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Fire Resistance of Timber Decking for Heavy Timber Construction†

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The National Building Code of Canada provides both prescriptive specifications for timber beams and columns afforded equivalency to wood-frame construction with 45 min fire-resistance ratings, and simple calculation methods for determining fire-resistance ratings of larger glued-laminated timber beams and columns. However, the building code does not accept calculation methods for determining the fire endurance of wood decking materials. Although heavy timber roof construction is quite common in construction projects today, the use of heavy timber floor construction is not. The fire performance of floor and roof decking in heavy timber construction is, however, a critical concern in the renovation of older buildings. The authors receive more enquiries about the fire resistance of specific deck combinations, and how to increase the fire resistance of these building elements, than about any other fire-resistance related subject. The inability of the wood industry to respond to these enquiries with accurate information almost always results in costly wood solutions or the selection of non-wood alternatives for renovation projects. This paper addresses many of those questions. Copyright © 2001 John Wiley & Sons, Ltd.

INTRODUCTION

The National Building Code of Canada (NBCC) defines *fire resistance ratings* as the time in hours or fraction thereof that a material or assembly of materials will withstand the passage of flame and the transmission of heat when exposed to fire under specified conditions of test ....[1] Those 'conditions of test' embody the time-temperature curve described in *ASTM E 119 Standard Test Methods for Fire Tests of Building Construction and Materials.*[2]

For at least two centuries, heavy timber construction has been recognized as having significant fire-resistance attributes.[3] For example, in Canada, if a building is required to have a fire-resistance rating of 45 min, the NBCC permits the use of heavy timber beams and girders as small as 89 mm by 140 mm if solid sawn and 80 mm by 152 mm if glued laminated. Similarly, the code permits the use of heavy timber columns as small as 140 by 191 mm if solid sawn or 130 mm by 190 mm if glued laminated. In addition, the NBCC provides a method for calculating the fire-resistance ratings of glued-laminated timber beams and columns having fire-resistance ratings of 1 h or greater. These analytical methods are based on the reduction of the cross section of the member due to the wood being charred and the consequent loss in strength of the member. Depending upon species, density, grain orientation and moisture content, wood is converted to char at approximately 288°C. Available data have shown that the average charring rate of wood subjected to ASTM E 119 fire exposures is usually between 0.6 and 0.8 mm/min.[4,5] Because of its low thermal conductivity, the temperature of wood as little as 15 mm from the char boundary is so low that there is little reduction in fibre strength.[6] The code-accepted design method for calculating fire resistance of large, heavy timber members is based on research by T.T. Lie at the National Research Council Canada (NRCC).[7] Lie assumed, based upon available empirical data, a charring rate of 0.6 mm/min, and that the strength and stiffness of the heated zone ahead of the char front is about 85% to 90% of the original strength and stiffness. Because Lie's calculations were limited to massive timber elements, his methods for calculating fire-resistance ratings of heavy timber beams and columns have proven to be quite accurate. However, his assumptions are not applicable to timber decking. Because decking is significantly thinner, reductions in strength and stiffness ahead of the char zone are important. For the same reasons, the increased rate of char formation at arrises (corner radii) in each board and the ability of heat to penetrate joints between adjacent boards in timber decks also are significant. Finally, one-dimensional char-rate data suggest that the charring rate of wood is somewhat non-linear, and estimates using linear models tend to underestimate char depth for short time periods (< 60 min).

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Eurocode 5 *Design of Timber Structures*[8] (EC5) provides methods for calculating failure times of timber decking exposed to standard fire conditions from below. Structural fire design involves standard timber design equations, and the determination of the 'effective cross section': the initial cross section reduced by the effective charring depth. EC5 utilizes the following effective char rates, β_θ, for timber/wood panel decking materials: for softwood timber having a minimum thickness of 35 mm β_θ is 0.8 mm/min; for glued laminated timber β_θ is 0.7 mm/min; for wood panels other than plywood, with a thickness of 20 mm β_θ is 0.9 mm/min; and for plywood with a thickness of 20 mm β_θ is 1.0 mm/min.

In addition, EC5 includes the following reduction coefficients, ζ, for failure at joints in timber decks: for simple butt joints with $\leqslant 1$ mm space between boards ζ is 0.2; for single tongue-and-groove (T&G) joints with $\leqslant 1$ mm space between boards ζ is 0.4; and for double T&G joints with $\leqslant 1$ mm space between boards ζ is 0.6.

EC5 then utilizes the following formula for calculation of the time for fire to penetrate a timber deck

$$t = \zeta[d/\beta_\theta]$$

where t is the time for burn through and d is the thickness of the decking material.

It should be noted that these same reduction coefficients are also applied to the deck boards in those situations where flooring or other panels are fastened to the top of decks.

Technical Report No. 10 *Calculating the Fire Resistance of Exposed Wood Members*[9] (TR 10), which is published by the American Forest & Paper Association, provides a mechanics-based method for calculating the fire resistance of wood members. To overcome problems associated with non-linear rates of char formation in wood, TR 10 specifies a nominal char rate for wood, β_n, of 0.63 mm/min, and then requires calculation of an 'effective char rate', β_{eff}.

$$\beta_{eff} = \frac{1.2\beta_n}{t^{0.187}}$$

where t is the length of fire exposure (min).

Single and double T&G decking is assumed to be exposed on only one face (not on the sides/edges). Butt-joined decking is assumed to be fully exposed on one face and partially exposed on its sides. To compute the effects of this partial exposure of the sides of butt-joined decking, the char rate for this limited exposure is reduced to one-third of the effective char rate. Because it is primarily a structural design tool, TR 10 does not provide design details for preventing penetration of fire through the joints between individual boards in floor or roof decks.

In Canada, many buildings intended for residential, mercantile or business occupancy may be of wood-frame construction. Floor assemblies in those buildings are required to have fire-resistance ratings of not less than 45 min or 1 h, depending upon the height and area of the building. This study focused on heavy-timber floor and roof decks that might be used for those buildings.

As noted earlier, the NBCC permits the use of heavy timber beams, columns and girders meeting prescribed minimum sizes in buildings required to have fire-resistance ratings of 45 min. However, the NBCC does not provide a method for calculating the fire resistance of timber floor decks. Instead, the building code supplies prescriptive specifications for floor decks in heavy timber construction. In buildings required to have floor assemblies with 45 min fire-resistance ratings, those floor decks must be constructed with glued-laminated or solid-sawn planks at least 64 mm thick with splined or T&G joints, or with boards that are at least 38 mm wide and 89 mm deep, set on edge and spiked tightly together. Furthermore, the floor decks must be covered with T&G flooring at least 19 mm thick, or with 12.5 mm thick T&G plywood or OSB. Roof decks must be constructed with glued-laminated or solid-sawn planks at least 38 mm thick with splined or T&G joints, or with boards that are at least 38 mm wide and 89 mm deep, set on edge and spiked tightly together. Additional prescriptive designs for solid wood floors and roofs with 1 h and 1.5 h fire-resistance ratings can be found in Section D-2.4 of the Appendix to the NBCC.

These requirements have served Canadians well for new construction. However, floor decks in many older heavy timber buildings, especially many of the historic buildings in large urban communities, were constructed with 38–75 mm flat-edged planks. Preservation of such buildings is a priority for most municipalities. Renovation and conversion of these turn-of-the-century warehouses and factories into modern, high-end residential, mercantile and business occupancies is the obvious answer. However, one of the primary obstacles to these renovation projects concerns the fire resistance of the floor and roof decks in these older structures. The authors receive more enquiries about the fire resistance of specific floor and roof deck combinations, and how to increase the fire resistance of these building elements in older structures, than about any other fire-resistance related subject. Therefore, a research project was initiated in order to verify some of the assumptions in EC5 and TR 10 that relate to decking for heavy timber construction. In addition, the study attempted to quantify the impact on the fire resistance of the deck resulting from the use of other materials in combination with timber decking (e.g. plywood or OSB nailed on top of timber decking, or gypsum wallboard fastened to the bottom of decking).

Because it is used for high-class construction where strength and appearance are required, heavy timber wood decking is considered a premium product. Consequently, great care is taken in its grading and milling. Douglas fir is the most commonly demanded species of timber decking. The rough-sawn lumber is dried to an average moisture content of 19% before being carefully milled. Once milled, decking boards are kept in dry storage. By the time the decking is applied, its moisture content is usually between 12% and 15%. The equilibrium moisture content of Douglas fir floor decking is usually between 10% and 14% during warm humid summer weather and 4% to 8% during the winter months when heating systems are operating in buildings.[10]

Shrinkage occurs when wood dries. The amount of shrinkage is directly proportional to the change in moisture content. Shrinkage also varies according to grain direction with shrinkage tangential to the annual growth rings in the tree from which a board was cut being

Table 1. Average linear shrinkage in Douglas fir lumber

Change in moisture content	Shrinkage radial to annual growth rings (%)	Shrinkage tangential to annual growth rings (%)
19%–15%	0.6	0.7
15%–12%	0.4	0.6
12%–9%	0.4	0.6
9%–6%	0.4	0.6
6% to 'dry'	1.3	1.5

slightly greater than shrinkage radial to the annual growth rings. Table 1 shows the average amount of linear shrinkage in Douglas fir lumber.[11]

Douglas fir boards 100 mm wide shrink approximately 1 mm when their moisture content is reduced from 15% to 10%, and 2 mm when their moisture content is reduced from 15% to 6%. Similarly, boards 133 mm wide shrink approximately 1.3 mm when their moisture content is reduced from 15% to 10% and 2.4 mm when their moisture content is reduced from 15% to 6%. Consequently, boards installed tightly against each other during construction can develop spaces approximately 2 mm wide between each other during the winter heating season. Also, even though great care is taken in its milling, slight variations in width may occur along the length of the decking boards further increasing the width of spaces between individual boards in floor decks.

TESTING PROGRAMME

All decking was 'Select' grade Douglas fir (NLGA Standard Grading Rules for Canadian Lumber[12]) conforming to the requirements of the NBCC for heavy timber decking.

Three decking materials were used. Two incorporated T&G details: 38 mm by 140 mm (nominal 2 × 6) single T&G boards having a 38 mm by 127 mm finish size, and 64 mm by 140 mm (nominal 3 × 6) double T&G boards having a 64 mm by 133 mm finish size. To create a flat-edge (butt edge) deck material, the tongues and grooves were cut from half of the stock of 38 mm thick material and the edges planed to produce boards approximately 110 mm wide. The profile of each is illustrated in Fig. 1.

The boards were assembled into test-deck specimens approximately 1.0 m wide by 1.5 m in length. In order to reproduce the spaces between deck boards that are observed in timber floor decking due to the dimensional changes in wood that result from changes in the decking's equilibrium moisture content, the boards in many of the deck specimens were aligned so as to leave spaces up to 4 mm wide between adjacent boards.

Three deck specimens were placed into a steel frame with blankets of ceramic-fibre insulation separating each deck from the adjoining ones and from the steel frame (Fig. 2). The decks were then exposed, three-at-a-time, to the fire conditions (time-temperature curve) described in ASTM E 119 using a 1.5 × 3.0 m horizontal furnace at Underwriters' Laboratories of Canada (ULC) in Scarborough, Ontario (Fig. 3). No structural loads were applied to the decks during testing. Although not reported

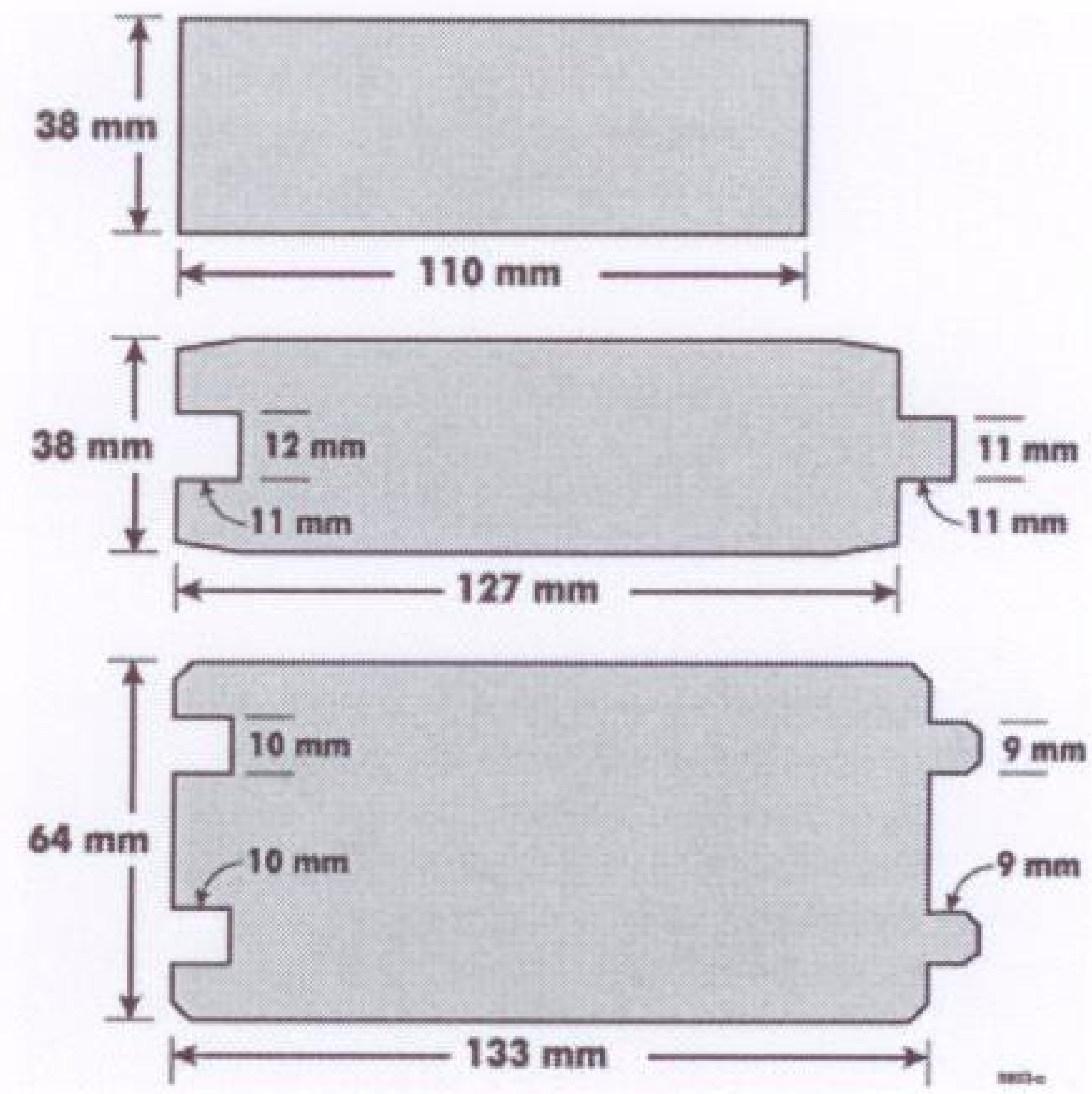

Figure 1. Profiles of various deck boards.

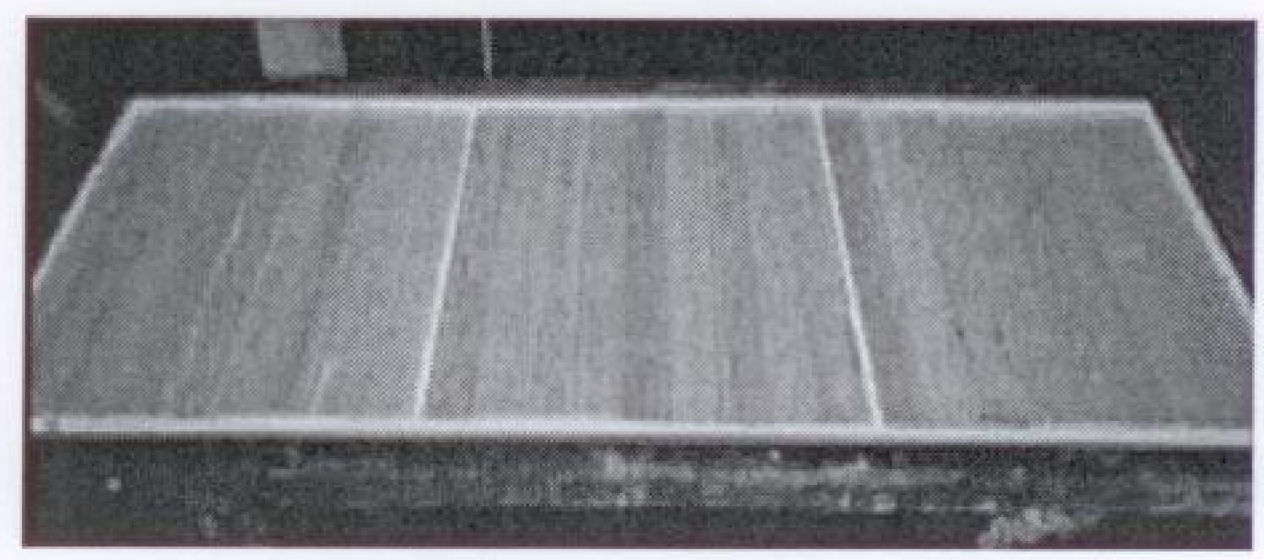
Figure 2. Three decks in specimen frame.

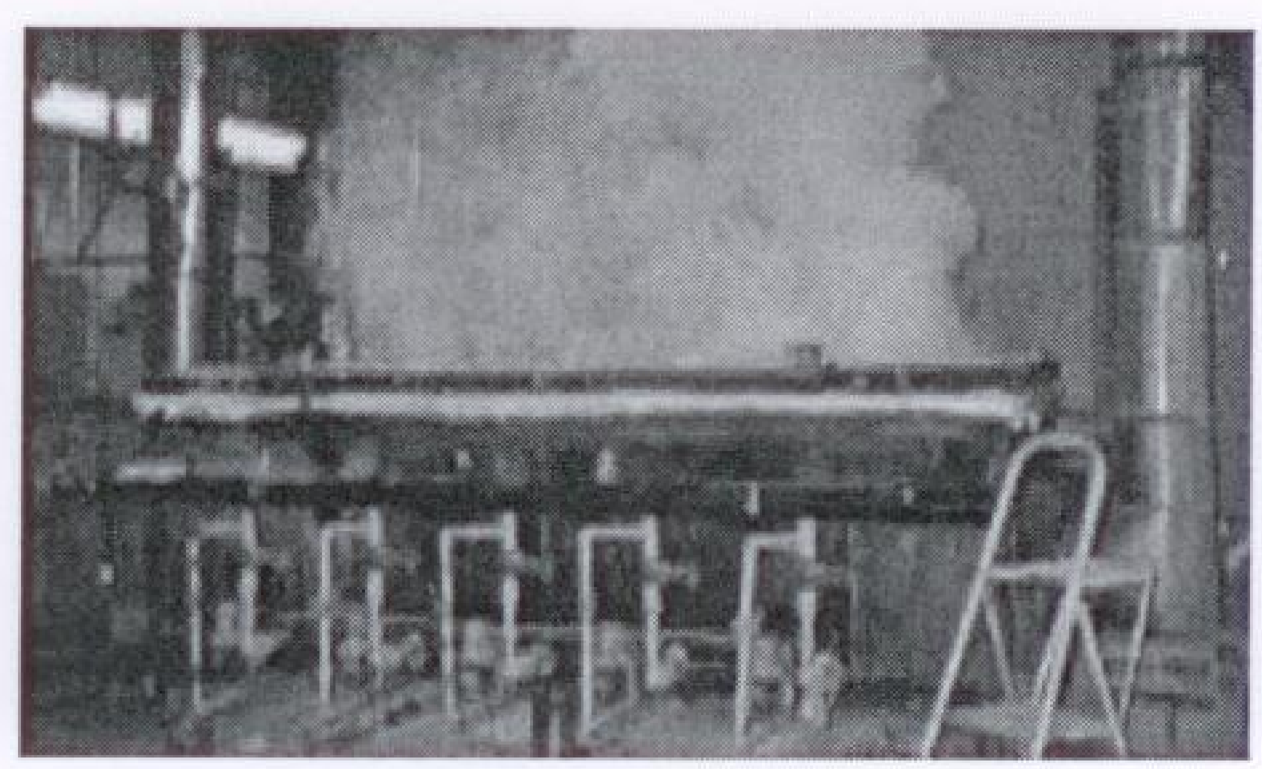
Figure 3. ULC's horizontal test furnace.

here, temperatures on the unexposed face of each specimen were measured throughout the tests. In every case, there was visual evidence of burning on the unexposed face of the decks, at the joints between adjoining boards, before temperatures on the unexposed face of the boards reached 140°C. Whenever the unexposed face of one deck ignited, that deck was covered with a blanket of ceramic-fibre insulation until the unexposed face of each of the other two decks had also ignited.

Test deck specimens

Table 2 summarizes the construction details for each deck. A detailed description of each deck follows the table.

Deck 1. Nine 38 mm by 110 mm decking boards with tongues and grooves removed were assembled into a deck and clamped tightly together. Two 38 mm by 89 mm (nominal 2 × 4) wood battens were attached to the unexposed side of the deck using screws in order to hold the deck together. One batten was placed approximately 150 mm from each end. Three holes, 3.18 mm in diameter, were drilled from the unexposed side of the deck, in the geometric centre of each of the three middle boards. These holes extended to a depth of exactly 6.4, 19.0 and 31.8 mm (1/4″, 3/4″ and 1 1/4″) from the fire-exposed face. One Type K thermocouple was inserted into each hole.

Decks 2 and 3. These two decks were identical to Deck 1, except that the boards were aligned so as to leave spaces ⩽ 1 mm wide between each board in Deck 2 and ⩽ 2 mm wide between each board in Deck 3. In addition to the thermocouples described in Deck 1, one thermocouple was placed 19.0 mm deep in the joint between the two middle boards (Figs 4 and 5).
Comment: To maintain the correct width of the spaces between individual deck boards as the decks were assembled, metal spacers were placed between the deck boards and then the boards were clamped tightly together. Lastly, wood battens were attached to the unexposed side to hold each board in place and the metal spacers removed.

Figure 4. Exposed face of deck specimen 2.

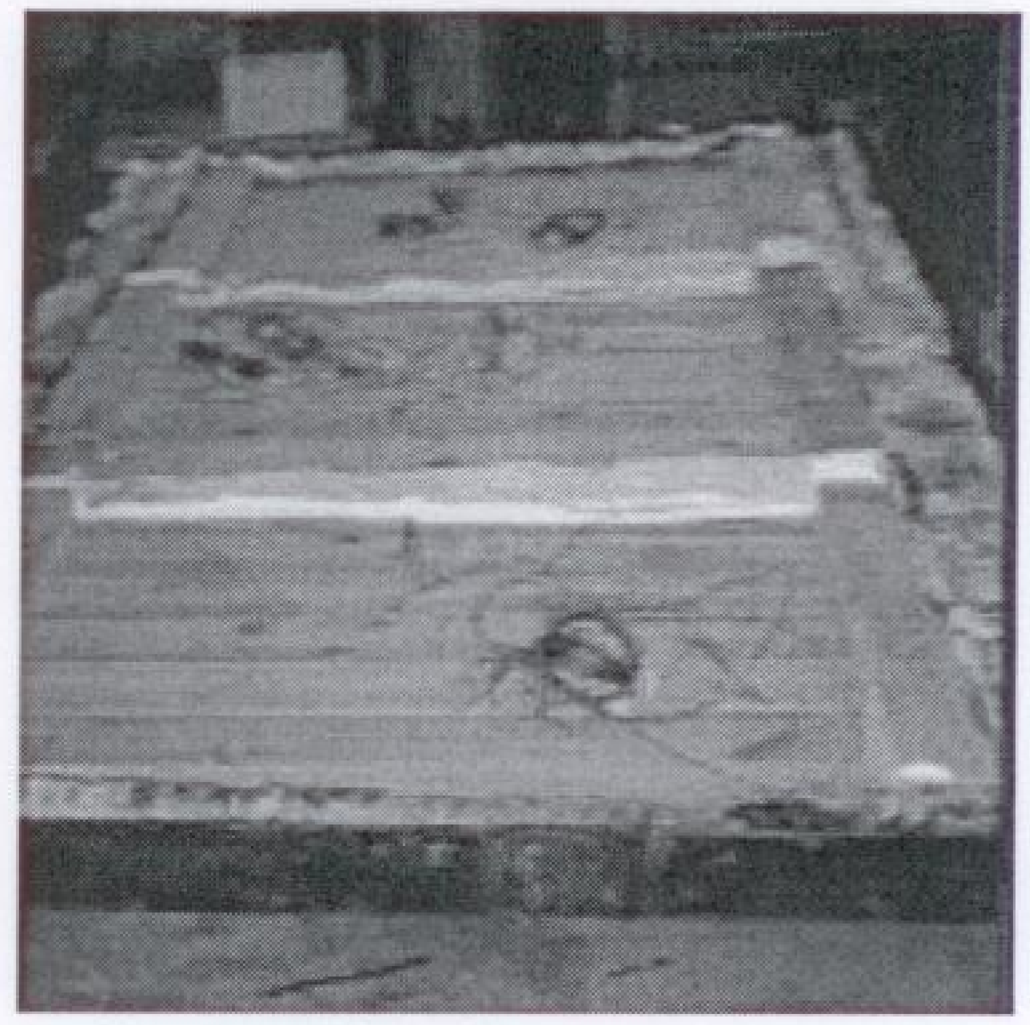

Figure 5. Unexposed face of deck specimens 1, 2 & 3, with thermocouples inserted.

Table 2. Construction details for test decks

Deck No.	Type of decking	Width of space between boards (mm)	Additional deck components	
			Unexposed face	Fire-exposed face
1	38 mm thick boards Flat	0	—	—
2	(butt) edges	1	—	—
3		2	—	—
4		4	15 mm OSB	—
5		4	15 mm fir plywood	—
6		2	15 mm fir plywood	—
7		4	15 mm fir plywood	15.9 mm gypsum board
8		2	—	15.9 mm gypsum board
9		4	—	15.9 mm gypsum board
10	38 mm thick boards Single	0	—	—
11	T&G edges	2.5	—	—
12		4	—	—
13	64 mm thick boards Double	0	—	—
14	T&G edges	2.5	—	—
15		4	—	—
16	38 mm thick boards Single T&G edges	4	15 mm fir plywood	—
17	64 mm thick boards Double T&G edges	4	15 mm fir plywood	—
18	38 mm by 110 mm Boards on edge	3	—	—

Deck 4. This deck was identical to Deck 3, except that the boards were aligned so as to leave spaces $\leqslant 4$ mm wide between the boards, and nominal 5/8″ (15 mm) OSB[13,14] was attached to the unexposed face of the deck using Type S wallboard screws. The OSB was installed as a single panel so that there was no joint in the face of the OSB. Also, one additional thermocouple was placed between the OSB and the deck boards about 25 mm from the geometric centre of the deck. 36 wallboard screws were used to attach the OSB to the deck. (In normal use, joints between adjacent sheets of OSB or plywood would be centred on deck boards.)

Deck 5. This deck was identical to Deck 4, except that nominal 5/8″ (15 mm) Douglas fir plywood[15] was attached to the unexposed face of the deck using type S wallboard screws. The plywood was installed as a single panel so there was no joint in the face of the plywood. One thermocouple was placed between the plywood and the deck boards about 25 mm from the geometric centre of the deck.

Deck 6. This deck was identical to Deck 5, except that the boards were aligned so as to leave spaces $\leqslant 2$ mm wide between the boards.

Deck 7. This deck was identical to Deck 4, except that 15.9 mm Type X gypsum wallboard was attached to the fire-exposed side of the deck using Type S wallboard screws. The gypsum wallboard was installed as a single panel so that there would be no joint in the face of the wallboard. 36 wallboard screws were used to attach the OSB to the deck. (In normal use, joints between adjacent sheets of gypsum wallboard would be centred on deck boards.)

Deck 8. This deck was identical to Deck 3, except that 15.9 mm Type X gypsum wallboard was attached to the fire-exposed side of the deck using Type S wallboard screws. The gypsum wallboard was installed as a single panel so that there would be no joint in the face of the wallboard.

Deck 9. This deck was identical to Deck 7, except that there was no plywood panel attached to the unexposed face.

Deck 10. Eight 38 mm by 127 mm (nominal 2×6) single T&G decking boards were assembled into a deck and clamped tightly together. As with each of the other decks, two 38 mm by 89 mm wood battens were attached to the unexposed side of the deck using screws in order to hold the deck together. Also, three holes 3.18 mm in diameter were drilled from the unexposed side of the deck, in the geometric centre of each of the three middle boards. These holes extended to a position 6.4, 19.0 and 31.8 mm from the exposed face. A fourth hole was drilled through the top half of the groove, directly above the tip of the tongue in the adjoining board.

Deck 11. This deck was identical to Deck 10, except that the boards were aligned so as to leave spaces $\leqslant 2.5$ mm wide between the boards.

Deck 12. This deck was identical to Deck 10, except that the boards were aligned so as to leave spaces $\leqslant 4$ mm wide between the boards.

Decks 13, 14 and 15. These decks were identical to Decks 10–12 except that 64 mm by 133 mm (nominal 3×6) double T&G decking boards were used. Also, a fourth hole was drilled, at an angle to the centre edge of one board so that the tip of a thermocouple could be placed in the joint between that board and the adjoining board.

Deck 16. This deck was identical to Deck 12 ($\leqslant 4$ mm space between each board), except that nominal 5/8″ (15 mm) Douglas fir plywood was attached to the unexposed face of the deck using Type S wallboard screws.

Deck 17. This deck was identical to deck 15 ($\leqslant 4$ mm space between each board), except that nominal 5/8″ (15 mm) Douglas fir plywood was attached to the unexposed face of the deck using Type S wallboard screws.

Deck 18. Thirteen 64 mm by 133 mm (nominal 3×6) decking boards with the tongues and grooves removed were assembled into a deck with each board on edge. The boards were aligned so as to leave spaces $\leqslant 3$ mm wide between the boards. Two 38 mm by 89 mm wood battens were attached to the unexposed side of the deck using screws in order to hold the deck together. This created a deck that was approximately 110 mm thick.

RESULTS AND DISCUSSION

Table 3 lists the times at which flames were observed on the unexposed faces of each deck.

Historically, most char rate data for wood have been obtained by exposing large-dimension specimens to specific conditions of heat and fire for varying lengths of time, and after quickly extinguishing all combustion of the specimens, physically measuring the depth of char that had formed in each specimen. If as generally reported, fire penetrates through Douglas fir at rates of 0.6–0.8 mm/min when exposed to ASTM E 119 fire conditions, fire should burn through 38 mm deck boards in $47\frac{1}{2}$–63 min. Similarly, fire should burn through 64 mm deck boards in 80–107 min. As noted above, when the boards in a deck were clamped and fastened tightly against each other (minimal space between the boards, fire burned through the deck constructed with 38 mm thick lumber having single T&G edges in 2014 s (≈ 33 1/2 min). This suggests that the average rate of fire penetration through test decks constructed with 38 mm boards was 1.13 mm/min. Fire burned through the deck constructed with 64 mm thick lumber having double T&G edges in 4172 s (≈ 70 min); thereby indicating that the average rate of fire penetration through test decks constructed with 64 mm boards was 0.92 mm/min. Notwithstanding the great care that is taken in the milling of timber decking, slight imperfections occur. Consequently, there were minute gaps between the boards in these deck specimens. Also, as can be seen from their profiles in Fig. 1, for ease of fit T&G boards are milled so

Table 3. Summary of results

Specimen No.	Additional deck components: Unexposed face	Additional deck components: Fire-exposed face	Width of space between boards (mm)	Time to observation of flames on unexposed face (s)
38 mm thick decking with butt edges				
1	—	—	0	1458
2	—	—	1	790
3	—	—	2	272
4	OSB	—	4	> 3000[a]
5	Plywood	—	4	> 3000[a]
6	Plywood	—	2	> 3000[a]
7	Plywood	Gypsum board	4	> 3600[a]
8	—	Gypsum board	2	2640
9	—	Gypsum board	4	3060
38 mm thick decking with single T&G edges				
10	—	—	0	2014
11	—	—	2.5	1086
12	—	—	4	1068
16	OSB	—	4	3862
64 mm thick decking with double T&G edges				
13	—	—	0	4172
14	—	—	2.5	1937
15	—	—	4	1673
17	Plywood	—	4	5352
110 mm deep decking (boards on edge)				
18	—	—	3	2602

[a]It was anticipated that the decking in these specimens would be consumed in 50–60 min. Therefore, for safety reasons, these tests were terminated at the indicated times even though flames had not been observed on the unexposed faces.

as to create 1 mm deep cavities between the tips of each tongue and the base of the groove in the adjoining board when the boards are fastened tightly together. This combination of factors made it highly likely that, in spite of every effort to prevent it, fire was able to penetrate the minute gaps in the joints between individual boards in the test decks. Therefore, the char-rates noted above could not be considered accurate measures of the one-dimensional rates of char-formation in 38 and 64 mm thick Douglas fir lumber.

Visual examination of cross-sections of the deck boards following the fire tests indicated that within 35 min char formation penetrated the 38 mm thick boards by approximately 32 mm. Similarly, within 70 min, char formation penetrated the 64 mm thick boards by approximately 45 mm. These data suggest that the rate of char formation in these boards was somewhere between 0.65 and 0.9 mm/min.

In order to estimate the rate of char formation in these deck boards, temperatures of the wood 6.4, 19.0 and 31.8 mm from the fire-exposed face of the deck were measured in the 38 mm thick boards. Since it is commonly held that, during relatively fast heating, 'dry' wood begins to char when heated to 288°C, that temperature was used as the yardstick in determining the rate of fire penetration. It is generally recognized that thermocouple measurements of wood temperature, made through holes drilled from the unexposed side of timber specimens, are inaccurate because of poor contact between the thermocouple tip and the wood at the bottom of the hole and subsequently differences in rates of heat transfer. Such problems result in widely varying times for wood to reach a specific temperature among groups of nominally identical specimens exposed to the same fire conditions. These variations among test results were certainly observed in this study. Nevertheless, it was concluded that while the overall rate of progress of the 288°C isotherm through 38 mm boards was approximately 0.62 mm/min, the average rate of its progress through the centre-section of the boards (6.4 mm–31.8 mm from the fire-exposed face) was 0.85 mm/min.

The various observations and temperature measurements made in this study confirmed the general assumptions in EC5 and TR 10 that fire penetrates Douglas fir lumber at rates of approximately 0.65–0.9 mm/min. Because of the somewhat non-linear nature of char formation in lumber, the higher values are applicable to thinner materials. Therefore, it was reasonable to conclude that fire should penetrate the 38 mm deck boards in 42–48 min (0.8–0.9 mm/min) and the 64 mm boards in 80–90 min (0.7–0.8 mm/min). That being so, and assuming there are 2 mm wide gaps between the individual boards in floor decks, the appropriate reduction coefficients, ζ, for failure at joints should be as follows: simple butt joints with $\leqslant 2$ mm space between boards, $\zeta = 0.10$; single T&G joints with $\leqslant 2$ mm space between boards, $\zeta = 0.40$; double T&G joints with $\leqslant 2$ mm space between boards, $\zeta = 0.40$.

The reduction coefficient identified here for single T&G joints is the same as that in EC5. The reduction coefficients differ from those in EC5 for simple butt (0.1 compared with 0.2 in EC5) and double T&G joints (0.4 compared with 0.6 in EC5). However, it must be remembered that the assumed width of the spaces between the boards is only 1 mm in EC5. The tests reported here suggest that the appropriate reduction coefficient for simple butt joints with $\leqslant$ 1 mm spaces between boards should be 0.3 rather than 0.2 listed in EC5.

As noted earlier, the NBCC requires floor decking in heavy timber construction to be covered with T&G flooring at least 19 mm thick or with 12.5 mm T&G plywood or OSB. In this study, the benefit of covering timber decking boards with nominal 5/8″ (15 mm) plywood and OSB was investigated. That thickness of plywood or OSB is commonly used for sub-floors in new construction. In addition, the benefit of attaching 15.9 mm thick Type X gypsum wallboard below the decking was also investigated.

Gypsum wallboard acts as a thermal barrier thereby protecting the bottom of the deck from direct exposure to fire. However, that protection is directly related to the ability of the gypsum wallboard membrane to remain in place. Typically, in fire-endurance tests of floor assemblies finished with gypsum wallboard, the paper face on the wallboard is burned completely away during the first 2 min. Then, the gypsum wallboard begins to calcinate and shrink. Calcination and loss of the paper face cause gypsum wallboard to lose much of its nail-head pull-through resistance. At the same time, calcination and shrinkage of the wallboard cause cracks to form throughout the board, and the wallboard to pull away from fasteners holding the gypsum wallboard in position. In comparison to when gypsum wallboard is attached to the underside of wood-joist floor assemblies, these effects are observed even sooner when the wallboard is attached to the bottom of solid wood decks.[16] Heat movement away from the unexposed side of the gypsum wallboard is restricted by the low thermal-conductivity of the wood decking. The additional heat that is entrapped within the gypsum wallboard accelerates calcination of the gypsum and hastens fall-off of the protective membrane (Fig. 6). Even the close fastener spacing used in this study to attach the gypsum wallboard to the deck specimens was unable to keep the wallboard in place for more than 45–50 min.

This study demonstrated that there are obvious benefits from attaching gypsum wallboard to the bottom of timber decks. When the gypsum wallboard was attached to the bottom of the deck, it took more than 50 min for fire to burn through a deck constructed with 38 mm thick lumber having flat (butt) edges and aligned with 4 mm spaces between individual boards. Figures 7 and 8 illustrate the thermal protection provided to the fire exposed side of timber decks when gypsum wallboard is attached to the bottom of the deck. These data suggest that gypsum wallboard provides 18–20 min of thermal protection for the decks.

As noted earlier, there were no structural loads applied to the deck specimens during fire testing and consequently no deflections in the specimens as the deck boards were consumed. If the deck specimens had begun to deflect, those deflections would have hastened the fall-off of the gypsum wallboard. However, even if a structural load had been applied to these deck specimens, by the time sufficient char formation could have occurred in the deck boards to permit deflection of the specimens, the gypsum wallboard would already have fallen off due to calcination and shrinkage.

When either 15 mm thick plywood or OSB was fastened to the top face of a deck that had been constructed

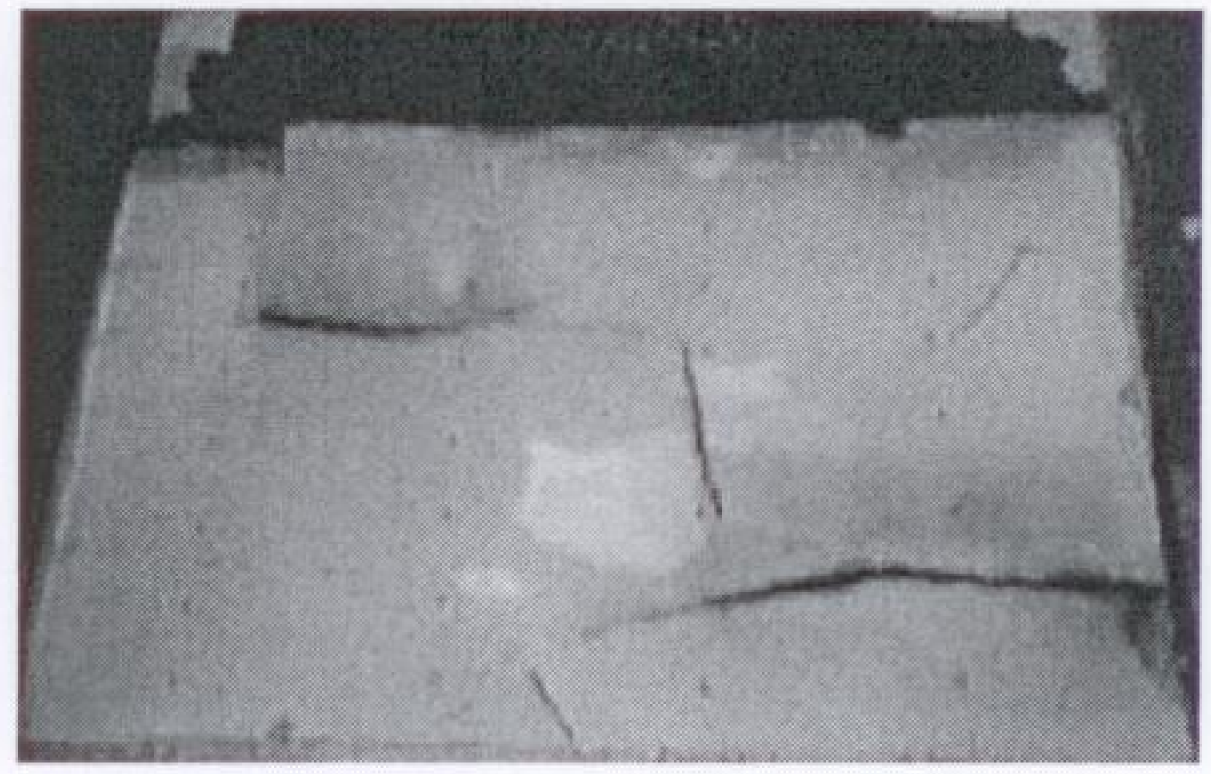

Figure 6. Gypsum wallboard protection for deck — after fire exposure.

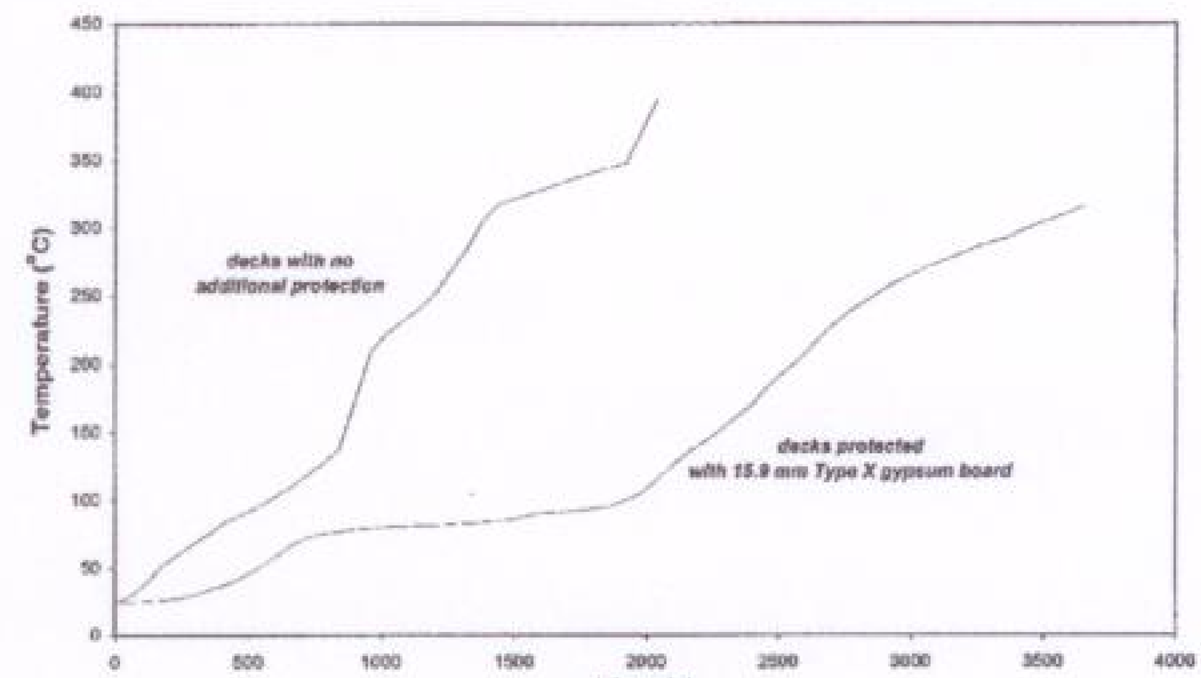

Figure 7. Effectiveness of gypsum wallboard protection (average temperatures of wood 6.4 mm from fire-exposed face).

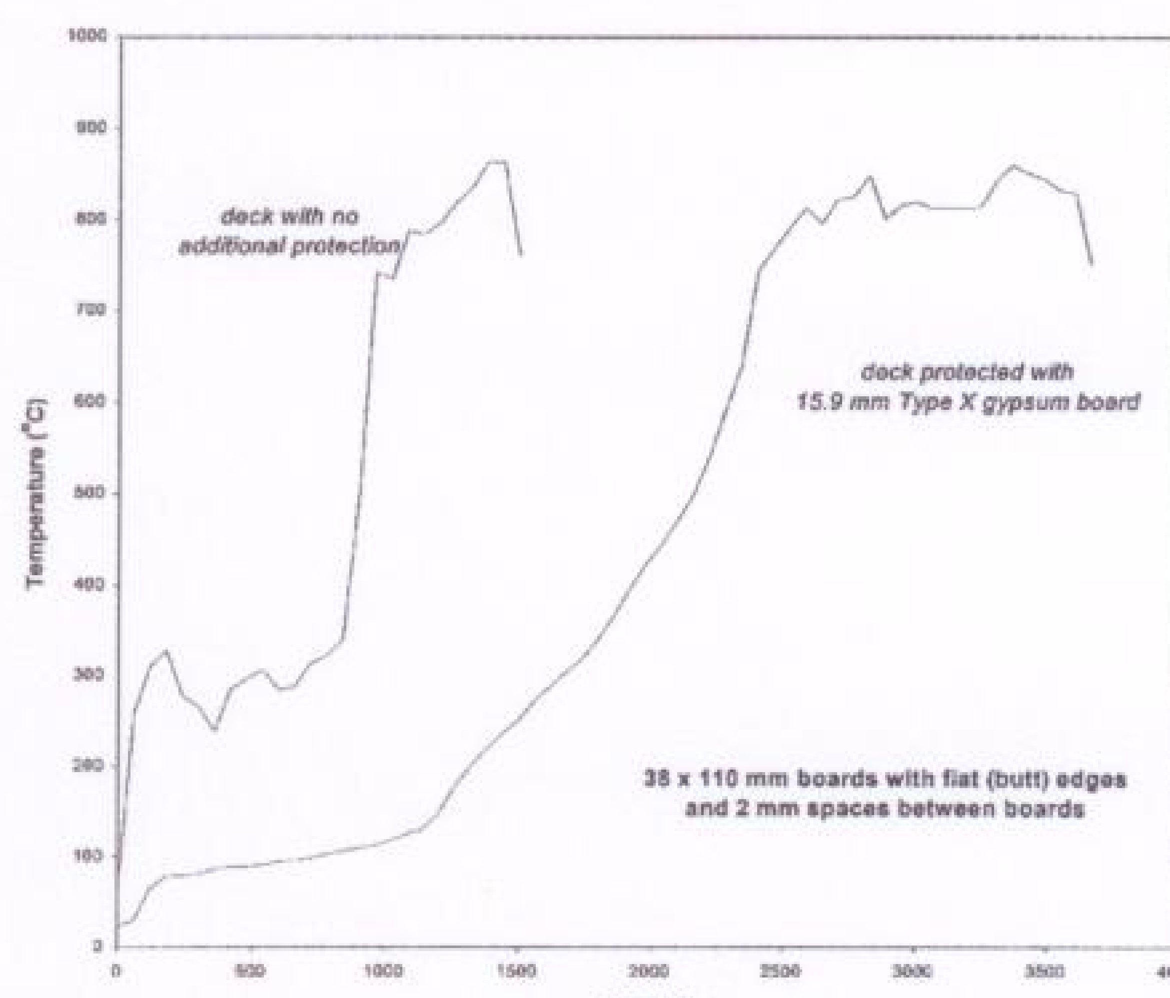

Figure 8. Effectiveness of gypsum wallboard protection (average temperatures in the spaces between deck boards and 19.0 mm from the fire-exposed face).

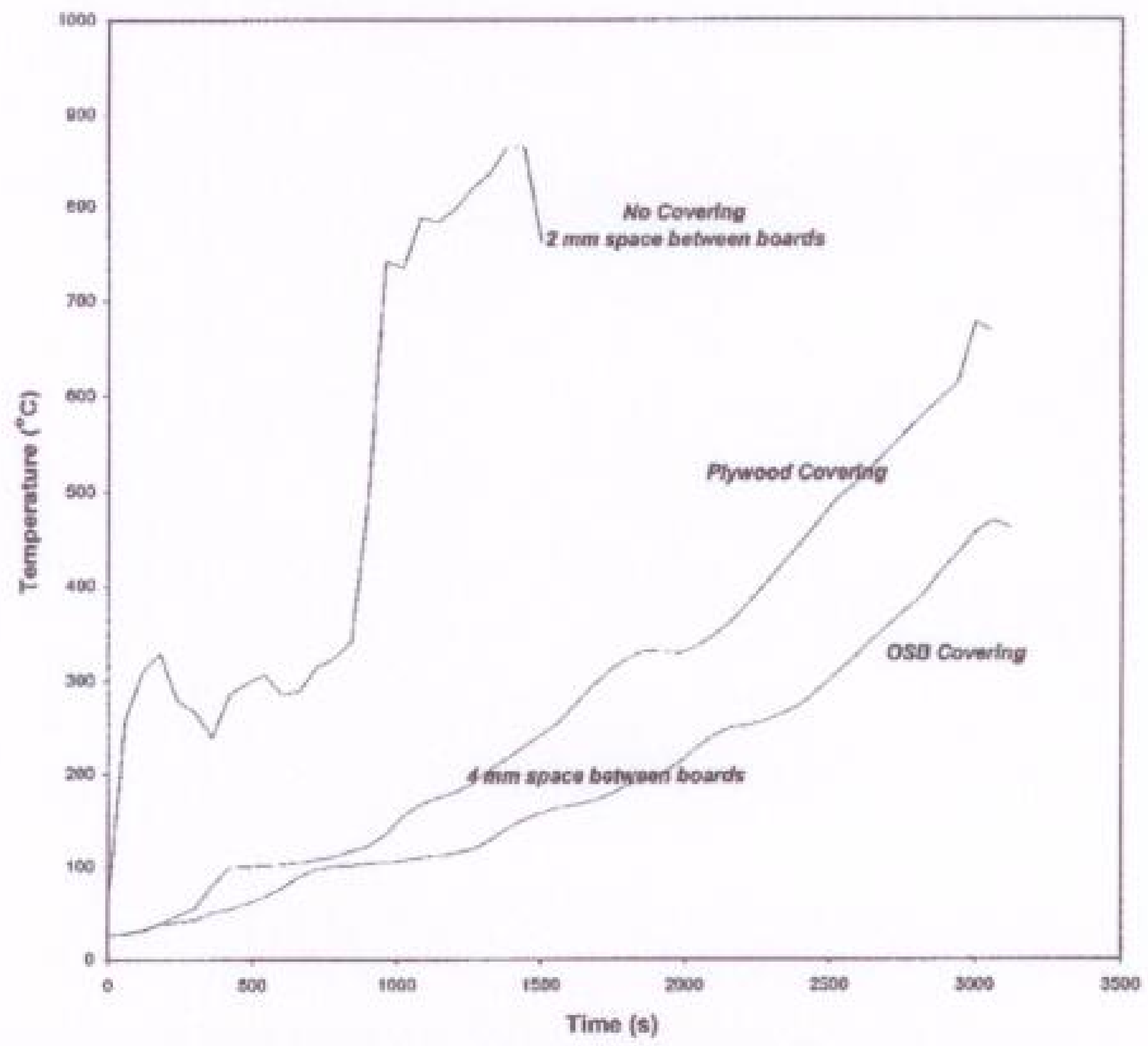

Figure 9. Effectiveness of coverings: 38 × 110 mm deck boards with butt edges (average temperatures in spaces between boards and 19.0 mm from fire-exposed face).

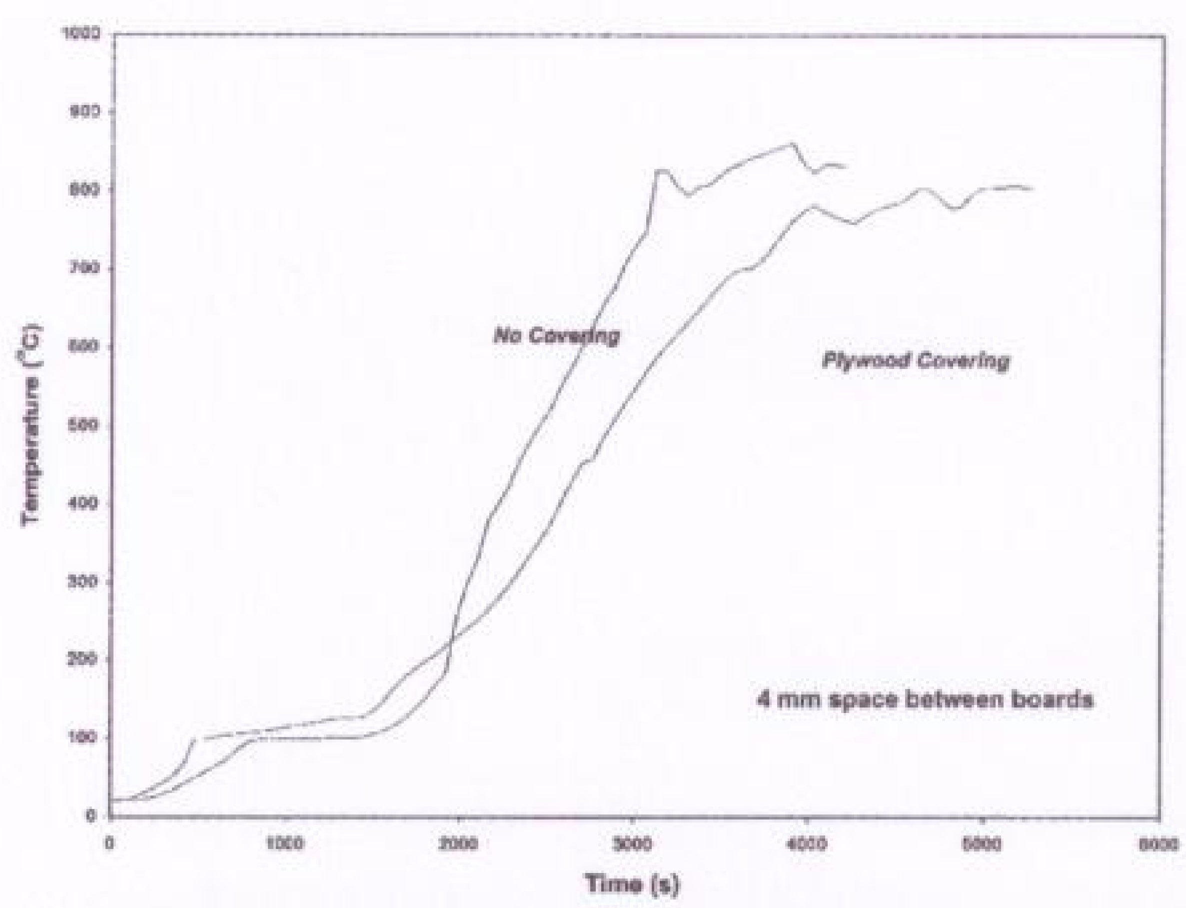

Figure 10. Effectiveness of coverings: 64 × 133 mm boards with double T&G edges (average temperature in spaces between boards and 32.0 mm from fire exposed face).

with 38 mm thick lumber having flat (butt) edges and 4 mm wide spaces between the boards, the amount of time required for fire to burn through the deck was more than 50 min. Covering the deck with either OSB or plywood prevents the upward flow of fire gases through the spaces between the boards, along with increasing the overall thickness of the deck. Figure 9 illustrates the effectiveness of plywood or OSB coverings in preventing the passage of hot fire gases through the spaces between individual boards in floor decks. While 4 mm wide spaces between deck boards is not observed in new buildings constructed with carefully milled timber decking, older timber structures are often found to have floor decking with spaces approaching that width between boards. Figure 10 illustrates temperatures in the spaces between boards in decks constructed with 64 mm thick double T&G boards with 4 mm spaces between the boards. As indicated by this figure, covering these decks with ply-

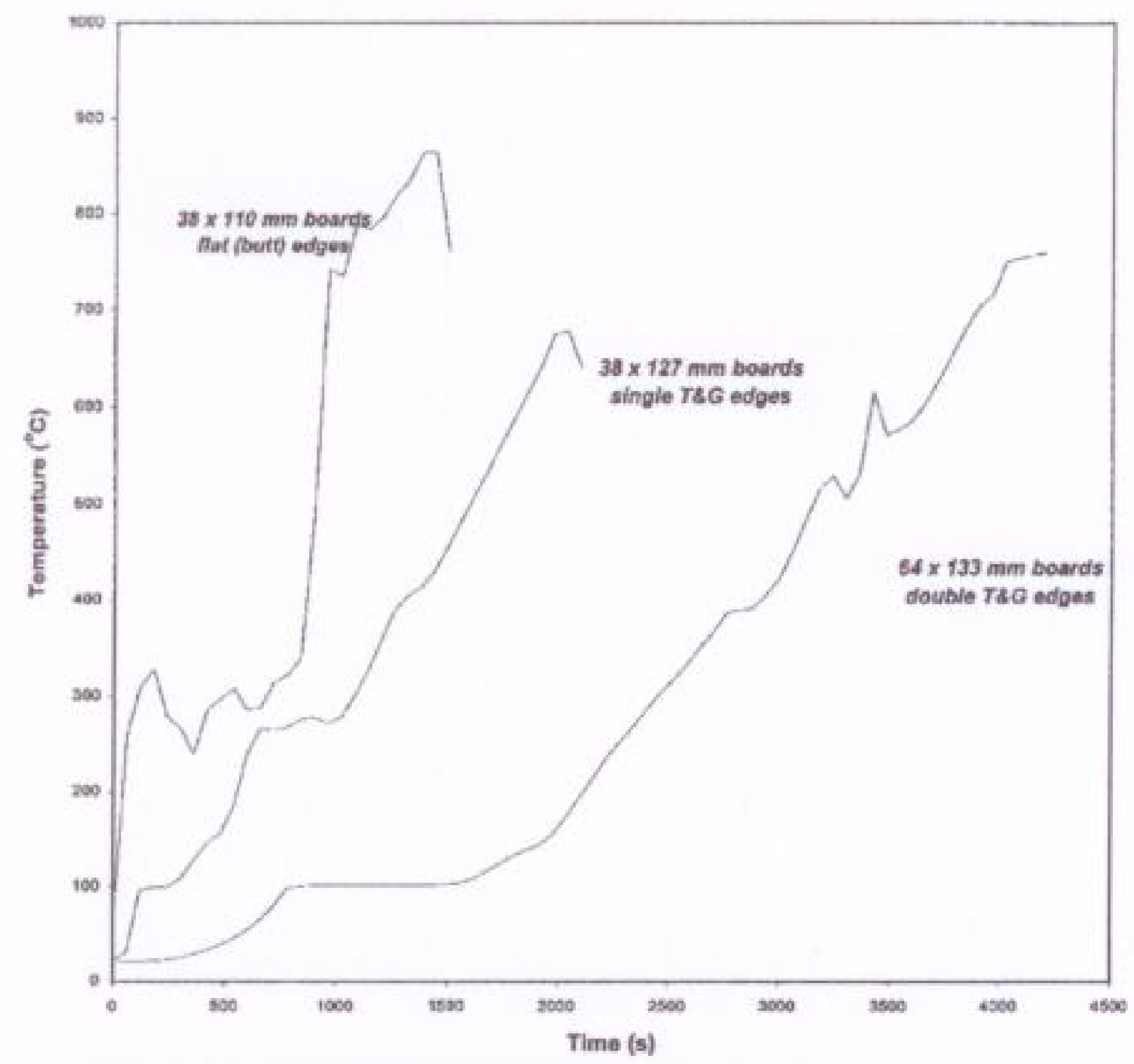

Figure 11.Effectiveness of joints between boards (average temperatures midway in the 2–2.5 mm space between boards).

wood provides only a small added benefit in terms of preventing heat from penetrating through the joints between boards. This is because the double tongue-and-groove design of the boards' edges provides sufficient obstacles to heat flow through these joints that there is little added benefit to be gained from the plywood or OSB covering. Moreover, this demonstrates that it is reasonable to assume, for purposes of calculating structural fire resistance of timber decking, that decks constructed with double T&G boards can be considered exposed on only their faces and char formation along the edges of each board does not need to be considered. As noted earlier, this is the specific approach taken in Technical Report 10. At the same time, Fig. 9 suggests that the design methods in TR 10 may somewhat overestimate a board's cross-section (underestimate char formation) by assuming that the sides of boards with flat (butt) edges are only one-third exposed. This assumption may only be reasonable if the deck is covered with plywood or OSB, or the boards are nailed very tightly together.

It took more than 1 h for fire to penetrate a deck constructed with 38 mm flat (butt) edge boards spaced 4 mm apart when either 15 mm T&G plywood or OSB covered the deck and 15.9 mm gypsum wallboard was fastened to the bottom of the deck.

Figure 11 illustrates temperatures at mid-height in the joints between individual boards in decks when those boards are spaced 2–2.5 mm apart. This information confirms the ease with which fire penetrates joints between boards with flat (butt) edges, and at the same time, it indicates the resistance to the passage of these fire gases presented by T&G joints in the deck boards. This is particularly noticeable for the deck constructed with 64 mm thick double T&G boards. Obviously, the exact dimensions and profiles of the tongues, in comparison with those of the grooves, are what control the amount of resistance to fire penetration through T&G joints. The profiles of the joints in these boards are typical of today's decking materials. Therefore, it can be concluded that the assumption in TR 10 that single and double T&G

decking may be assumed to be exposed on only one face, as opposed to being exposed on one face and two edges, is not an unreasonable approximation.

CONCLUSIONS

The fire resistance of timber decking used with heavy timber construction was investigated. The primary focus throughout much of the study was on problems commonly encountered with decking in older heavy-timber buildings undergoing renovation, and whether decking design information in EC5 and TR 10 might be used in resolving some of those problems. As noted earlier, decking in these older buildings is often found to have been constructed with 50 or 75 mm (2″–3″) thick flat-edged planks. Further, it is not uncommon to observe 2–4 mm spaces between those planks.

It was concluded that the assumptions regarding rates of char formation in timber decking specified in EC5 and TR 10 are essentially correct. Fire penetrates Douglas fir planks at rates of 0.7–0.9 mm/min. It was also concluded that the 'reduction coefficients' in EC5 for failure at joints between boards in timber decks, while somewhat conservative, are justifiable within the limitations specified in that document. At the same time, it was concluded that the assumed spacing between boards in EC5 may be less than those in modern Canadian buildings during the winter heating season or between the decking boards in many older heavy timber structures. In some cases, reduction coefficients for failure between boards should be up to twice those specified in EC5. The importance of covering timber decking with either plywood or OSB panels in order to prevent fire penetrating through the joints between boards in timber decks was noted. Finally, the added protection afforded timber decks by attaching gypsum wallboard to the underside of these decks was determined.

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REFERENCES

1. Canadian Commission on Building and Fire Codes. *National Building Code of Canada* 1995. National Research Council of Canada: Ottawa, ON, 1995.
2. ASTM. *Standard Test Method for Fire Tests of Building Construction and Materials.* ASTM Designation E 119-95a; ASTM: Philadelphia, PA, 1995.
3. Boyd RB. *Wood and Fiber* 1977; **9**(1): 33–39.
4. Schaffer EL. *Structural Fire Design: Wood.* Research Paper 450. US Department of Agriculture, Forest Service, Forest Products Laboratory: Madison, WI, 1984.
5. White RH, Nordheim EV. *Fire Technol* 1992; **28**(1): 5–39.
6. King EG, Glowinski RW. *Forest Prod J* 1988; **38**(10): 31–36.
7. Lie TT. *Can J Civil Engin* 1977; **4**(2): 161–169.
8. European Committee for Standardization. *Eurocode 5: Design of Timber Structures — Part 1-2: General Rules — Structural Fire Design.* EV: Brussels, 1994.
9. American Forest & Paper Association. *Calculating the Fire Resistance of Exposed Wood Members.* Technical Report No. 10. American Forest & Paper Association, American Wood Council: Washington, DC, 1999.
10. Garrahan P, Meil J, Onysko DM. *Moisture in Framing Lumber — Field Measurement, Acceptability and Use Surveys.* Canada Mortgage and Housing Corporation, Project Implementation Division: Ottawa, ON, 1991.
11. Forest Products Laboratory. *Wood Handbook — Wood as an Engineering Material.* General Technical Report FPL-GTR-113. US Department of Agriculture, Forest Service, Forest Products Laboratory: Madison, WI, 1999.
12. National Lumber Grades Authority. *NLGA Standard Grading Rules for Canadian Lumber.* NLGA: Burnaby, BC, 1994.
13. Canadian Standard Association. *OSB and Waferboard.* CSA Standard CSA-O437.0-93. CSA: Etobicoke, ON, 1993.
14. Canadian Standard Association. *Design Rated OSB: Specifications.* CSA Standard CSA-O452.0-94. CSA: Etobicoke, ON, 1994.
15. Canadian Standard Association. *Douglas Fir Plywood.* CSA Standard CSA-O121-M78: CSA: Etobicoke, ON, 1978.
16. Richardson LR, McPhee RA, Batista M. *Fire Mater* 2000; **24**(1): 17–27.