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EFFECT OF ADHESIVES AND PLY CONFIGURATION ON THE FIRE PERFORMANCE OF SOUTHERN PINE CROSS-LAMINATED TIMBER

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ABSTRACT: Thirteen Southern pine cross-laminated timber panels were tested in the intermediate scale horizontal furnace at the Forest Products Laboratory to determine the effects different adhesives and ply configuration had on fire performance. Four different adhesives were tested: melamine formaldehyde (MF), phenol resorcinol formaldehyde (PRF), polyurethane reactive (PUR), and emulsion polymer isocyanate (EPI). There were two ply configurations: Long-Cross-Long (LCL) or Long-Long-Cross (LLC) where "long" indicates the wood was parallel to the longer edge of the panel. The MF and the PRF prevented delamination and associated problems while the LLC configuration resulted in uneven charring patterns.

KEYWORDS: Wood, Cross-Laminated Timber, Adhesives, Delamination, Char Rate

1 INTRODUCTION

Cross-laminated timber (CLT) is a mass-timber product manufactured by laminating pieces of dimensional lumber in layers, or plies. Typically, the wood grain orientation of each ply is perpendicular to adjacent plies to create a thick, solid wood panel similar to the manufacture of plywood. To maximize panel strength, the outer plies commonly have their wood grain orientation following the major strength direction, with the orientation of the interior plies alternating between the minor and major strength direction.

CLT is a relatively new building system that was first developed in Switzerland in the 1970s. Further research in Austria in the mid-1990s led to CLT as we know it today. The use of CLT in Austria, Germany, Switzerland, Sweden, Norway, and the United Kingdom increased tremendously in the early 2000s, due mainly to public interest in green building and as a result of changes in building codes in those countries [1].

With its long span, excellent strength and stiffness properties, and relatively light unit weight compared to other construction materials, CLT is viewed as having tremendous potential to displace concrete, masonry, and steel in low- and mid-rise residential and commercial construction. Current efforts to increase the use of wood in non-residential and mid-to-high rise residential construction has led to a surge in the desire to use wood composites, such as CLT. For commercial construction, one important attribute for building components that needs to be demonstrated is the fire resistance rating. While several mechanics-based models exist in Europe and North America for calculating the structural fire-resistance of CLT assemblies [1, 2, 3, 4], as the market for CLT panels continues to grow, different methods for constructing the panels are studied in an effort to optimize fire performance. Both the adhesive used to bond the plies together and the configuration of each ply affects fire performance.

Currently, many models assume a one-dimensional char rate of 0.635 mm/min and suggest increasing the rate when the char front (300°C isotherm) reaches the first glue line due to adhesive heat delamination [1]. An effective charring rate of approximately 0.80 mm/min is suggested in the Canadian CLT Handbook for CLT manufactured with 35-mm thick plies and takes into account the impact of adhesive heat delamination [3]. Charring rates are also impacted by ply thickness, as detailed in [1, 2, 5, 6, 7], where thinner plies would exhibit a faster effective charring rate than thicker plies.

This study analysed the effect of four different adhesives on char rate and delamination; one adhesive specifically formulated for Southern pine and three traditionally used for structural composite lumber. Additionally, two different ply configurations are compared to determine

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the effect on fire performance. This project included the testing of thirteen panels in the intermediate-scale horizontal fire resistance furnace at the Forest Products Laboratory (FPL).

2 MATERIALS AND METHODOLOGY

2.1 MATERIALS

The lumber was stored in an unconditioned space prior to planing. Face- and back-planing of the lumber was performed prior to gluing to activate the wood surface and to minimize thickness variation within a CLT layer.

Eleven of the CLT panels tested were three-ply and two were five-ply. Each ply was constructed with 35 mm thick, visually graded Southern pine (*Pinus spp*.). The Southern yellow pine group species consists of loblolly pine (*Pinus taeda*), longleaf pine (*Pinus palustris*), shortleaf pine (*Pinus echinata*), and slash pine (*Pinus elliottii*). These are the most commonly available wood species in the Southeast region of the United States.

The four different structural adhesives evaluated were: melamine formaldehyde (MF), phenol resorcinol formaldehyde (PRF), polyurethane reactive (PUR), and emulsion polymer isocyanate (EPI). These cold-set adhesives were chosen since the pressing operation is very slow when heat-cured adhesives are used to produce thick panels. MF is typically used in the production of composite panels such as medium density fibreboard and particleboard, is moisture resistant and is light in colour. However, MF is expensive when compared to PRF. PRF is an exterior type adhesive used widely in the manufacture of glulam. It is curable at room temperature, durable and economical. However, similar to MF, it off-gases because of the formaldehyde and is dark in colour. PUR is moisture-activated and is widely used in Europe for CLT panels because it is formaldehyde- and solvent-free. However, the fire resistance of PUR is generally poorer than the adhesives containing formaldehyde. The PUR adhesive for this project was specifically formulated to be used with Southern pine. EPI is a moisture resistant adhesive typically used in the manufacture of I-joist and glulam. Due to the emulsifiability of isocyanate, adequate mixing is important and, as a result, EPI has low workability. EPI is also costly compared to MF and PRF. The 965 mm by 1194 mm panels were constructed at Clemson University with a platen pressure of 345 kPa. The adhesive mix ratios and press times are provided in Table 1 [9].

Table 1. *Mix ratio and spread rate for adhesives*

Adhesive	Mix Ratio (Resin-Hardener)	CAT[1] (minutes)	Press Time (hours)
MF	100:60	30	3
PRF	100:40	30	3
EPI	100:15	10	3
PUR	n/a	40	4

[1] *Close Assembly Time (CAT) refers to the time interval from substrate assembly to the application of full pressure.*

Two different ply configurations were evaluated: Long-Cross-Long (LCL), which is the traditional configuration with each ply perpendicular to the next, and Long-Long-Cross (LLC), which has two parallel plies next to each other with staggered joints. Figure 1 illustrates the two configuration types and the red line indicates the fire exposed side. The two five-ply CLT panels tested were both in an LCLCL configuration. Table 2 provides the text matrix.

Figure 1: *Long-Cross-Long and Long-Long-Cross configurations*

Table 2: *List of specimen adhesive and configuration*

Specimen No.	Specimen Label
1	MF-LCL
2	MF-LLC
3	PRF-LCL
4	PRF-LLC
5	EPI-LCL
6	EPI-LLC
7	PUR-LCL
8	PUR-LLC
9	PUR-LCL
10	PUR-LLC
11	PUR-LCLCL
12	PRF-LCLCL
13	PUR-LCL+GB[1]

[1]Gypsum board is 16 mm thick Type X fire rated, installed at FPL.

2.2 PREPARATION OF SPECIMENS

Each specimen was instrumented with thermocouples at various depths to observe the char front during the test. The thermocouples were made at FPL from 24 gauge, Type K glass insulated thermocouple wires (Omega Engineering: GG-K-24). The thermocouples were installed within the specimens by drilling holes from the non-fire exposed surface. They were then inserted in the holes at 11.5, 23.3, 35, 46.5, 58.3, 70 and 81.5 mm from the fire exposed surface on a 457 by 457 mm grid pattern, centered on the specimen (Figure 2). Additionally, thermocouples were attached to both the fire exposed and non-fire exposed surfaces of the specimens. For specimen 13, an additional four thermocouples were installed between the gypsum board and the CLT surface.

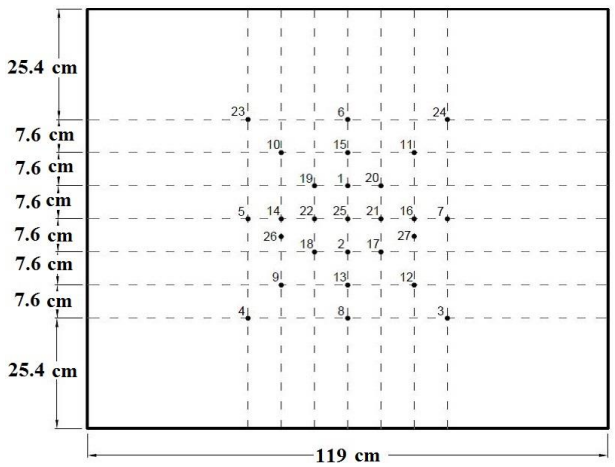

Figure 2: *Thermocouple placement grid in CLT panel*

2.3 METHODOLOGY

2.3.1 Fire Exposure

Our test procedure is based on ASTM E119 [9]. This test determines hourly ratings specified in the International Building Code for walls and floors required to provide a fire-resistance rating. Some of our most significant deviations from the standard include the reduced size of the specimen and the lack of any external loading during the test. However, sample conditioning and the specified time-temperature curve were adhered to during the tests.

Prior to testing, the panels were conditioned at FPL in a 21ºC / 50% relative humidity chamber for a minimum of 30 days. The panels were tested on FPL's intermediate-scale horizontal furnace, which is heated by eight diffusion-flame natural gas burners on the floor of the furnace. The interior dimensions of the furnace are 1.83 m long, 1.09 m wide and 1.27 m high. A frame was used to hold the panels and included two noncombustible inserts on each side of the specimen (Figure 3). The test frame with the test specimen was placed on top of the furnace. All air for combustion was provided by natural draft through vents at the bottom of the furnace. Six capped furnace thermocouples were located 305 mm from fire-exposed specimen surface.

The gas flow was controlled so that the temperature of the capped thermocouples followed the standard time temperature curve specified in ASTM E119. Temperatures on the curve include 538°C, 927°C, 1010°C and 1052°C at 5, 60, 120 and 180 minutes, respectively. Temperature data for the furnace and the specimen were recorded in five second intervals.

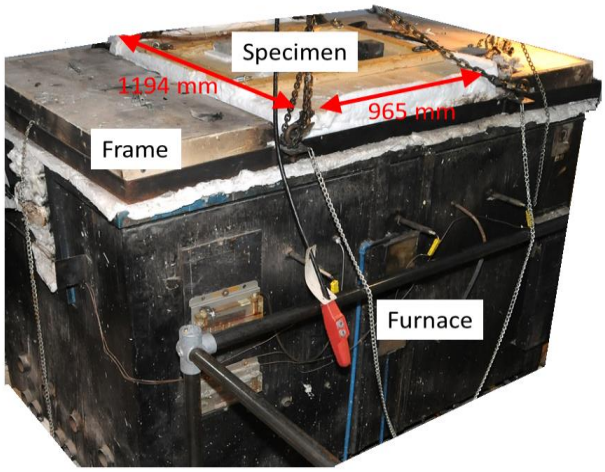

Figure 3: *Horizontal furnace with test frame and specimen installed.*

ASTM E119 requires furnace temperatures be recorded at intervals of five minutes or less and deviations of the area under the average furnace temperature curve from the corresponding area for the standard curve be less than 10% for one hour or less, less than 7.5% for one to two hours and less than 5% for times exceeding three hours. The calculated percent deviations from the standard curve, averaged over the 13 tests, were never greater than 1.3% and the deviations for all tests were within the standard requirements.

2.3.2 Test Termination

These tests were performed without external loading, so in lieu of the sustained load failure criteria in ASTM E119, tests were terminated when the second glue line from the fire exposed surface in the three-ply specimens or the third glue line from the fire exposed surface of the five-ply specimens reached 300°C. It is commonly accepted that reaching a temperature of 300°C correlates to the base of the char layer [12, 13, 14].

A second condition to terminate a test in ASTM E119 involves the ignition of cotton waste by hot gases penetrating the unexposed surface. We replaced this condition with the visual observation of flames penetrating the unexposed surface to simplify the test and reduce personnel exposure to combustion products.

ASTM E119 requires that the temperature of the unexposed side of the specimen be measured in nine places by thermocouples placed under insulating pads. The thermocouples are then to be monitored and the test terminated when the average temperature rise of these thermocouples reach 139°C above their starting point. Due to the reduced size of our specimen we only used two thermocouples on the unexposed surface.

The size of the specimen and available crane allowed the specimen to be removed quickly after termination of the test so that the fire could be extinguished. Visual observations, photographs and residual thickness measurements were made. The modes of failure and time at which failure occurred are summarized in Table

3. The flame through time is the time at which flames were first observed penetrating the unexposed side of the specimen. The time to 300°C is the average time at which all of the thermocouples had reached 300°C at the second glue line in the three-ply specimens or the third glue line in the five-ply specimens. When it was deemed safe, the test was continued beyond the failure point to obtain additional char rate data; the times at which the test was actually stopped can also be found in Table 3. In the cases where both a time to flame through and a time to 300°C are recorded, the failure time can be taken as the lower of the two. There were no failures due to the 139°C temperature rise criteria.

Table 3. *Failure times in minutes*

Specimen	Flames	300°C	End
1	--	98	102
2	104	--	104
3	--	97	102
4	113	--	113
5	93	101	104
6	96	--	96
7	--	89	95
8	100	--	100
9	80	--	80
10	108	94	108
11	--	153	173
12	--	168	186
13	166	--	166

3 RESULTS

3.1 TEMPERATURE DATA

The char rate of wood refers to the dimensional rate, such as mm per minute, at which wood converts to char. The times to reach 300°C at the various depths within the wood slab were recorded and an example of the temperature data collected during a test is illustrated in Figure 4. The char rates and predicted failure times are derived from this collected data.

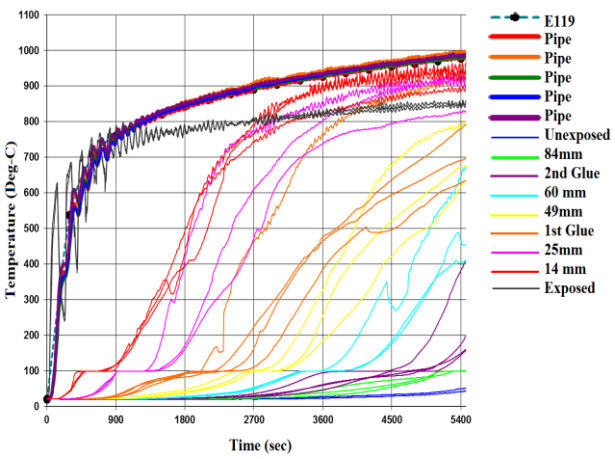

Figure 4. *Thermocouple data for specimen 3 (PRF-LCL)*

In Figure 4, the thermocouple readings labeled "Unexposed" are on the top, unexposed surface of the CLT panel while the thermocouple readings labeled "Exposed" are attached to the surface of the specimen inside the furnace. The other thermocouple readings are labeled with respect to their position; either the depth from the exposed surface or the glue line at which they were installed. A thermostatic dwell is visible when each depth reaches 100°C; the temperature at which the water evaporates and there is forced diffusion of moisture.

3.2 LINEAR CHAR RATE

One way to model the char rate is with a simple linear model for each ply. The time that it takes each thermocouple to reach 300°C and the distance of each thermocouple from the fire exposed surface are fit using a linear least squares algorithm to:

$$depth = s(t_{300C}) + b \tag{1}$$

The slope, s, is the char rate in mm per minute with the depth equal to the measured distance in mm of the thermocouples from the fire exposed surface and $t_{300°C}$ equal to the time that it takes each thermocouple to reach 300°C. The time axis intercept is b. The results of this fitting procedure can be seen in Table 4 below and Figure 5. The model is fit within each of the first two plies in the three-ply specimens and within the first three plies in the five-ply specimens. The error bars on Figure 5 represent the 95th percent confidence interval of the fit and can be used as an estimate of the spread of the data. For specimen 13, the times used to calculate char rates were reduced by 33 minutes to account for the layer of gypsum board.

Table 4. *Linear char rate (s) results in mm/min*

Specimen	Ply 1	Ply 2	Ply 3
1	0.63	0.70	--
2	0.66	0.74	--
3	0.75	0.67	--
4	0.56	0.56	--
5	0.77	0.62	--
6	0.66	0.88	--
7	0.74	0.81	--
8	0.71	0.72	--
9	0.70	0.98	--
10	0.70	0.64	--
11	0.66	0.62	0.41
12	0.65	0.57	0.38
13	0.36	0.66	--

The linear char rates through the first ply have an average of 0.66 mm/min for all specimens. The linear char rate average for the second ply of all specimens was 0.71 mm/min. At 0.36 mm/min, the char rate of the first ply for specimen 13 is significantly lower than the average due to encapsulation with gypsum board. The gypsum board provided 33 minutes of protection to the CLT specimen calculated from the average time that it took for four thermocouples located between the gypsum and the surface of the CLT to reach 300°C.

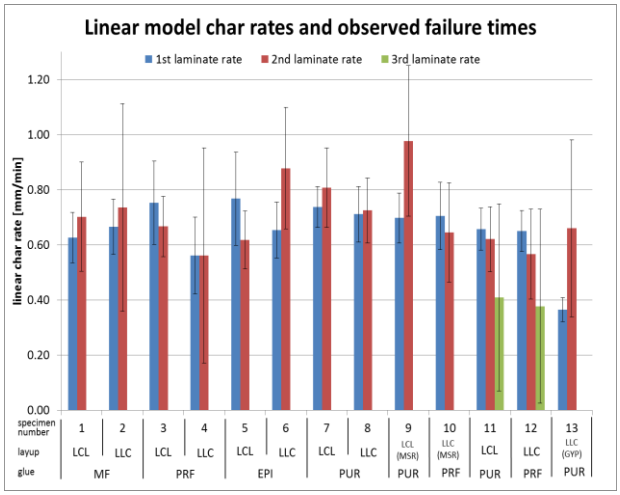

Figure 5: *Linear model char rates and observed failure times*

3.3 NONLINEAR CHAR RATE

While the data could be represented by linear models as discussed, there was considerable and consistent nonlinear behavior in the charring. Nonlinear charring may be due to increased char layer thickness and delamination of the char layer at the glue lines.

The calculation of the fire resistance ratings in the US CLT Handbook uses a form of the nonlinear char rate model:

$$t_{300C} = 0.390 \, \text{min} \Big/ \text{min}^{1.23} \left(\frac{x}{\beta} \right)^{1.23} \tag{2}$$

where x = depth in mm and β = char rate in mm/min. This model is a two-dimensional model derived from the one-dimensional nonlinear model developed by White [3, 10]. White's model, as follows, is based on the results of 40 one-dimensional wood slab charring tests of various species:

$$t = m(x_{char})^{1.23} \tag{3}$$

where m = char slope in min/mm$^{1.23}$. This model accounts for accelerated charring which occurs early in the fire exposure. Since the nominal char rate values, β_n, are based on an exposure time of one hour, solving White's model for the char depth and using a time of 60 minutes allows for the comparison of char slopes and nominal char rates:

$$\beta_n = \left(\frac{60 \, \text{min}}{m} \right)^{0.813} \tag{4}$$

where m =min/mm$^{1.23}$, β_n =mm/min.

The nominal char rates that were calculated using the nonlinear model for the 13 specimens are found in Table 5 and Figure 6. The nominal char rates were obtained by fitting the US CLT Handbook nonlinear model to data from each ply. The error bars on Figure 6 represent the 95 percent confidence interval of the fit and can be used as an estimate of the spread of the data. The time for the surface of the CLT on specimen 13 to reach 300ºC was 33 minutes due to the gypsum board.

Table 5. *Nonlinear char rate (β_n) results in mm/min*

Specimen	Ply 1	Ply 2	Ply 3
1	0.58	0.72	--
2	0.63	0.75	--
3	0.70	0.79	--
4	0.60	0.83	--
5	0.71	0.77	--
6	0.64	0.78	--
7	0.65	0.8	--
8	0.63	0.73	--
9	0.63	0.77	--
10	0.66	0.76	--
11	0.62	0.72	0.81
12	0.64	0.71	0.76
13	0.38	0.53	--

Using the nonlinear char rate method, the char rates through the first ply have an average of 0.62 mm/min for all specimens. The char rate for the first ply of specimen 13 is 0.38 mm/min, which is significantly lower than the average due to the protection provided by the layer of gypsum board. The nonlinear char rate average for the second ply of all specimens was 0.74 mm/min.

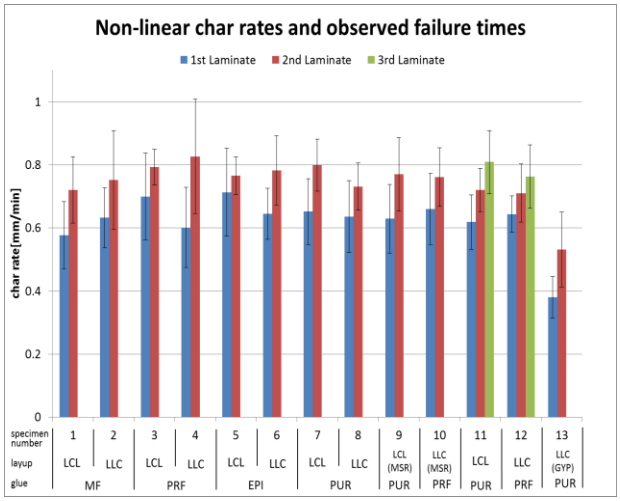

Figure 6: *Nonlinear model char rates and observed failure times*

3.4 DELAMINATION

Three observations related to delamination were made during the tests: (1) Listening for the sound of material falling to the floor of the furnace; (2) Observing the relative amount of char on the furnace floor through the air inlets; and (3) Spikes in the temperature signals measured near the glue lines. However, these observations do not help quantify how much of each layer delaminated, which could have a significant effect on the observed char rates. To quantify this information, photographs were taken of each specimen after the test and the areas of each ply remaining were measured. For

each specimen, a centrally located area of approximately 685 mm by 838 mm was analyzed because the severity of the fire exposure was reduced near the edges.

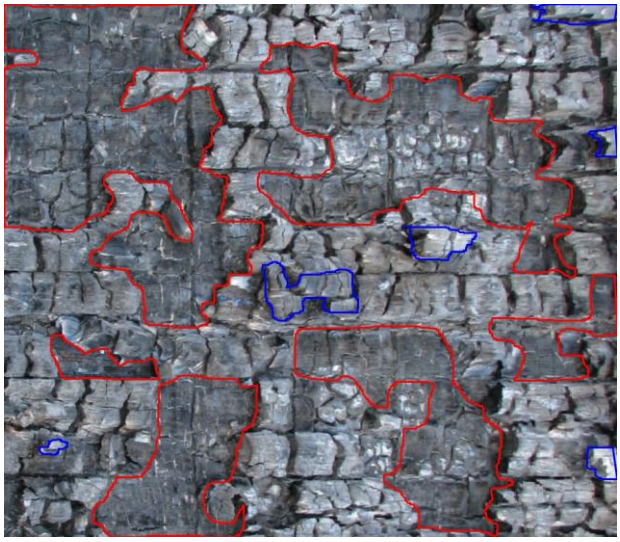

Figure 7: *Delaminated area analysis of specimen 6*

An example of an image that was analyzed can be seen in Figure 7. The areas inside the blue lines are portions of the first ply that are still in place, the areas inside the red lines are areas of the third ply that are exposed, everything else is intact portions of the second ply. These areas were measured for all specimens and the results of this analysis can be found in Table 6. It should be noted this method is not precise and that some of this delamination may have occurred while the specimen was being removed from the furnace and extinguished and that a loaded specimen may exhibit more delamination. In Table 6, a flame failure mode indicates that the specimen failed due to flame penetration of the unexposed surface while char indicates that the char front reached the second glue line in the three-ply specimens or the third glue line in the five-ply specimens.

Table 6. *Percent of ply area remaining at end of test*

Specimen	Adhesive	Failure Mode	Percent of Ply Area Remaining	
			Ply 1	Ply 2
1	MF	Char	96	100
2	MF	Flame	100	100
3	PRF	Char	100	100
4	PRF	Flame	100	100
5	EPI	Flame	12	76
6	EPI	Flame	3	60
7	PUR	Flame	15	93
8	PUR	Flame	77	82
9	PUR	Flame	6	97
10	PRF	Flame	83	95
11	PUR	Char	22	79
12	PRF	Char	100	100
13	PUR	Flame	19	92

4 DISCUSSION

4.1 CHAR RATES

The nominal char rate can be affected by several factors including the external heating rate, total time of heating and the properties of specific wood species such as density. White found that the average char slope for Southern pine was 0.55 min/mm$^{1.23}$ [4]. Using Equation 4, this is approximately equivalent to a nominal char rate of 0.75 mm/min. The US CLT Handbook assumes a nominal charring rate of 0.635 mm/min, which is the commonly assumed value for solid-sawn and glue-laminated softwood members [1]. Table 7 gives the average char rates through the first two plies of each specimen. For both the linear and nonlinear model, the average char rate over all tests was 0.70 mm/min. This value falls directly between the value used in the CLT handbook and that found by White [4].

Table 7. *Average char rate in mm/min of first two plies*

Adhesive	Specimen	Average Char rate (mm/min)	
		Linear	Nonlinear
EPI	5	0.70	0.74
EPI	6	0.77	0.71
MF	1	0.67	0.65
MF	2	0.70	0.69
PRF	3	0.71	0.75
PRF	4	0.56	0.72
PRF	10	0.67	0.71
PRF	12	0.61	0.68
PUR	7	0.78	0.73
PUR	8	0.72	0.68
PUR	9	0.84	0.70
PUR	11	0.64	0.67

Table 8 provides the average char rate through the first two plies for each adhesive. While delamination was visually observed for the specimens with PUR and EPI, overall, the nominal char rates obtained for all specimens are not significantly different between the adhesives.

Table 8. *Average char rate of first two plies in mm/min for adhesives*

Adhesive	Adhesive Average Char Rate (mm/min)	
	Linear	Nonlinear
EPI	0.73	0.73
MF	0.68	0.67
PRF	0.64	0.71
PUR	0.74	0.69

Specimen 13 is not included in Tables 7 and 8 due to the effect encapsulation with gypsum board had on the char rate. The significant reduction in char rate for both the first and second plies in specimen 13 suggests that the gypsum board continues to supply some amount of protection from full exposure to the furnace temperatures until it falls off.

4.2 DELAMINATION

The most obvious effect that the adhesives had on fire resistance of the CLT specimens was observed through delamination (Figure 8). The delamination results in a sudden exposure of the next ply's surface that has not yet initiated pyrolysis.

Figure 8: *Specimen 6 after removal from furnace with evidence of delamination*

The results show that the MF and PRF specimens exhibited little, if any, delamination while the EPI and PUR adhesives exhibited high degrees of delamination. Furthermore, the results in Table 6, suggest that there may be a correlation between high amounts of delamination and premature flame through. According to a thermal model developed by Janssens and White [13], a residual thickness of 7 mm would maintain the temperature at the glue line slightly below 220°C. For a lamination of 35 mm in thickness, only 28 mm is actually converted into char before fall-off occurs. At a rate of 0.635 mm/min, fall-off would then occur shortly after 44 minutes. If the adhesive could maintain its bonding capacity at temperatures associated with charring of wood (i.e., at least 300°C), the time to char a lamination of 35 mm would increase to 54 minutes and therefore enhancing its structural fire-resistance.

As seen in Figure 5, some of the specimens that used PUR and EPI appear to have higher char rates in the second ply than the specimens that used MF or PRF. However, this increased char rate is not seen in all of the PUR or EPI samples, nor is there a substantial difference in the linear char rates in the first ply corresponding to different glues. Furthermore, Figure 6 does not appear to show any significant differences related to nonlinear char rates among adhesives.

4.3 CONFIGURATION

To compare the effects of the traditional LCL configuration with the LLC configuration, specimens 1 through 8 were considered so that direct comparisons between LCL and LLC configurations could be made. The average failure time, nonlinear char rate in the first two plies, nominal char rate, calculated thickness at 1.5 hours, and measured thickness at 1.5 hours were found for the LCL tests (1,3,5,7) and the LLC tests (2,4,6,8).

The average failure time for the LLC tests was found to be five minutes, or approximately 5%, longer than the LCL tests. However, all of the LLC tests failed by flame through while two of the four LCL specimens failed by the char front reaching the second glue line. This suggests that any measures taken to prevent flame through, such as edge gluing, could improve the failure time of the LLC specimens further. Similarly, the nominal char rate was found to be slightly lower in the LLC specimens. Due to the small population size of the measurements, it is difficult to tell if this difference is statistically significant, and the charring models used in this analysis cannot account for this difference.

Surprisingly, the lower measured nominal charring rates of the LLC specimens do not translate into greater remaining thicknesses at 1.5 hours or beyond. This can most likely be explained by the uneven charring phenomenon that was observed in all of the LLC tests. An example of the charring behavior for the LLC specimens is illustrated below in Figure 9. The char front, when observed from the edge of the specimen after the test, is very irregular with deep cracks that coincide with the location of the edge seams in the fire exposed ply. These deep cracks were not observed in any of the traditional LCL configured specimens. Wood is non-isotropic and when cracks form, it is typically perpendicular to the grain direction [16]. However, the deep grooves in the LLC specimens formed along the grain in the longitudinal and radial directions rather than across the grain in the tangential direction. These large grooves coincide with the seam in the first ply and may be the source of earlier flame through in the LLC specimens.

Figure 9: *Specimen 3 PRF-LCL (top) and 4 PRF-LLC (bottom) showing edge char patterns*

These deep grooves cause an uneven char front and may cause significant errors in the measurement of the char rate for the LLC specimens. The measurement method used is not ideal for such a non-uniform char front. Additional thermocouples would be needed to accurately determine the charring behavior under these conditions. Additionally, the CLT charring models assume that the char front is one dimensional. A different model would be needed to accurately predict the uneven charring behavior for the LLC configuration.

Because a flame through failure only requires a small area of the unexposed surface to be compromised, these

deep cavities whose fronts are well beyond the average char depth will tend to cause premature failure due to flame penetration. Similarly, the structural integrity of the CLT will tend to be compromised well before the models predict. Edge gluing the boards, or having a thin perpendicular layer or other barrier between the two parallel layers may help to prevent this phenomenon. Further testing would be required to confirm this.

5 CONCLUSIONS

This paper analyzed the char rates of CLT specimens when different adhesives and configurations are used. While a significant difference in char rate and failure time was not detected between adhesives, the MF and PRF adhesive showed less potential for delamination and associated problems. The overall average char rate through the first two plies was found to be 0.70 mm/min, which is slightly higher than that used in the CLT handbook (0.635 mm/min) and slightly lower than that found by White (0.75 mm/min). The LLC configuration resulted in uneven char front and large grooves in the second ply that coincide with the seam in the first ply. These large grooves are the source of earlier flame through in the LLC specimens. Additionally, the uneven charring associated with the LLC configuration makes it difficult to predict how the specimen will behave at full scale and under load.

The specimens tested were not glued along the edges of the individual boards. Edge gluing or another mitigation technique may prevent this uneven char front phenomena and help to increase the fire resistance time of CLT. Conversely, edge gluing could cause splitting of the lumber along its length and, therefore, requires further evaluation.

The joints between CLT panels themselves are likely to be a critical factor for the failure criteria in ASTM E119 for flame penetration and excessive temperature rise. Joints were not tested in this study and would require further study.

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Fire safety of structures made of timber and other bio-based products - COST Action FP1404

MS4-08D: 4 Effect of adhesives and ply configuration on the fire performance of Southern pine cross-laminated timber
Hasburgh, L. E; Bourne, K. J; Peralta, P.; Mitchel, P.; Schiff, S.; Pang, W.

Abstract
Thirteen Southern pine cross-laminated timber panels were tested in the intermediate scale horizontal furnace at the Forest Products Laboratory to determine the effects different adhesives and ply configuration had on fire performance. Four different adhesives were tested: melamine formaldehyde (MF), phenol resorcinol formaldehyde (PRF), polyurethane reactive (PUR), and emulsion polymer isocyanate (EPI). There were two ply configurations: Long-Cross-Long (LCL) or Long-Long-Cross (LLC) where "long" indicates the wood was parallel to the longer edge of the panel. The MF and the PRF prevented delamination and associated problems while the LLC configuration resulted in uneven charring patterns.
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Citation

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