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NUMERICAL MODELLING OF CONTEMPORARY MASS TIMBER CONNECTIONS IN FIRE

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ABSTRACT: Timber buildings are becoming increasingly popular due to their sustainability and aesthetic appeal. There remains however, a need to fully understand the fire performance of mass timber construction, including the fire performance of the connection. Beam-column connections can be complex to assess in fire, due to the proprietary and custom nature of many connection designs. The purpose of this study is to create a numerical model that can assess the residual fire resistance capacity of mass timber connections exposed to fire. This endeavour was completed using finite element modelling considering heat transfer of mass timber connections. Two approaches were taken, first, the heat flux through the fastener's shank establishes the reduction factors that predict the residual thermal capacity of fasteners, and the second establishes the residual length of penetration that provide adequate structural capacity into timber elements. These thermal analyses work towards developing a simplified design method for evaluating mass timber connections exposed up to two hours of standard fire exposures. By providing additional information related to the expected temperatures and strengths of timber connections in fire, novel designs become more accessible for innovative timber structures.

KEYWORDS: fire, connections, mass timber, numerical modelling

1 INTRODUCTION

Fire design of connections in timber buildings faces unique challenges due to the interaction of combustible structural elements and noncombustible metallic fasteners that perform differently in fire conditions. Given that there are a multitude of possibilities for how mass timber connections might be designed, with trends for connection configurations continuing to be developed, design tools are needed for timber connections to understand the effect of parameters such as the number and size of fasteners used, as well as the spacing in between fasteners. While standard fire tests are always an option, this type of testing can be costly and time consuming when only a small change is made to a design in attempt to optimize either the thermal or the thermomechanical performance of the mass timber connection.

Traditionally, heavy timber construction used steel or iron caps, as well as large metallic hangers and plates (Figure 1). These were used on buildings where little to no fire-resistance rating was prescribed in building codes. When such a connection is used, the metallic cap directly transfers the gravity loads to the column below and the beams are directly supported on top of that column. As such, even if this cap heats and loses strength, it will most likely not result in structural collapse. Based on their good historical performance, it is usually agreed that this type of construction provides an acceptable level of fire safety.

Figure 1: *Traditional heavy timber construction using iron/steel connections.*

With the recent advances in mass timber construction and products, construction and design techniques have also evolved. Taller buildings are also typically required to provide greater fire-resistance ratings, up to 2 and 3-hours, which is much beyond the deemed performance of traditional timber construction. Innovative fasteners such as self-tapping screws are gaining lots of popularity due to their ease of use and high capacity, while being aesthetically pleasant. While there has been a shift towards shear-type connection (i.e., similar to steel

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construction), modern connection design is going back to traditional timber engineering method – that is to use as much of the timber embedment and compression strength and conceal all metallic components. Figure 2 shows a modern version of the same type of connection shown in Figure 1. Gravity loads are being transferred directly to the column underneath and beams are also supported by that column. Little to no forces are being transferred in the metallic (concealed) fasteners. While the engineering behind these designs are sound, there is a need to better understand the underlying thermomechanical properties and performance of modern mass timber connections.

Figure 2: *Modern timber construction using concealed connection.*

The objective of this study is to develop a numerical model using finite element analysis software that can predict the thermomechanical behaviour of contemporary mass timber connection configurations, for exposure durations longer than one hour. The development of these models will provide information to designers regarding the distribution of the temperatures in different connection configurations, allowing for an understanding of the heating rate through the fastener's shank into timber element for a standard fire exposure. The results will ultimately be used to validate an analytical model to predict the structural fire resistance of connections in design standards.

2 BOLTED CONNECTIONS

Herein, a series of experimental studies will be discussed to assess the developed numerical model. Many of these tests consider the timber assembly loaded in tension parallel to grain, and for a relatively short duration.

From the University of Canterbury, Chuo [1] considered the fire performance of Hyspan laminated veneer lumber connections. The connections were loaded to either a factor of the characteristic strength of the bolts used, and exposed to the ISO 834 [2] standard fire. The fire resistance of the connections was found to be less than 25 minutes.

In 2010 from Carleton University, Peng [3] published an experimental test series looking at the performance of wood-steel-wood and steel-wood-steel bolted connections using 20f-EX S-P glulam (test groups 2 through 5) and No. 2 SPF dimensional lumber (test group 1), loaded in axial tension and exposed to the CAN/ULC-S101 [4] standard fire, where it was found that the fire resistance of the bolted connections was less than 45 minutes. The tests were loaded to a fraction of their calculated ultimate load capacity. The experimental component of the study was followed by the creation of a finite element model which agreed well with the experimental data.

Also from Carleton University were test series completed by Alam [5] and Ali [6]. Alam tested four wood-steel-wood connections in tension, exposed to the CAN/ULC-S101 standard fire. The wood members in Alam's study were 24F/NPG glulam while Ali used 24F/ES12 glulam. Alam's assemblies were loaded to their calculated faxtored axial tensile strengths, and times to failure ranged from 12 to 32 minutes. Ali performed bending tests of beam-to-column timber connections, with either concealed, seated, or exposed steel plates. The glulam beams were 140 × 191 × 1 900 mm, and were loaded using third point loading configuration. The specimens were exposed to the CAN/ULC-S101 standard fire. Only Tests 1.1 and 1.2 by Ali are considered herein, both concealed steel connections (e.g., knifeplate connections).

Select connections from the above experimental tests from literature are considered in analysing the model results in Section 2.2 of this study. The connections considered herein are outlined in Table 1.

2.1 METHOD

A numerical model was created using ABAQUS to carry out transient heat transfer modelling of metallic fasteners into the timber. The purpose of this model was to determine the temperature profiles of the metallic fasteners, in order to understand how much strength could potentially be lost during heating that occurs during the thermal exposure. Bolted connections were considered due to experimental data regarding these connection types being widely available in literature.

In developing the ABAQUS model, bolts were assumed to have a hole 2 mm greater than the diameter of the bolt, as per CSA O86 [7]. Thus for this analysis, a 1 mm air space was assumed to be evenly surrounding the bolt. In reality, a portion of the bolt would be in contact with the surrounding wood, and a portion will have an air gap larger than 1 mm, however, previous studies have found that the size of air gap has little effect on heat transfer when the size of the gap is less than 4 mm [3]. Washers were assumed to be located between the bolt head and the top surface of the timber, and were taken as the maximum washer size as permitted by CSA O86. Fastener threads have been neglected in this model, as previous studies have found that neglecting threads can reduce computational time without significantly affecting the heat transfer of the model [8].

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__Table 1:__ Summary of parameters of experimental tests from literature considering bolted connections.

Test	t_1[1] (mm)	t_2[2] (mm)	d_f[3] (mm)	n_R[4]	n_c[5]	Load (kN)
Chuo – 1	45 × 150	63	12	1	1	23
Chuo – 2	45 × 150	63	12	3	1; 2[6]	4.9
Peng – 1	2@38 × 140	9.5	12.7	1	2	17.4
Peng – 2	130 × 190	9.5	12.7	2	2	34.5
Peng – 3	130 × 190	9.5	19.1	1	1	19.5
Peng – 4	130 × 190	9.5	19.1	2	2	68.1
Peng - 5	2@80 × 190	9.5	19.1	2	2	72.9
Alam – 1	137 × 178	9.5	12.7	2	2	72
Alam – 2	2@86 × 178	9.5	12.7	2	2	80
Alam – 3	228 × 267	9.5	19.1	2	2	162
Alam – 4	2@137 × 267	9.5	19.1	2	2	175
Ali – 1[7]	140×191 ×1900	9.5	19.1	2	2	21.5
Ali - 2[7]	140×191 ×1900	9.5	12.7	2	2	21.5

1 – Side member thickness
2 – Centre member thickness – all steel; except Chuo 1 and 2
3 - Fastener diameter
4 – Row number
5 - Number of fasteners in a row
6 – Two rows of 2 fasteners, 1 row of 1 fastener
7 – Concealed beam-column connection

Connections were subjected to the CAN/ULC-S101 from one side, and the distribution of temperatures through the fastener's shank into timber element were observed. A schematic of the ABAQUS model is seen in Figure 3. The transient heat transfer modelling was compared to temperatures as reported in existing literature.

Based on the interaction of timber and steel, the residual capacity of the connections exposed to the CAN/ULC-S101 standard fire was estimated. This was done by assessing the temperature at the interface of the shank of the bolt with the timber, and reducing the strength of the bolt according to temperature, as per the steel reductions outlined in CSA S16 [9]. Though the temperature on the outside of the bolt may not be quite as hot as at the centre of the bolt, assessing temperature along the side will allow for comparison with any future experimental testing in which a thermocouple could be placed at the interface of the timber and the bolt. The degradation of the timber followed the reduced cross section method as outlined by Annex B of CSA O86. A schematic of the ABAQUS model for a 12.7 mm bolt after 15 minutes of standard fire exposure is seen in Figure 4.

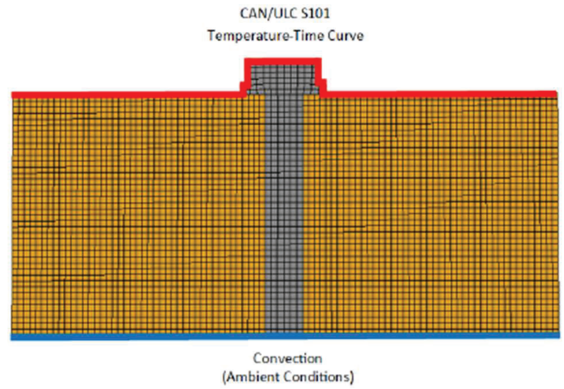

***Figure 3:** Schematic of ABAQUS model (15 min exposure).*

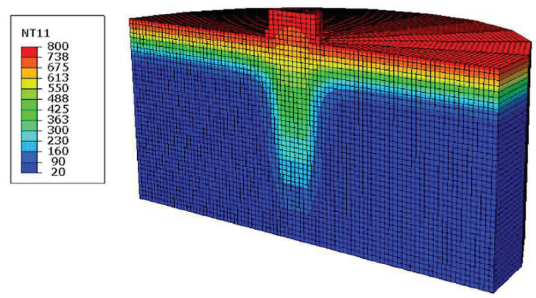

***Figure 4 :** Schematic of ABAQUS model (15 min exposure).*

It is noted that only thermal degradation of the timber and the metallic bolt are considered herein. Strength loss of any steel plates used in the connection is not considered. This assumption was made as the ABAQUS model only considers heat transfer in one dimension. Thus, the steel plates largely remained at ambient temperature throughout the duration of the thermal exposure. However, for longer thermal exposures and more severe thermal exposures, strength loss of the steel plate due to fire should be explicitly considered.

2.2 RESULTS

Figure 5 presents a comparison of the experimental fire resistance as reported in the literature, the calculated fire resistance time considering only the degradation of the timber (the bolt is considered to retain full strength), and the calculated failure resistance time considering both the degradation of the timber, as well as a reduction of strength of the bolt using temperatures extracted from the ABAQUS model and reduced per Annex K of CSA S16. The temperature of the bolt was taken at the intersection of the bolt and the timber, along the top surface of the timber (immediately below the washer). Through the analysis, temperature of the bolt was taken at other locations along the shank for consideration and analysis into the optimal depth to read bolt temperature – these

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depths included at set depths (e.g., 10 mm from the face of the timber), and as a function of the final char depth (e.g, 10% the depth of the char). It was found that using the temperature directly beneath the washer resulted in greater temperature (thus greater steel strength reduction), and ultimately better predictions of the failure times.

For the most part, the calculated results were more closely aligned with the experimental results when considering a strength reduction for the steel bolt, correlated with temperature. The exception to this would be the experiments performed by Alam [5], where the specimens were loaded to the CSA O86 predicted ambient factored failure load. Thus, any additional reduction in strength, either via the charring of the timber cross-section or the reduction in steel strengths only shortened the calculated fire resistance time. The experimental fire resistance time was therefore much greater than predicted.

The test series by Ali [6] considering beam-column connections in bending were also analysed using the method outlined above. It can be seen in Figure 5, in the case of Ali, that the modelling used to reduce the strength of the fastener did not affect the predicted fire resistance of the assembly. This is because the failure mode, considering only the timber's reduction in cross-sectional area, was found to be bending at the connection, which is not dependant on the strength of the fastener. Nevertheless, considering the degradation of the timber only, the calculated results had relatively good agreement with the experimental tests (with a calculated failure at 38 min, compared to 33 min for Test 1.1, and 40.3 for Test 2.1).

The calculated results, as seen in Figure 5, still had some deviation from the experimental results. However, considering the reduction in steel fastener strength at high temperature in addition to reduction of timber cross section did make a considerable difference in more closely aligning the experimental and calculated fire resistance times. Considering the degradation of the timber only, the average percent difference between the experimental and calculated fire resistances was 87%, whereas considering the degradation of the timber in addition to the strength reduction of the bolt, the average percent difference between experimental and calculated fire resistances was 37%.

2.3 DEVELOPMENT OF REDUCTION FACTORS FOR BOLTS

As it was found that the calculated fire resistance times were better aligned to the experimental results when the strength reduction of the bolts at high temperatures are considered, a series of reduction factors are proposed herein. From the temperature of the bolt at a given time – either 15 or 30 mins – a reduction factor was determined per the reduction factors outlined in CSA S16-19 Annex K [9] which is applied to the ultimate and yield strengths of the steel fastener. The reduction factors are in relation to the initial strength of the material (i.e., the strength at 20 °C). The resulting reductions for each fastener type are summarized in Table 2. It should be noted that the results of this study are, at this point in time, limited to the tests available in literature. Thus, the results are limited to 12.7 and 19.1 mm bolts, tested for up to a maximum of 31 minutes. Model development also relied on experimental tests of tension connections, with a bending test also considered as a point of comparison (however the calculated failure mode of the bending test was independent of bolt temperature). Thus, the results of Table 2 apply to short duration fires where the members are loaded in tension.

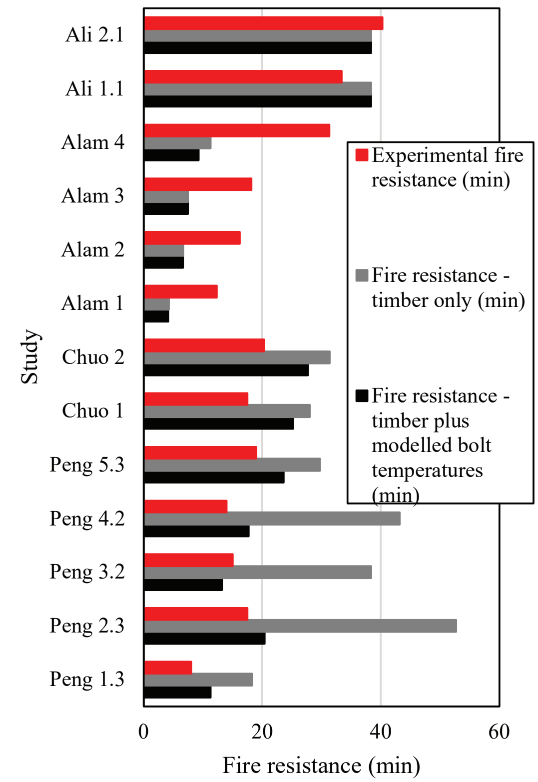

Figure 5: *Experimental and calculated fire resistance times for the tensile tests.*

The reduction factors were applied to the steel strengths within the connection equations of CSA O86-19. In essence, the reduction factors would be applied to the steel fastener strengths, and the capacity evaluation of the connection would be combined with a reduced cross-section approach for the timber portion of the connection (i.e., the dimensions of the timber will reduce with the time of fire duration, accounting for the charring rate and zero-strength layer set out by Annex B of CSA O86-19 [7]).

While the outcomes detailed herein provide a basis towards a calculation method in which the connection of timber structures can be considered at high temperature, further research and testing are needed to expand the applicability of these results. With additional testing of longer durations and testing of other connection configurations, the method presented in this study of deducing a reduction factor from the expected thermal

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profile of a fastener can be extended to scenarios beyond short duration fires on tension connections.

Table 2: *Proposed reduction factors*

Bolt size (mm)	Standard Fire Exposure (min)	Steel Reduction Factor
12.7	15	0.22
	30	0.13
19.1	15	0.26
	30	0.15

3 SELF-TAPPING SCREWS

The fire performance of the self-tapping screw (STS) is mainly influenced by the residual capacity of the wood surrounding the fastener, i.e., the residual penetration length. This residual penetration length is affected by the heat conduction through the fastener shank which depend on its thermal capacity and fire exposure [10].

To evaluate the conductive heating rate of different mass timber fasteners, another transient heat transfer model using the finite element (FEM) method was developed to compare the effects of geometric parameters on the thermal behaviour of the fastener, such as the length, the size of the head, and the shank diameter.

3.1 MATERIALS AND METHODS

Six full-thread screws with self-drilling tip and countersunk head (SWG ASSY®3.0 VG CSK) and one full-thread screw with self-drilling tip and cylinder head (SWG ASSY®3.0 VG CYL) were examined with the head exposed to CAN/ULC-S101 standard fire. The STS are made of carbon steel and have a bending yield strength of 1015 to 1147 MPa and a shear strength of 341 to 533 MPa, depending on the types of STS [11]. Three high-strength structural bolt diameters (Ø12.7 mm, Ø19.1 mm and Ø25.4 mm) were examined. A length of penetration of 200 mm was assumed for all bolt-type fasteners. In attempt to evaluate the impact of bolt head, one dowel diameter of Ø12.7 mm were also examined. The dimensions of fasteners are presented in Table 3 and Table 4.

Table 3 : *Dimensions of self-tapping screws in accordance with CCMC 13377-R [11]*

Outside Thread Diameter (d_F) (mm)	Head Diameter (d_{head}) (mm)	Shank Diameter (d_{min}) (mm)	Length (L)/ Threaded length (L_F) (mm)	Penetration (mm)
10[1]	13.4	6.2	200/185	200
8	14.8	5	200/183	200
10	19.6	6.2	100/77	100
10	19.6	6.2	200/185	200
10	19.6	6.2	400/385	400
10	19.6	6.2	800/782	800
12	22.1	7.1	200/185	200

[1] Full-thread screw with self-drilling tip and cylinder head

Table 4 : *Dimensions of dowel and bolts.*

Fastener Head Diameter (d_F) (mm)	Shank diameter (d_{min}) (mm)	Length (L)/Threaded Length (L_F) (mm)	Lead Hole Diameter (mm)	Penetration (mm)
12.7[1]	12.7	177.8/25.4	12.7	200
22.23	12.7	177.8/25.4	12.7	200
31.75	19.05	177.8/34.9	19.1	200
41.28	25.4	177.8/44.5	25.4	200

[1] Dowel

Each fastener was inserted in a glulam of the 20f-EX spruce-pine stress grade conforming to CSA O122 [12]. The exposed top surface of timber element was 100 mm diameter with 8-ply of 35 mm, as shown in Figure 6. For the STS with a length of 400 mm and 800 mm, the STS was inserted in a 17-ply glulam and a 24-ply glulam to fully surrounding the STS with wood fibres.

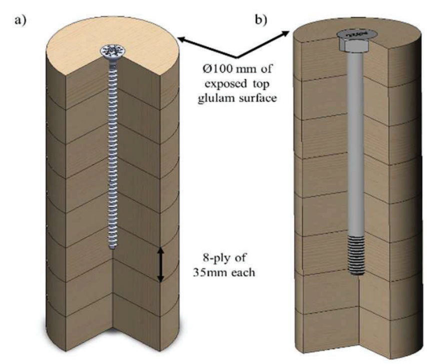

Figure 6 : *Geometrical configurations: a) Ø10 × 200 mm SWG ASSY®3.0 VG CSK inserted in 8-ply glulam; b) Ø12.7 × 179 mm A325 bolt inserted in 8-ply glulam.*

The three-dimensional transient heat transfer model through a solid timber using ANSYS was developed with a fastener inserted at the geometric center of the glulam element in attempt to characterize the thermal penetration depth of fasteners. The top surface of the glulam specimen and the head of the fastener were exposed to the CAN/ULC S101 standard fire for two hours. Eleven (11) heat transfer models were developed, i.e. one for each fastener type. The same boundary conditions were applied, as previously discussed in Section 2.1. Due to symmetry, the transient thermal model was performed only for one quarter of the specimen and cylindrical shank of the fastener (i.e., no threads), as shown in Figure 7a). The 3D temperature fields were also divided into elements with a length of 3 mm using 3D hexahedral elements.

To compare the temperature distribution between the simulation and the fire tests, five (5) coordinate systems and five (5) thermocouples were created in the heat transfer model at the exposed surface (0 mm), 1st glueline (35 mm), 2nd glueline (70 mm), Mid-length of the fastener, 3rd glueline (105 mm), and the tip of the fastener as presented in Figure 7b).

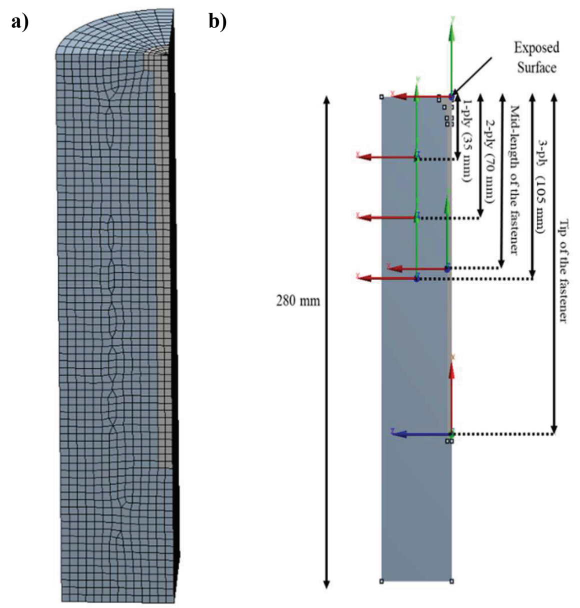

Figure 7 : *Geometrical parameters used for heat transfer modelling of 8-ply glulam.: (a) Meshing; (b) Distance of thermocouples from the exposed surface along Ø10 × 200 mm SWG ASSY®3.0 VG CSK.*

3.2 RESULTS

3.2.1 Influence of STS fastener diameter

Exposing the cylinder head (CYL) and the countersunk head (CSK) of Ø10 × 200 mm STS had some influence on the temperature distribution along the fastener. For similar temperatures at the fasteners' head, the thermocouples at the mid-length (100 mm), and at the tip (200 mm) of the STS estimated temperatures of 402 °C and 143 °C for CYL, whereas the temperatures reached 413 °C and 151 °C for CSK after two hours of fire exposure, as shows in Figure 8. The variation of temperatures between the two STS was due to the larger head diameter at the exposed surface, which was 19.6 mm for the CSK compared to 13.4 mm for the CYL. While little differences were observed, the results suggest that the larger heated area of CSK increases the amount of heat conduction along the shank inside the timber.

Moreover, the shank diameter of the fastener was also influencing the temperature distribution along the fastener when comparing the different diameter shank of CSK fastener. For instance, the temperature of the Ø8 mm CSK at the tip (200 mm) was around 110 °C, compared to 133 °C at the tip (200 mm) of the Ø12 mm CSK after two hours, as shown in Figure 8.

The same results are being observed with bolts and dowel where the temperature through the fastener increases with the diameter of the head and shank. Figure 9 shows the measured temperatures of the bolts and dowels analyzed. As expected, the bolt and dowel fasteners reached much higher temperatures along the fastener shank due to the larger thermal capacity.

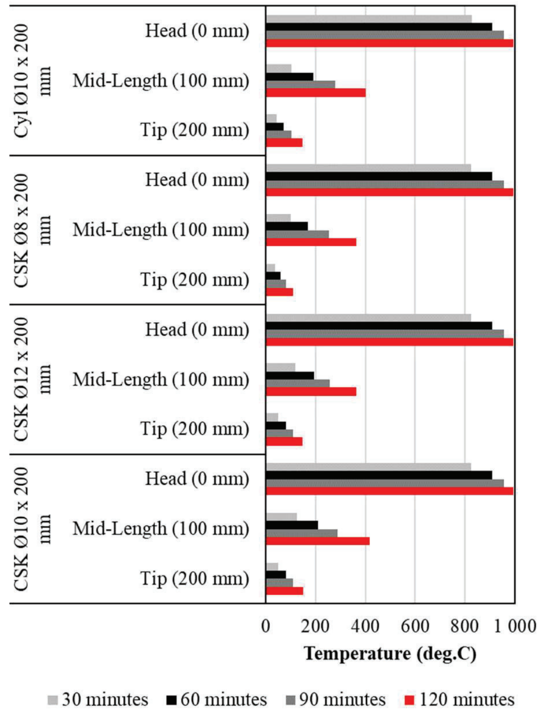

Figure 8 : *Distribution of temperatures on unprotected STS head using three (3) various STS outside diameters under the CAN/ULC-S101 [4] standard fire .*

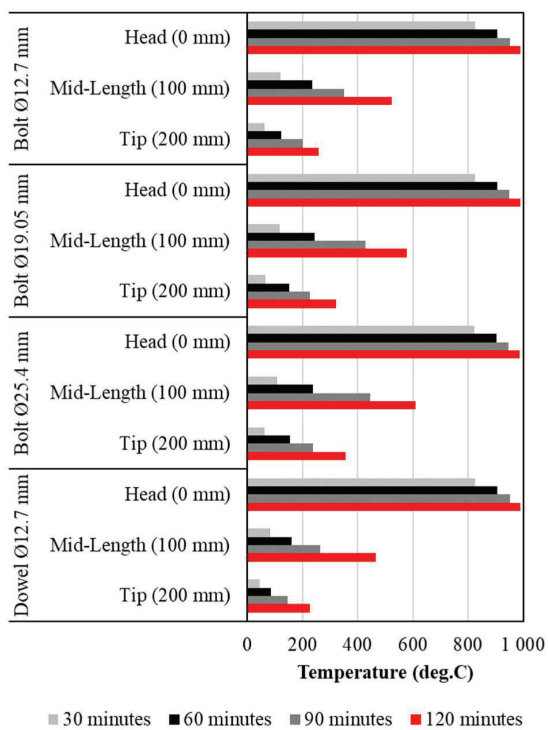

Figure 9 : *Distribution of temperatures on unprotected bolt and dowel head using (3) various shank diameters under the CAN/ULC-S101 [4] standard fire .*

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In attempt to evaluate the impact of the shank diameter on the temperature distribution along the fastener, Figure 10 presents the temperatures at the mid-length (i.e., depth of 100 mm) of the screw-type and bolt-type of 200 mm long fasteners when exposed to the standard fire of CAN/ULC S101 for one and two hours. Three (3) shank diameter of screw-type fasteners (i.e., Ø5 mm, Ø6.2 mm, and Ø7.1 mm) and three (3) shank diameter of bolt-type fasteners (i.e., Ø12.7 mm, Ø19.05 mm, and Ø25.4 mm) were analyzed to compare the heat transfer through the fastener's shank.

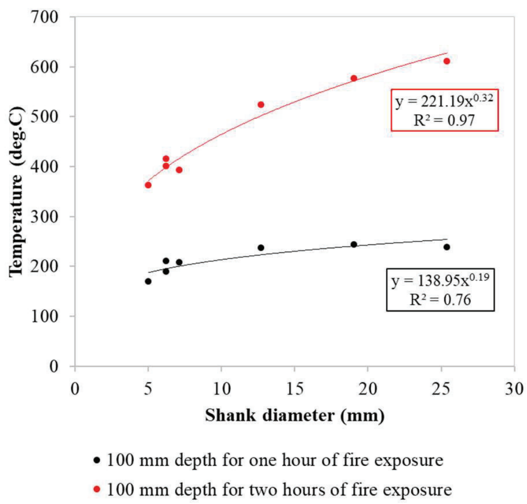

Figure 10 : *Temperatures on different fastener shanks exposed to the CAN/ULC-S101 [4] standard fire .*

The temperature distribution seems to increase as a power function with the shank diameter of the fastener, as illustrated in Figure 10. Influenced by the duration of fire exposure with higher temperatures for longer exposure, the power functions generated from the temperature data predicted by the FEM model shows high coefficients of determination R^2, suggesting that the natural power fitting curve is adequate (which is somewhat expected given that the standard fire exposure is characterized using a power curve). This effect demonstrates that the temperature along the fastener seems to increase as a power function with the shank diameter of the fastener, regardless of fastener types. Therefore, the results support the assumption that the conductive heating rate through the fastener shank is proportional to the amount of exposed area and thereby increasing as a power form with the shank diameter of the fastener, regardless of fastener types.

3.2.2 Influence of fastener length

The length of fasteners showed the greatest influence on the temperature distribution along the fastener shank. The ability of STS to penetrate the timber further away from the exposed surface allows the timber thermal capacity to limit heat transfer along the fastener. This effect was observed by increasing the length of Ø10 mm STS exposed to two hours of fire exposures, as shown in Figure 11.

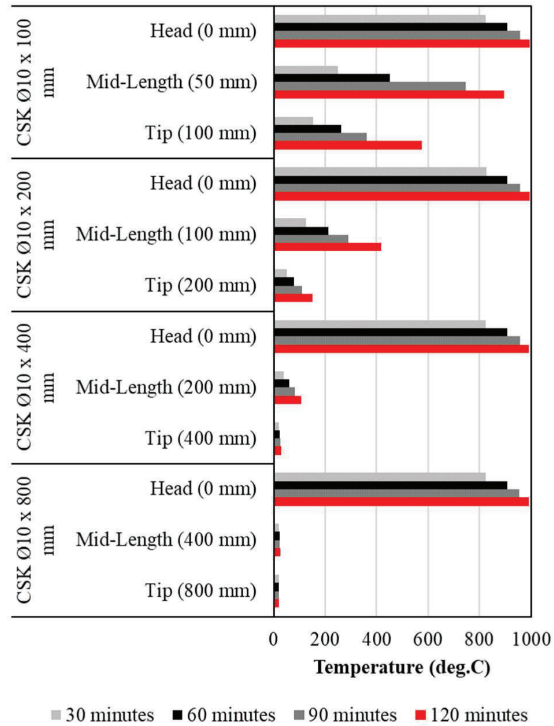

Figure 11 : *Distribution of temperatures on unprotected STS head using three (3) various STS lengths exposed to under the CAN/ULC-S101 [4] standard fire.*

For similar diameter at the head and the shank, using longer STS decreases the temperature along the fastener. For instance, the tip temperature of a 100 mm long STS (i.e., depth of 100 mm) is 154 °C, while a mid-length temperature of 200 mm long STS reached of 124 °C at the same distance from the exposed surface after 30 min, as shows in Figure 11. In addition, the 400 mm and 800 mm long STS maintain temperatures under 100°C along the screw at its mid-length and tip for up to two hours of fire exposure.

In attempt to evaluate the impact of the length of the fastener on the temperature distribution along the fastener, Figure 12 presents the temperatures at a depth of 100 mm and at a depth of 200 mm for a Ø10 mm STS by increasing the length of STS between 100 mm to 800 mm. The temperature distribution by increasing the length of fastener did not have a substantial influence on the heat transfer through the fastener, as similar temperatures were noted at the same depth from the exposed surface under one and two hour of fire exposures. Although the temperatures were very high for the screw length of 100 mm, the temperatures were similar for all screws at a depth of 100 mm and 200 mm, as illustrated in Figure 12. This effect demonstrates that longer STS did not substantially influence the temperatures through the fastener shank under longer fire exposure. The insulation effect of timber limits the thermal penetration along the fastener by the high slenderness of the STS (i.e., the ratio of their diameter to their length). It should be noted that higher temperatures for the screw length of 100 mm are likely because the tip of the STS was not deep enough to limit the thermal penetration than those at a depth of 200 mm. Therefore, the temperature profiles through fasteners depend mainly on the diameter of the fastener rather than its length.

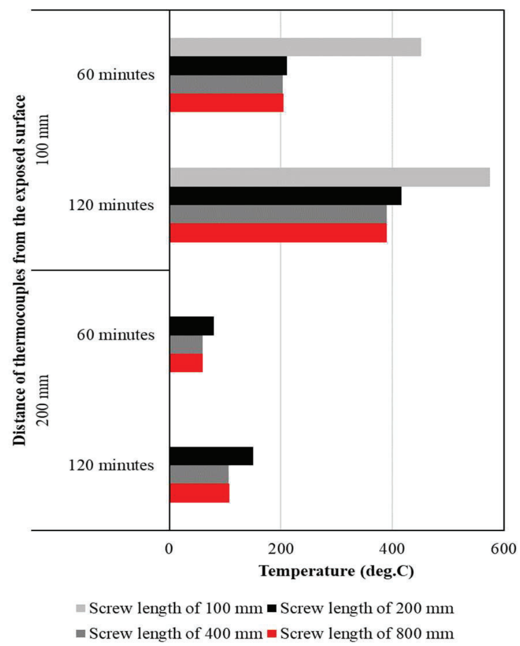

Figure 12 : *Temperatures on different lengths of Ø10 mm STS exposed to the CAN/ULC-S101 [4] standard fire.*

3.2.3 Effect of Fasteners on the Timber Charring Rate

The heat transfer model after two hours of standard fire exposure is presented in Figure 13 and Figure 14. These results were obtained by applying the 300 °C isotherm of the heat transfer model and measuring the distance between the char line to the exposed surface after one and two hours of standard fire exposures.

The fastener contributes by increasing the charring depth due to the larger thermal capacity. Due to the high conductivity of the steel, the heat transmitted through the fastener shank leads to higher temperatures into the timber. This effect was observed when comparing the heat transfer model of the bolt and the STS after two hours of fire exposures. For instance, the char depth was limited along the STS shank while the bolt shank created a notable char depth. This difference was caused by the larger heated area of the bolt shank that conducted heat faster and affected the timber surrounding the steel shank, whereas smaller screws had limited the temperature into the timber.

Although the diameter was found to be the major geometric parameter on the heating rate along the STS, longer fastener will increase the STS's effective length of penetration with more threads fully secured in unaltered wood fibers, which are still at ambient conditions (i.e., full capacity). When considering the mechanical properties of the wood fibers at a maximum of 100°C to retain sufficient residual strength, Létourneau-Gagnon et al. [10] demonstrated that the capacity of a STS was not influenced with an increase of fire exposure duration. While CSK Ø10 × 100 mm and CSK Ø10 × 200 mm have wood fibers above 100 °C along the entire shanks, CSK Ø10 × 400 mm and CSK Ø10 × 800 mm have wood fibers of 100 °C at a depth of 218 mm from the exposed surface. In fact, the residual penetration length for the 400 mm and 800 mm STS is 182 mm and 582 mm, respectively, after two hours of standard fire exposure, which can be defined as the length of penetration that will provide adequate structural capacity [10]. Therefore, longer screws would provide longer fire-resistance than shorter screws.

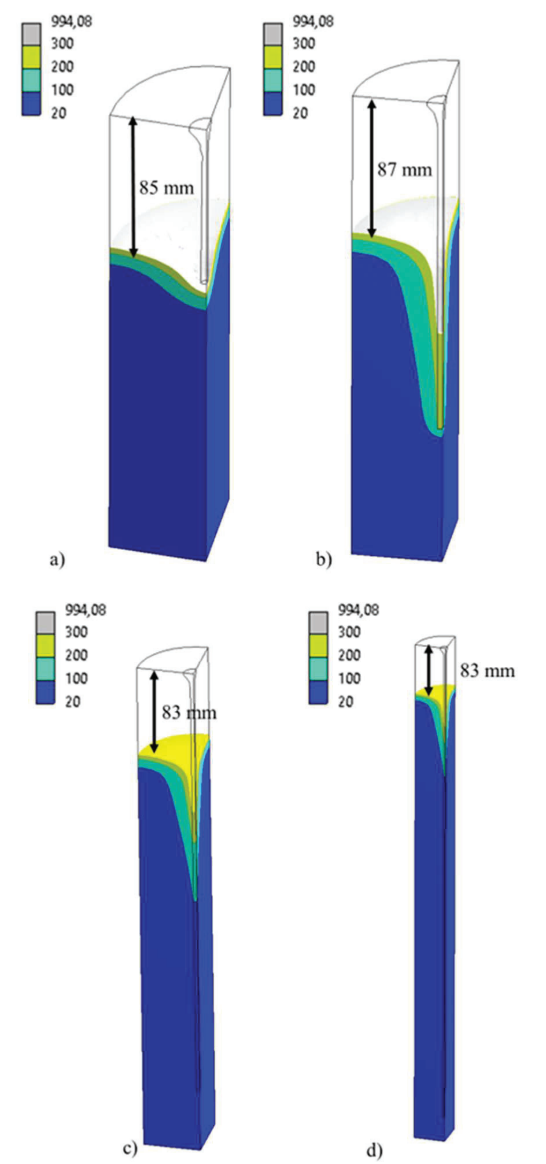

Figure 13 : *Heat transfer model exposed to the CAN/ULC-S101 [4] standard fire curve for two hours: a) Ø10 × 100 mm SWG ASSY®3.0 VG CSK; b) Ø10 × 200 mm SWG ASSY®3.0 VG CSK; c) Ø10 × 400 mm SWG ASSY®3.0 VG CSK; d) Ø10 × 800 mm SWG ASSY®3.0 VG CSK (Temperature in °C)*

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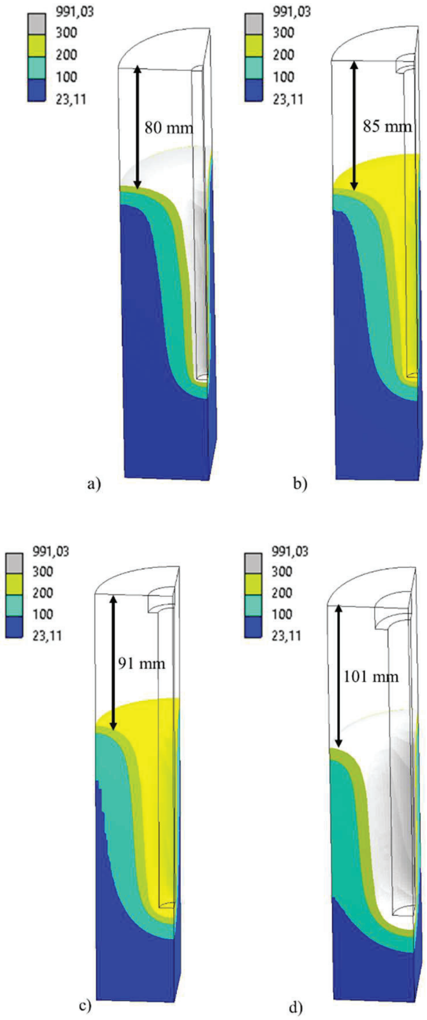

Figure 14 : *Heat transfer model exposed to the CAN/ULC-S101 [4] standard fire curve for two hours: a) Dowel Ø12.7 mm ; b) Bolt Ø12.7 mm; c) Bolt Ø19.05 mm; d) Bolt Ø25.4 mm (Temperature in °C)*

4 CONCLUSION

With the recent advances in mass timber construction and products, construction and design techniques have also evolved. Taller buildings are also typically required to provide greater fire-resistance rating, up to 2 and 3-hours, which is much beyond the deemed performance of traditional heavy timber construction. There is a need to better understand the underlying thermomechanical performance of the mass timber connection.

This study continues the development of a numerical model that aims to comprehensively simulate the thermal-structural performance of mass timber connections. The results of the novel developments towards this endeavour include the determination of reduction factors reflective of a simplified method for calculating the strength of a connection subject to a standard fire (e.g., CAN/ULC S101). The existing model was also expanded to consider contemporary connection types including those that use self-tapping screws.

Results from the numerical modelling suggest that for connections using bolts, using the steel strength reduction factors from CSA S16 as a function of the fastener temperature at the surface of the timber (i.e., underneath the washer) combined to the reduced cross-section of the timber components, provides reasonable agreements when compared to actual fire test data.

For connections using self-tapping screws (STS), the modelling predictions suggest that the STS shank diameter has an impact on the heat transfer, although minimal. Head of STS seems to have more impact on the heat conduction along the shank than the STS length. However, the length allows to slower heat conduction along the shank, and thus prevent undesired charring of the wood fibres surrounding the STS. Using longer STS will allow to maintain the connection capacity longer in fire conditions, when compared to using shorter screws.

Although this study provides valuable insight on the thermal performance of modern timber connections, their structural fire-resistance has not yet been evaluated through full-scale fire tests. Additional fire testing are currently planned at FPInnovations to further validate these assumptions and develop design guidelines for future implementation in CSA O86 wood design standard.

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