasers, were removed and the specimens brought to failure to evaluate their bending resistance. For all tests, the load was applied at a loading rate of 8 mm/min when evaluating the bending stiffness and increased to 20 mm/min for the bending resistance. The mid-span displacement was measured using 2 lasers positioned at the bottom level of the glulam element. The same position was used for the reinforced elements, where the lasers were positioned at the interface between the LVL and glulam. Figure 9 shows the full-scale bending test configuration at FPInnovations' laboratory in Quebec City.

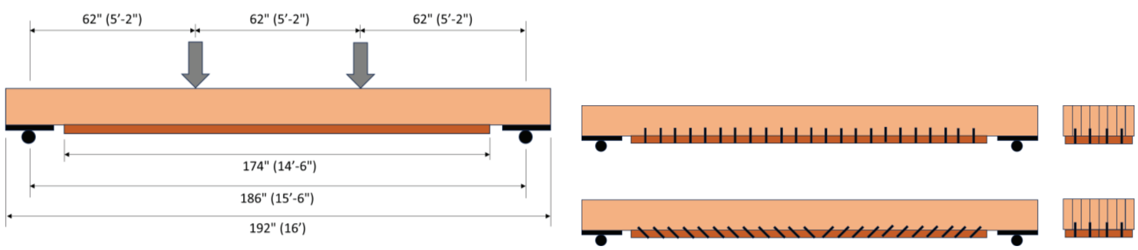
The following steps were followed throughout the full-scale bending tests:

1. Characterize unreinforced char-damaged glulam element;
2. Fasten the reinforcing LVLs to their assigned glulam specimen using SK/VGZ screws;
3. Perform stiffness evaluation (3 times);
4. Remove half of the screws;
5. Perform stiffness evaluation (3 times);
6. Remove the LVLs, apply the adhesive uniformly, and refasten the LVLs with the SK/VGZ screws;
7. Let the adhesive cure for 7 days at room temperature;
8. Perform stiffness evaluation (3 times) and then load until failure for resistance evaluation

Table 2: Full-scale bending test matrix

ID	Glulam ID – Thickness (mm)	LVL ID	Connection	Failure
1	1 – 190	-	-	Yes
2	2 - 190	-	-	Yes
3-SK150	3 – 175	7 + 8	SK at 90° @ 150 mm	No
3-SK300	3 – 175	7 + 8	SK at 90° @ 300 mm	No
3-Glue	3 – 175	7 + 8	SK at 90° @ 150 mm and glue	Yes
4-VGZ150	4 – 175	10 + 11	VGZ at 45° @ 150 mm	No
4-VGZ300	4 – 175	10 + 11	VGZ at 45° @ 300 mm	No
4-Glue	4 – 175	10 + 11	VGZ at 45° @ 150 mm and glue	Yes
5-Glue	5 – 175	5 + 1	SK at 90° @ 300 mm and glue(1)	Yes
6-SK150	6 – 180	6 + 12	SK at 90° @ 150 mm	No
6-SK300	6 – 180	6 + 12	SK at 90° @ 300 mm	No
6-Glue	6 – 180	6 + 12	SK at 90° @ 150 mm and glue	Yes
7-VGZ150	7 – 180	3 + 9	VGZ at 45° @ 150 mm	No
7-VGZ300	7 – 180	3 + 9	VGZ at 45° @ 150 mm	No
7-Glue	7 – 180	3 + 9	VGZ at 45° @ 300 mm	Yes
8-Glue	8 – 180	2 + 4	SK at 90° @ 300 mm and glue(1)	Yes

(1) Screws were used only to applied pressure for 7 days. Screws were removed before testing.



a) *Elevation view of the third-point bending test*

b) *Reinforcement pattern*

Figure 8: Full-scale third-point bending test

Figure 9: Bending test at FPInnovations' laboratory at Quebec City

The apparent bending stiffness (EI_{app}) and bending resistance (M_{max}) are calculated per ASTM D198 [13], as follow:

$$EI_{app} = \left(\frac{P}{\Delta}\right)\frac{23L^3}{1296} \quad (1)$$

$$M_{max} = \frac{P_{max}L}{6} \quad (2)$$

Where P is the force (N), L is the span (mm), Δ is the mid-span displacement (mm) and P_{max} is the maximum force at failure (N). P/Δ is the slope of the force-displacement curve (N/mm).

4 – RESULTS

4.1 CHARACTERIZATION OF REINFORCING MATERIALS

The results from the E-computer are shown in Table 3. It can be observed that all the predicted MOE exceeded the MOE of 12 411 MPa (1.8 x 10^6 psi) published by the LVL manufacturer, with the lowest estimation being 13 652 MPa. From the MOE predictions, each LVL was grouped together in attempt to limit variability in the full-scale bending testing. As an example, LVL specimens 2 and 4, with a MOE of 16 892 MPa, were grouped together when reinforcing the char-damaged glulam element 8, as defined in Table 2.

https://doi.org/10.52202/080513-0283

Table 3: Results from the E-Computer

LVL ID	Density (kg/m)	Frequency (Hz)	MOE	Assigned GLT
1	669	4.39	15 582	5
2	692	4.50	16 892	8
3	694	4.38	16 134	7
4	691	4.50	16 892	8
5	675	4.31	15 168	5
6	683	4.36	15 651	6
7	662	4.13	13 652	3
8	663	4.16	13 858	3
9	693	4.41	16 272	7
10	669	4.27	14 755	4
11	673	4.28	14 893	4
12	674	4.40	15 789	6

4.2 CHARACTERIZATION OF CHAR-DAMAGED GLULAM ELEMENTS

The results of the characterization of the char-damaged glulam elements are given in Table 4. The average modulus of elasticity (MOE) of all specimens is 9 364 MPa, which is slightly lower than the design MOE of 9 500 MPa, as published by the glulam manufacturer and conforming to CSA O86 [3] for vertically glued-laminated timber beams. The lowest MOE was 8 581 MPa, which is 10% lower than the published value of 9 500 MPa. Figure 10 shows the failure mode of GLT-1.

Table 4: Bending test results of the unreinforced char damaged glulam elements

GLT ID	Width (mm)	Thickness (mm)	Avg. MOE (MPa)	MOR (MPa)
1	290	192	9 426	25.1
2	291	196	8 658	20.3
3	303	168	9 288	-
4	304	168	9 803	-
5	300	174	8 553	-
6	303	177	9 857	-
7	298	177	9 299	-
8	298	180	10 144	-

Figure 10: Failure in tension zone of GLT-1, between the loading points

4.3 FULL-SCALE BENDING TESTS OF THE REINFORCED ELEMENTS

After characterizing both the reinforcing LVL and the char-damaged glulam elements, specimens GLT-3 to GLT-8 were reinforced following the various methods presented in Table 2. Except for GLT-5 and GLT-8 where the specimens were tested with the LVL being only glued (no screws), all other specimens had reinforcing elements fastened using various methods. Table 5 summarize the full-scale bending tests on the reinforced glulam elements. The screw at 150 mm spacing corresponds to the full screwing staggered pattern and screws at 300 mm means that half of the screws were removed to assess the influence of the screw pattern on the MOE.

Figure 11 show the failure mode for GLT-3 where tension failure was observed in the reinforcing LVLs as well as in the tension zone of the glulam.

Table 5. Bending test results of the reinforced glulam elements with LVL

ID	EI_{app} (kN-m^2)	Effect on EI_{app} (%)	M_{max} (kN-m)
3-SK150	2194	-	-
3-SK300	2113	-3.7	-
3-Glue	2253	2.7	80.8
4-VGZ150	1874	-	-
4-VGZ300	1675	-10.6	-
4-Glue	2381	27.1	84.8
5-Glue	2319	-	78.8
6-SK150	2679	-	-
6-SK300	2635	-1.6	-
6-Glue	2708	1.1	89.9
7-VGZ150	2029	-	-
7-VGZ300	1843	-9.2	-
7-Glue	2619	29.1	82.9
8-Glue	2819	-	95.9

Figure 11: Failure mode observed for the specimen 3-Glue

5 – DISCUSSION

5.1 EFFECT OF FASTENERS AND GLUING

As indicated in Subsection 3.3, the fastening pattern and gluing was investigated when evaluating the bending stiffness. For all specimens, the full screw pattern was used during the adhesive curing period. A reduction in the bending stiffness is observed for all reinforced specimens when half of the total number of screws were removed, however this reduction is much more evident when fully threaded screws are used (VGZ) when compared to that of partially threaded screws (SK) as in can be observed in Table 5. As expected, in all tests, the largest bending stiffness is achieved when a gap-filling adhesive is used which creates a full composite action. It is noted that when partially threaded screws are used, the bending stiffness is very near to the full composite action bending stiffness. This is most likely cause by the friction force created between the timber elements.

5.2 EFFECT ON BENDING STIFFNESS

The initial bending stiffness of the undamaged glulam element is calculated as 2 360 kN·m². This value is referred as "Published" in Table 6. The column "Non-reinf. EI" refers to the bending stiffness of the char-damage glulam element alone. The test results suggest that the reinforcement methods used in this study were able to restore the bending stiffness to at least 95% of its initial value, as shown in Table 6.

Table 6: Effect of reinforcement on bending stiffness

ID	Non-reinf. EI (kN-m²)	Reinf., EI (kN-m²)	Reinf. / Non-reinf. (%)	Reinf. / Published (%)
3-Glue	1178	2 253	191	95
4-Glue	1134	2 381	210	101
5-Glue	1380	2 319	168	98
6-Glue	1281	2 708	211	115
7-Glue	1425	2 619	184	111
8-Glue	1612	2 819	175	119

5.3 EFFECT ON BENDING RESISTANCE

The bending resistances are compared in Table 7. The initial factored bending resistance of the undamaged glulam element is calculated as 27.0 kN·m, and estimated as a mean resistance of 46.6 kN·m which is referred as "published mean" in Table 7. The test results suggest that the reinforcement methods used in this study were able to restore the initial bending resistance in all scenarios. The bending resistances are calculated as follows:

$$M_R = \phi\left(f_b K_{fi} K_D K_H K_{Sb} K_T\right)\left(\frac{b\,d^2}{6}\right) K_{Zb} K_L \quad (3)$$

Where f_b is 11.8 MPa, K_H = 1.10, K_{Sb} = 1.00, K_T = 1.00, K_{Zb} = 1.00 and K_L = 1.00. For the "Damage" value, $\phi =$ 1.00 , $K_D = 1.15$ and $K_{fi} = 1.35$ estimated with the measured dimensions of the glulam element alone after removal of char. The Reinforced value is a laboratory value determined with (2).

Table 7: Effect of reinforcement on bending resistance

ID	Damaged M_R (kN-m)	Reinf, M_R (kN-m)	Reinf. / Damaged (%)	Reinf. / Published mean (%)
3-Glue	35.9	80.8	225	173
4-Glue	37.5	84.8	226	182
5-Glue	28.7	78.8	274	169
6-Glue	28.8	89.9	312	193
7-Glue	30.5	82.9	272	178
8-Glue	31.9	95.9	301	206

5.4 ANALYTICAL METHOD VALIDATION

An analytical method for predicting the bending stiffness and resistance was presented in the report for Phase 1 [2]. The methodology is based on the mechanically jointed beam theory (gamma method). When using the material properties obtained for the reinforcing LVLs and the glulam elements, it can be observed in Table 8 that the proposed methodology provides reasonable predictions when compared to test data. The MOE of the glulam elements is taken from the test results of Table 4. The MOE of the reinforcing LVLs is taken as the average of both assigned LVL presented in Table 3.

It is noted that when using the published design values for both the glulam decking and LVL, a calculated bending stiffness and an estimated mean bending resistance of 2 360 kN·m² and 46.6 kN·m are obtained, respectively.

The results presented in Table 8 suggest that the calculation method provides reasonable predictions of all full composite action scenarios. In case of partial composite action, when fully threaded screws are used, GLT-4 and GLT-7, the partial bending stiffness is predicted with reasonable precision. However, when partially threaded screws are used, GLT-3 and GLT-6, the calculated bending stiffness is largely underestimated. This is most likely due that the proposed methodology does not consider possible friction effect between timber elements.

https://doi.org/10.52202/080513-0283

Table 8: Comparaison of the analytical method with the experimental results

ID	Exp. EI (kN-m^2)	Calc. EI (kN-m^2)	Diff. (%)	Exp. M_R (kN-m)	Calc. M_R Comp. (kN-m)	Calc. M_R Tension (kN-m)	Diff. (%)
3-SK150	2194	1832	-16.5	-	-	-	
3-SK300	2113	1651	-21.9	-	-	-	
3-Glue	2253	2206	-2.1	80.8	40.9	79.9	-1.1
4-VGZ150	1874	1931	3.0	-	-	-	
4-VGZ300	1675	1735	3.6	-	-	-	
4-Glue	2381	2352	-1.2	84.8	41.2	78.4	-7.5
5-Glue	2319	2372	2.3	78.8	44.8	76.6	-2.8
6-SK150	2679	2233	-16.6	-	-	-	
6-SK300	2635	2004	-23.9	-	-	-	
6-Glue	2708	2736	1.0	89.9	45.2	83.0	-7.7
7-VGZ150	2029	2135	5.2	-	-	-	
7-VGZ300	1843	1906	3.4	-	-	-	
7-Glue	2619	2645	1.0	82.9	45.5	79.5	-4.1
8-Glue	2819	2893	2.6	95.9	45.3	81.9	-14.6

Lastly, when following the calculation procedure, the calculated bending moment is always limited by the compression strength of the glulam element, while all test data showed an axial tension failure in the reinforcing LVLs. When comparing the test data to the estimated mean bending resistance limited by the axial tension strength of the LVLs, it can be observed, in Table 8, that the calculation method provides much more accurate predictions. Such discrepancies can possibly be attributed to the conservative provision in CSA O86 stating that design values of visually-graded lumber is to be used for vertically glued-laminated timber.

6 – CONCLUSION

This project is the 2nd phase of a larger initiative aiming at identifying and evaluating post-fire structural rehabilitation methods for mass timber construction and is intended to validate the analytical method proposed in Phase 1 through a series of full-scale bending tests of reinforced char-damaged glue-laminated timber elements.

Following the calculation method proposed in Phase 1 of this study, a total of 6 char-damaged glulam elements were reinforced using laminated veneer lumber (LVL) planks fastened with 2 patterns of self-tapping screws and a gap-filling adhesive. Two char-damaged unreinforced glulam elements were used as control specimens for the bending stiffness and resistance.

The E-computer was used to characterize the reinforcing LVLs. It is a non-destructive test (NDT) method that can easily be done on-site for providing greater accuracy in the calculations. While not technically feasible on-site, the char-damaged elements were also characterized from full-scale bending tests.

The test results suggest that a reduction in the bending stiffness is observed for all reinforced specimens when half of the total number of screws are removed (no adhesive). When only gluing was considered (all screws removed), an increase in bending stiffness is observed for both of the glued-only specimens. The results also suggest that the reinforcement methods used in this study were able to restore the bending stiffness to at least 95% of its initial value in all of the scenarios and able to restore the initial bending resistance for all scenarios.

It is further observed from the test results that the methodology detailed in [2] provides reasonable predictions when compared to test data.

7 – REFERENCES

[1] D. Brandon, J. Sjöström, and K. Fredrik, "Post-fire rehabilitation of CLT," RISE - Division safery and transport fire research, Sweden, RISE Report 2021:67, 2021.

[2] C. Dagenais, S. Cuerrier-Auclair, and S. Lebel, "Expanding Wood Use Towards 2025: Post-Fire Structural Rehabilitation - A Preliminary Investigation," FPInnovations, 301015759, 2023.

[3] *CSA O86-19 Engineering Design in Wood*. Mississauga (ON): CSA Group, 2019.

[4] *ASTM D5456 Standard Specification for Evaluation of Structural Composite Lumber Products*. West Conshohocken (PA): ASTM International, 2019.

[5] CCMC, "CCMC 12472-R: Boise Versa-Lam LVL," Canadian Construction Materials Center, 2022.

[6] ASTM, *ASTM D6874: Standard Test Methods for Nondestructive Evaluation of the Stiffness of Wood and*

Wood-Based Materials Using Transverse Vibration or Stress Wave Propagation. West Conshohocken (PA): ASTM International, 2021.

[7] ICC-ES, “ICC-ESR 4645: Rothoblass Self-Tapping Wood Screws,” International Code Council - Evaluation Service, 2023.

[8] ICC-ES, “ICC-ESR 3179: SWG ASSY Screws,” International Code Council - Evaluation Service, 2022.

[9] *ANSI A190.1 American National Standard for Wood Products - Structural Glued Laminated Timber*. Tacoma (WA): APA - The Engineered Wood Association, 2022.

[10] CSA, *CSA O112.7 Resorcinol and Phenol-Resorcinol Resin Adhesives for Wood (Room- and Intermediate-Temperature Curing)*. Rexdale (ON): Canadian Standards Association, 1977.

[11] CCMC, “CCMC 13050-L: Cascophen G1260-A Resin with Cascoset H80,” Canadian Construction Materials Center, 2023.

[12] ASTM, *ASTM D4761 Standard Test Methods for Mechanical Properties of Lumber and Wood-Based Structural Materials*. West Conshohocken (PA): ASTM International, 2019.

[13] ASTM, *ASTM D198-22a Standard Test Methods of Static Tests of Lumber in Structural Sizes*. West Conshohocken (PA): ASTM International, 2022.

https://doi.org/10.52202/080513-0283