# LAMINATED VENEER LUMBER PLATED CONNECTIONS IN FIRE

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## ABSTRACT

Society is constantly being pushed in a more sustainable direction, which has resulted in substantial advances in Engineered Wood Product (EWP) technologies in the construction industry. Engineered wood products have many benefits including a high strength to weight ratio, carbon sequestration as well as ease of construction as many EWP systems are prefabricated. The purpose of this research was to produce material data sets for future modelling of Laminated Veneer Lumber (LVL) to aid in a more robust numerical modelling effort of connection systems. The research was performed at small scale using a Cone calorimeter and LIFT apparatus and material focused. Additional to this testing, advanced instrumentation was utilised which considered imaging technology utilising narrow-spectrum illumination to selectively filter out the light from the flame in order to study the underlying charring mechanisms associated to flame spread. The technology was found to be promising. Preliminary conclusions show that external connections may perform better than internal connections with short term heating applications.

## INTRODUCTION

Engineered wood products have become a competitive option worldwide due to emerging technology and building code advances. Laminated Veneer Lumber (LVL) is a common engineered wood product due to its strength in comparison to conventional dimensional lumber. As building codes allow for larger scale structures to be constructed out of wood, the use of LVL is expected to increase. In standard building applications with LVL members, connections are commonly fabricated out of steel. This steel plating is present either externally surrounding the member, or internally in a concealed-type connection. The former is the focus of this study. The behavior, both structurally and thermally, of these composite-type connections when exposed to fire is relatively unknown [1]. For this reason, there is a need to research and for implementation of fire-safe and resilient LVL structural components usage in construction industry. This paper begins to investigate the thermal response of the interface between the steel and LVL elements through focus on the development of charring through flame spread and concentrated heating. The research provides a necessary prerequisite for a more complete structural and study of connections in fire.

## BACKCRGOUND AND MOTIVATION

With the development of mid-rise (6+ storeys) and high-rise (8+ storey) timber construction in Canada, there has been a surge in supporting research focused on assessing how timber behaves in real fires [2]. At the time of publication, the tallest timber building to be constructed in Canada was Brock Commons at the University of British Columbia. The building is an eighteen story hybrid mass timber structure built primarily out of engineered wood products (EWP) or commonly referred to as engineered timber. Engineered timber being high quality timber glued using adhesives to build up a larger section. The construction methodology is sustainable in the sense that mass timber is not needed as trees can be grown more quickly, harvested responsibly and built up into a larger and more defect free structural member. This building in British Columbia has pushed the boundaries for mass timber construction and code compliance through the alternative solutions measures in the Canadian building code. To enable alternative solutions in future timber infrastructure for fire design, significant modelling and testing may be required.

Figure 1: Brock Commons Building in British Columbia

The bulk of testing in Canada performed for alternative solution development has focused on engineered timber testing with standard fire furnace tests [2] and comparison with more conventional materials like steel and concrete. While these standard tests in Canada, have been informative for purposes of generating valuable information towards the development of novel alternative solution development for floors, walls and beams, they have not necessarily improved our understanding of the underlying mechanisms and theory for which can govern engineered timber in fire – particularly the role of connections. This theme has been identified as a research need and interest by many international research bodies [3, 4].

The underlying 'thermo- physical' mechanisms in particular to fire spread and char formation under non-standard formations are critical when considering how a real fire interacts with timber connections, particularly those with external plated connections. The addition of steel and associated heat transfer only complicates these analyses.

The research herein involves testing LVL sections using a Lateral Ignition and Flame Spread Test (LIFT) apparatus [5] and Cone Calorimeter [6] to study flame propagation and heat penetration through and beneath the steel plates used commonly in connections. This testing style was deemed appropriate in light of more difficult to perform standardized fire testing. These tests were performed in initiating construction of a robust numerical model for evaluating timber connections for future work which can be later used in analyzing full-scale tests, or within possible performance based analyses – the data can provide a basis for future model verification and validation.

The cone calorimeter tests were used to quantify the effect of the steel plate on pyrolysis and charring. Alternatively, the LIFT apparatus was used to quantify the influence of the geometry of the steel plate section on retarding a spreading flame as may be seen in real construction. These apparatuses were located at Carleton University Campus Fire Safety Engineering Lab.

Novel to this study is the testing of a new Digital Image Correlation technique which was adapted within the LIFT apparatus testing herein [5, 7]. As the envelope for timber construction is pushed, in particular with the emerging EWP technologies, our current methodology for testing and understanding these assemblies in fire needs to keep pace with these innovations.

## METHODOLOGY

A combination of testing was performed on LVL samples, primarily in two phases. First to consider a controlled heat source and study char formation followed by a controlled flame spread and study of its interaction with the timber material. These two phases were chosen as they can represent timber material assemblies in heat exposures similar to real fires. LVL samples were prepared with and without steel plating screwed into the surface at a sufficient depth. All LVL samples had a moisture content between 5.5 and 5.9% by mass.

### Quantification of Char

For both phases, the char depth of these test specimens were determined visually by measuring the unheated material thickness from the samples after the applied heat flux and comparing this to the original sample thickness. This technique ensures that the char depth is measured accurately as the mass loss that occurs may make visual estimation of char on its own challenging.

### Controlled Heat Flux Testing

The first phase of this project was to study samples of LVL with and without steel plating to determine the influence of the steel plates on char and pyrolysis depth. See Figure 2. This was completed using a Cone Calorimeter to induce a constant and incident heat flux on the samples at fixed durations of time typical to previous testing by others for comparison. Standard incident heat fluxes of 30kW/m$^2$ and 50kW/m$^2$ were used to simulate two severities of heat fluxes.

Figure 2: Plated and Un-plated Sample LVL sections

The LVL for these samples was obtained from a manufacturer in Ottawa, Ontario. The adhesive used in this LVL is proprietary to the company. This is quite common with EWP products. A series of 44.5mm by 240.0mm Grade 2.0E single ply LVL beams were acquired and cut down to 100mm x 100mm x 44.5mm test samples. The samples have a coating on the exterior faces for weathering, which is green in colour, and this coating was left on for the testing. See Table 1 for test schedule.

Table 1. Test Schedule for Applied Heat Flux Testing

| Sample | Plate Thickness [mm] | Applied Heat Flux [kW/m$^2$] |
|---|---|---|
| A30-C-1, A30-C-2, A30-C-3 | n/a | 30 |
| A30-4.7-1, A30-4.7-2 | 4.7 | 30 |
| A30-9.5-1, A30-9.5-2 | 9.5 | 30 |
| A30-12.7-1, A30-12.7-2 | 12.7 | not tested |
| A50-C-1, A50-C-2, A50-C-3 | n/a | 50 |
| A50-4.7-1, A50-4.7-2 | 4.7 | 50 |
| A50-9.5-1, A50-9.5-2 | 9.5 | 50 |
| A50-12.7-1, A50-12.7-2 | 12.7 | 50 |

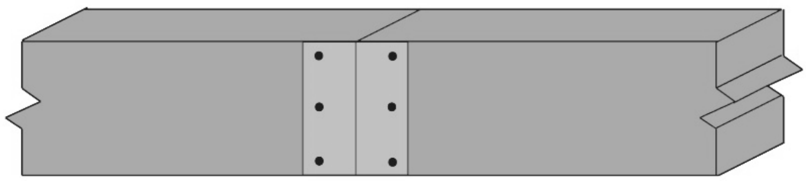
The samples were tested for 10 minutes at either 30kW/m$^2$ or 50 kW/m$^2$ incident heat flux in accordance to Table 1. The time is common in other cone testing by other researchers and can also be used for comparison with other EWP testing done by the authors and collaborators. The specimens were prepared to standardized test procedures where adjacent faces were covered in foil to reduce any subsequent charring which could influence the recorded char depth along the sides among other functions. After testing, the samples were cut so that the char depth in the center could be measured, as the worst case char depth is assumed to would be located in the center of the sample. This area will be exposed to the most uninterrupted heat flux. The samples 12.7 mm samples were not tested at the $30kW/m^2$ as the 9.5 mm plated samples would later show no observable char or pyrolysis formation for the given test times.

**Flame Spread Heat Flux Testing**

The LIFT apparatus is being used for phase two of the project to understand the behavior under a defined length of steel used in a LVL external plated connection (see Figure 3). The test program for Phase two is designed to study the minimum length required in an external style connection to disrupt flame spread across (or beneath) connections in the case of a primary structural system of timber. This experimental plan was to observe if a severe localized fire could spread over the connection and to study how the char and flame spread front develop for this material.

In consideration of typical conventions in practice, external steel plates varied in thickness and length. This variability in plate thickness allowed for the consideration of geometry effects of external connections to either impede flame as well as to study heat conduction through a composite connection.

Figure 3: Typical steel tie plate style external connection



In this sense, the pyrolysis and charring of the LVL under the steel plates is also studied herein. The char depth was measured using the same process as the control heat flux and the samples were cut down the centerline to measure the depth, as per the standard ASTM 2013 E1321 [5]. These tests are underway at the time of publication.

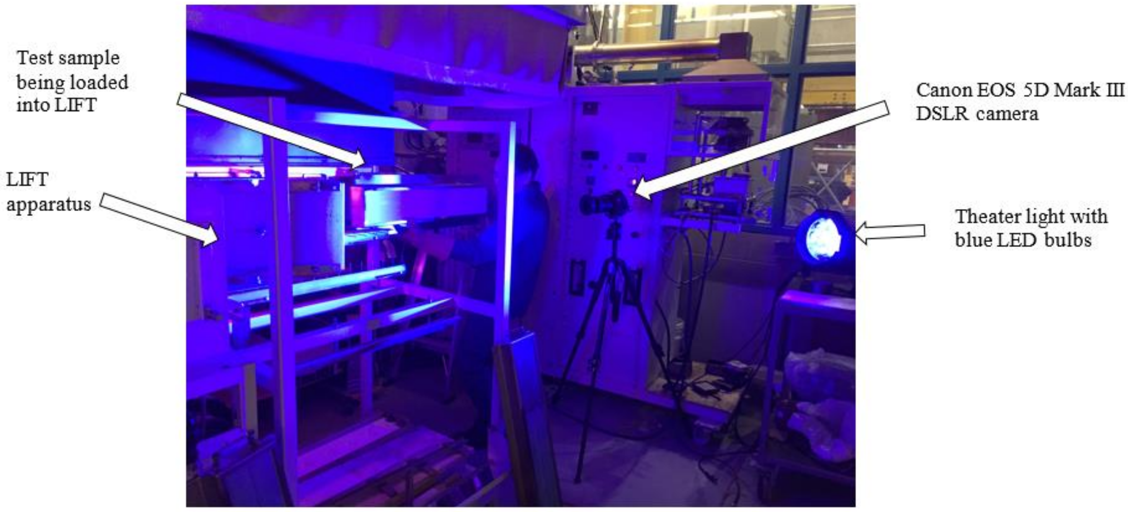
Table 1. Planned LIFT Test Schedule

| Sample | Plate Thickness [mm] | Plate Length [mm] |
|---|---|---|
| B-C-1 | - | - |
| B-C-2 | - | - |
| B-C-3 | - | - |
| B200-4.7-1 | 4.7 | 200 |
| B300-4.7-1 | 4.7 | 300 |
| B400-4.7-1 | 4.7 | 400 |
| B200-9.5-1 | 9.5 | 200 |
| B300-9.5-1 | 9.5 | 300 |
| B400-9.5-1 | 9.5 | 400 |
| B200-12.7-1 | 12.7 | 200 |
| B300-12.7-1 | 12.7 | 300 |
| B400-12.7-1 | 12.7 | 400 |

Testing using the LIFT deviated slightly from the ASTM standard as it was performed for research purposes to investigate common external connections in such mass timber applications it was deemed an acceptable deviation.

An imaging technique, using narrow-spectrum illumination and bandpass optical fitering, developed at the National Institute of Standards and Technology (NIST) National Fire Research Laboratory (NFRL) was used for this set of tests using the LIFT apparatus (see [8] for previous application where objects engulfed in clean-burning (natural gas) diffusion flames were observed. This test series is ongoing as the technique is still being refined. The technique aims to allow heated LVL timber to be viewed with reduced obstruction by flames induced by the radiant heater of the LIFT apparatus. A Light Emitting Diode (LED) light that emitted light in a narrow spectrum near the bottom of the visible range (approximately 450 nm) was used to illuminate the sample. The LED light had sufficient power (95 watts) to overcome the radiation in this portion of the electromagnetic spectrum emitted by the flames. A bandpass optical filter that allowed illumination from the LED light to pass, but filtered out electromegatic radiation above and below the target frequence was adapted to fit the lenses on a Canon EOS 5Ds Mark III DSLR camera. This camera has a 50 Megapixel resolution (images of 5792 x 8688 pixels) which allows it to be placed farther away from the sample during testing. This placement eliminates any risk of damage to the camera, lenses and parts due to heating and radiation from the LIFT apparatus. The resolution of the camera still provides detailed resolution of the timber material while it is flaming. To assess the technology an 'adaptive' flame spread analysis was performed by the authors which considered correlation between sequenced images by color intensity change being the marker for char front development (not flame spread). This was opposed to the traditional image correlation measurement through photo sequencing which relies on overall pixel movement [6]. The set up can be viewed in Figure 4.

Figure 4: LIFT Apparatus and Imaging Setup in Carleton Campus Fire Lab



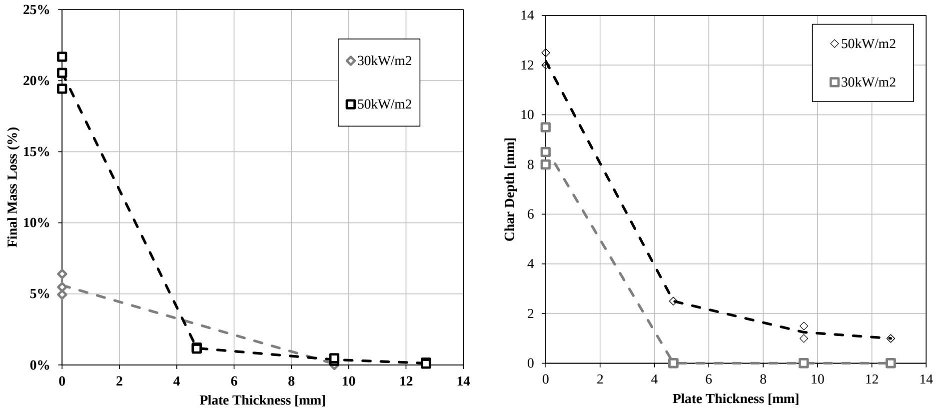

## RESULTS AND DISCUSSION

The results presented herein are preliminary as the authors are currently developing additional data sets and expanding and refining their test procedures to holistically consider this topic and to have adequate data to enable model verification and validation.

### Controlled Heat Flux Testing

The standardized char rate for LVL members is 0.65mm/min which is similar to other EWPs [2]. Averaged char rates herein were found slightly in excess to these for even low non-standard heat flux exposures but comparable to those seen by the authors for other short term heat exposures [9]. This may be of consequence of the lower moisture contents observed for the LVL samples tested (~5%) and of the use of non-standard heat fluxes outside standard fire testing (ie., not the E119 fire), and smaller developed char layering for low heating times of 10 minutes.

Figure 5: Plate thickness versus Char Depth and Mass Loss for 10 minute exposure




By increasing the thickness of the plate there was a quantifiable difference in depth of charring. The addition of a 4.7mm plate to the LVL caused a 19% mass loss reduction in the 50kW/m$^2$ heat flux case. The use of external plating in the 30kW/m$^2$ case has a lessened impact overall as the mass loss was roughly a quarter of that in the 50kW/m$^2$. The mechanisms are deemed to be related to steel reflectivity, heat transfer and lack of oxygen all contributing to a slowing of pyrolysis and progression to char. This data shows that the relationship between mass loss and heat flux is not linear at least for the testing conducted to date. Utilizing these material trends and developing associated computational tools, as is being considered in industry, could aid in creating better connections. As connections are often the weakest building component in fire, this consideration of the underlying thermal mechanics of the composite materials heightens the overall performance of the building.

The data seems to suggest that structural stability on the basis of the minimal char alone is likely to remain in the connection for the test configuration configured. Its representation of reality though can be open for discussion. Additional testing at different test durations would be essential in order to develop more comprehensive models. The data does suggest that external connections would perform better than an internal connection because the steel may delay the heat transfer to the timber.

**Flame Spread Heat Flux Testing**

The LIFT apparatus was used to study the influence of steel plating on flame spread therefore an 18-minute basis was used for the testing. Eighteen minutes was chosen arbitrarily as this was the time for the fire to spread during the first unexposed test from one end to the other. As these tests are underway, caution is given to the reader in formulating specific conclusions on the data presented particularly in reference to adhesive performance. Though preliminary insights are considered herein.

The behaviour of plated LVL sample was unique, as the progression of charring along the length of the timber was reduced. As can be seen below in Figure 6, the black-hashed line represents the start point and end point of the steel plating. The top sample has a reduction in char depth directly before the start of the steel plate and the initial char under the plate is reduced by approximately 60% compared to the uncovered samples. The behaviour observed reflects the idea of the steel plate working as a heat sink. This comparative test showed that the sample stopped charring approximately 150mm into the steel plate and that the plate was successful at inhibiting flame spread with this length.

The imaging technique developed at NIST was used on the control tests and showed promising results for the filtration of the flame front in the testing. Figure 7 demonstrates the technique results in the first control tests. The image on the left shows an overall view of the test setup, which was taken with a non-lensed camera, and the flame can be observed. The second image (on the right) shows an image taken from the double-lensed camera where the flame is filtered out successfully.

Figure 6: Char Depth of Sample Compared to Induced Heat Flux

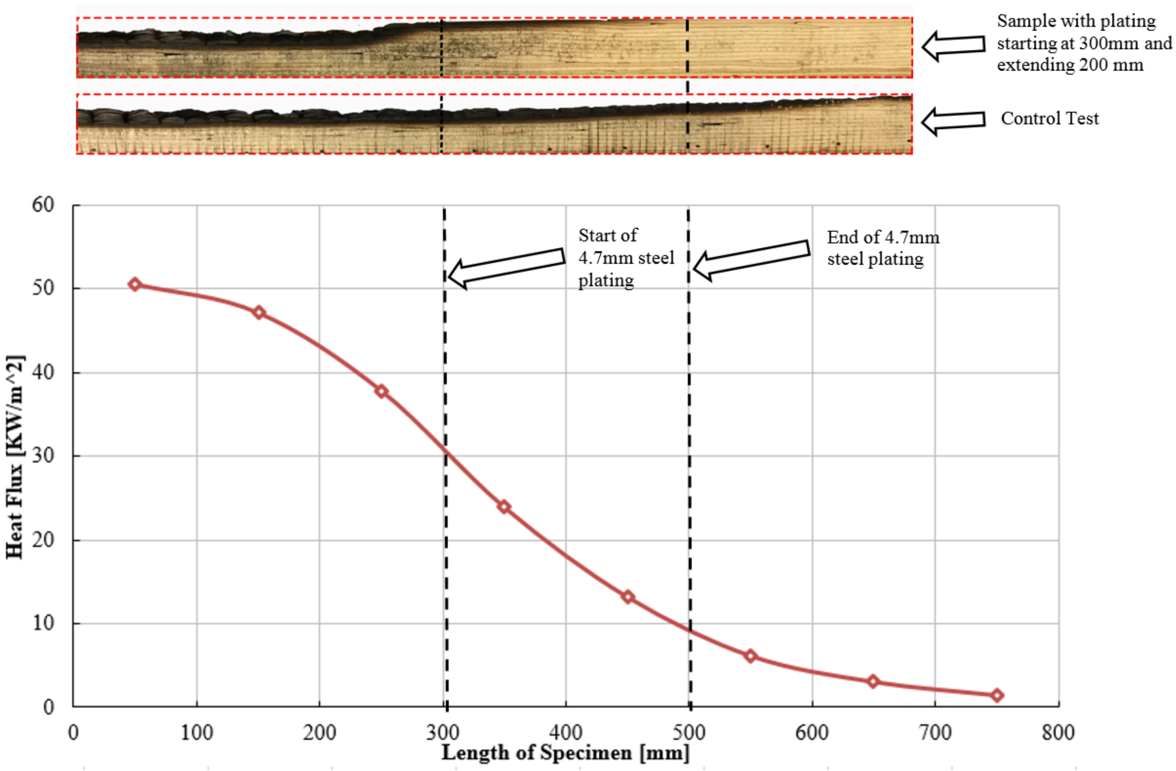
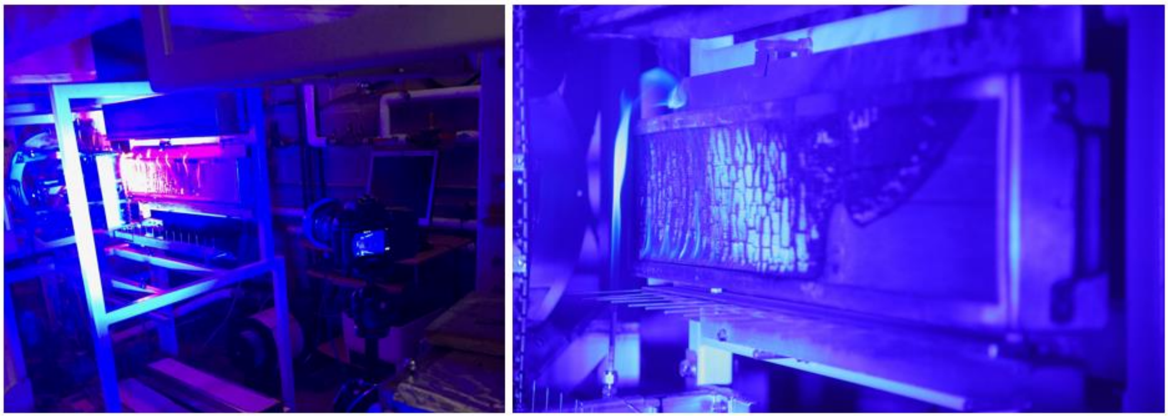
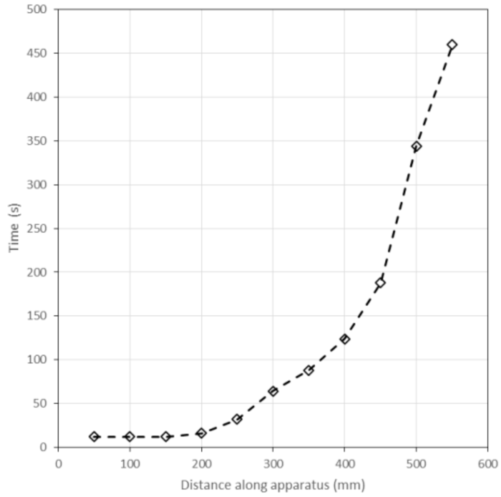



Figure 7: LIFT Testing and Imaging Technique Result



By using narrow-spectrum illumination and optical filtering, the char front progression could be directly observed, rather than the traditional method of tracking the flame front. The below table compares the measured char front to the measured flame spread as is traditionally measured through the naked eye. Since the flame front is fairly turbulent, measured by the naked eye, it could be beneficial and important to consider a spread rate from char front as opposed to the flame front – providing the mechanisms from char to ignition are rationally understood. Figure 8 provides a preliminary analysis of char spread estimated through image correlation based upon color change. Beyond lift testing, the ability to filter the emission of light from fire could allow the measurement of in-fire mechanical properties of polymers and other engineered materials – which the authors are also currently studying.

Figure 8: Char spread measurement




## PRELIMINARY CONCLUSIONS AND FUTURE WORK

Engineered timber is gaining competitive economic popularity in the construction industry and this leads to timber performance in fire being more intensely studied. This means that evaluation and modelling techniques for timber in fire are being globally scrutinized for usability and accuracy. This need for more realized fire modelling was the basis for this testing. This testing demonstrates the use of the new imaging technology in fire engineering to understand the development of the char layer rather than the development. The program herein is ongoing and designed to study the optimal configuration required in an external style connections in LVL to disrupt flame spread and reduce char depth from fire exposure. Initial conclusions show that external connections perform well in short term heating applications leading to the structural stability of the structure during egress in the case of fire. Timber structures have proven resiliency despite the ever-changing standards for testing. As these testing methods change we only become more aware of how industry changing engineered wood construction is.

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