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Fire Resistance of Floor Framing Members

Development of an Intermediate-Scale Screening Test

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Abstract

Engineered wood floor framing members, such as I-joists, must pass full-scale fire endurance tests to demonstrate equivalency to unprotected nominal 2 by 10 dimension lumber (actual dimensions 38 by 235 mm (1.5 by 9.25 in.)) if used in fire-rated assemblies. The full-scale test is performed in a furnace with dimensions of at least 3.7 by 3.7 m (12.1 by 12.1 ft) with a floor assembly loaded to 50% of the allowable stress design bending load. The standard fire curve is used during the test. The acceptance criteria of 15.5 min was determined from equivalence to the calculated fire resistance of a solid wood 2 by 10 assuming three-sided fire exposure. However, the full-scale test is expensive and cumbersome, making it difficult to assess potential new fire-protective technologies. The purpose of this study was to examine the suitability of an intermediate-scale test method for floor framing members for the purpose of screening new technologies before the expense, time, and effort of conducting the full-scale test. The intermediate-scale test used two joists spaced 406 mm (16 in.) on center and 3 m (120 in.) long with a 1.8-m (72-in.) heated length. Two hydraulic actuators loaded the assembly creating maximum bending stress equal to 50% of the allowable stress design bending load. Solid wood 2 by 10 dimension lumber and I-joists with various web protection strategies were used to evaluate the suitability of this intermediate-scale test. Failure times and failure modes varied across different protection strategies. Although, in general, the intermediate-scale test had shorter times to failure than did the full-scale test, the intermediate-scale test may still be useful for screening new fire protective technologies for engineered wood.

Keywords: fire endurance; ASTM E119; I-joists; light-frame construction; engineered wood construction

Contents

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Introduction

Light-frame construction dominates the market for buildings less than six stories high in North America. It is estimated that 95% of homes constructed in the United States utilize this method of dimension lumber framing (Loferski 2015). Light-frame construction was popularized in the 1830s and has changed to accommodate innovations in wood technology such as engineered wood sheathing and subfloors.

One such innovation was the development of wooden I-beams (Leichti and others 1990). Because these beams are often used as joists in floor or roof assemblies, they are commonly called wood I-joists. Wood I-joists were developed in the 1920s. However, they were not commonly manufactured until the 1960s. Widespread adoption happened in the 1980s, with the market for wood I-joists tripling during that time.

Wood I-joists have many advantages over the solid-sawn dimension lumber they replaced. Wood I-joists are stronger and stiffer than solid wood, allowing larger spans. They are also lightweight and efficiently utilize the wood resource by concentrating high quality lamination stock where the greatest bending stresses occur and making use of lower-value products in the web.

However, the efficiency of wood I-joists may present special concerns in a fire scenario. Solid wood chars in a well understood and repeatable manner at 0.6 mm min^{-1} (1.5 in. h^{-1}) (Dietenberger and others 2021). Because I-joist webs are made from a thin panel of engineered wood, the fire resistance (fire endurance) of an I-joist floor system may be inferior to the dimension lumber it replaces.

As early as the 1980s, various fire service groups were voicing concerns about the potential safety of wood I-joists in light-frame construction (e.g., Routley (1989) and Brannigan (1989)). In response to these concerns, in 1990, the National Fire Protection Research Association launched the National Engineered Lightweight Construction Fire Research Project to gather information about the fire performance of wood I-joists and trusses (Grundahl 1992). Fire testing has found that unprotected wood I-joists loaded to 100% of a design load have a fire endurance of 2.33 min, whereas 2 by 10 dimension lumber (actual dimensions 38 by 235 mm (1.5 by 9.25 in.)) loaded to 100% of its design load has a fire endurance of 7.0 min (Kerber and others 2012, White and others 1983).

As a result of these investigations into the fire performance of engineered wood products, the International Residential Code now requires that floor assemblies in many scenarios be covered with a 12.7-mm (1/2-in.) gypsum wallboard membrane or 15.9-mm (5/8-in.) wood structural panel membrane to protect the framing members (ICC 2021). However, wood floors consisting of dimension lumber equal to or larger than a nominal 2 by 10 are permitted to be used without protection. The code also allows a wood product with "equivalent fire performance" to a nominal 2 by 10 to be used without a gypsum wallboard or structural panel membrane.

The Wood I-Joist Manufacturers Association (WIJMA) published a report that can be used for determining the fire equivalency of wood I-joists or other floor framing members (WIJMA 2019). Floor framing members analyzed in this report must pass the International Code Council Evaluation Services (ICC-ES) Acceptance Criteria (AC14) for Prefabricated Wood I-joists (ICC 2019). The AC14 criteria specifies that a full floor system be built and tested in accordance with ASTM E119 (ASTM 2014) with modifications. Namely, the load in the test shall be 50% of its full allowable stress design (ASD) bending design load. The engineered floor framing member must last a minimum of 15.5 min. (For reference, fire resistance calculations using a common engineering approach (AWC 2021) show that an unprotected, solid-sawn 2 by 10 should last for 15.5 min).

The full-scale AC14 test serves as an entry to the marketplace. However, for research purposes, it is very costly and difficult to perform. As such, it cannot easily be used to find or screen promising new technologies. Recently, intermediate-scale tests have been developed to predict the performance for glulam (Zelinka and others 2021) and cross-laminated timber (Zelinka and Bourne 2022). In this report, we examine if similar scaling techniques can be used to develop an intermediate-scale test to screen the performance of new technologies for the AC14 test.

Materials and Methods

Two different floor framing materials were tested, solid-sawn dimension lumber and manufactured I-joists. In total, four different treatment groups were analyzed:

- Solid-sawn joists (positive control)
- Unprotected manufactured I-joists (negative control)
- Manufactured I-joists protected with oriented strandboard (OSB) (positive control)
- Manufactured I-joists protected with an experimental intumescent coating

It was expected that both the solid-sawn joists and the I-joists protected with OSB could pass the full-scale AC14 tests with a performance of at least 15.5 min, but the unprotected I-joist was not expected to last 15.5 min. Therefore, by testing these positive and negative controls, it was possible to both benchmark the experimental treatment (group 4) and determine how the intermediate-scale test compares with the full-scale test.

Solid-Sawn Dimension Lumber Joists

The solid-sawn joists used in this study were obtained from a lumber supplier in Madison, Wisconsin, USA. The joists were nominal 2 by 10 dimension lumber. These joists were from the Hem-Fir lumber group and were Select Structural grade.

Wood joists are a natural material and are known to vary in strength even within a particular wood species or lumber grade. Therefore, it was important to test specimens with a range of strengths. Although joist strength can only be determined destructively, there is a positive relationship between modulus of elasticity (MOE) and modulus of rupture (MOR) (Green and Kretschmann 1991), which allows strength to be estimated. To estimate the relative strengths of 30 individual joists, the dynamic MOE was measured using the nondestructive transverse vibration methods described in ASTM D6874 (ASTM 2021). A total of 30 2 by 10 joists were found to have dynamic MOEs from 6.07 to 12.5 GPa (880.4 $\times 10^3$ to 1,813 $\times 10^3$ lbf/in^2). Of these, 20 joists were selected to make 10 specimens, each with two joists joined together; the two joists in each assembly were matched to have the closest MOEs possible. Two “low MOE” joist assemblies were tested: (6.07–6.83 GPa (880.4 $\times 10^3$ to 990.6 $\times 10^3$ lbf/in^2)), five “medium MOE” joist assemblies were tested (6.9–10.9 GPa (1,001 $\times 10^3$ to 1,580.9 $\times 10^3$ lbf/in^2)), and three “high MOE” joist assemblies were tested (11.7–12.5 GPa (1,696.9 $\times 10^3$ to 1,813 $\times 10^3$ lbf/in^2)).

Manufactured I-Joists

Commercially available I-joists were obtained for use in this study. The joists were 302 mm (11.9 in.) deep and 3.05 m (10 ft) long. The flanges were made from finger-jointed stock that was 89 mm (3.5 in.) wide and 38 mm (1.5 in.) deep. The web was 9.5-mm- (3/8-in.-) thick OSB. The manufacturer rated the bending moment capacity at 6,894 N·m (5,084.1 lbf·ft).

One set of I-joists had 11-mm- (7/16-in.-) thick OSB added to both sides of the web as a sacrificial protection layer. The OSB was cut to 225 mm (8.9 in.) wide and stapled to the flange with 25-mm- (1-in.-) long 16-gauge crown staples.

Another set of I-joists had a proprietary intumescent coating applied to both sides of the web for added fire resistance.

Fabrication of Joist Assemblies for Testing

Specimens were made of two joists connected on each end with a short rim joist and covered with OSB subfloor. The joists were each 3.05 m (10 ft) long and were spaced 406 mm (16 in.) on center. The rim joists were 445 mm (17.5 in.) long and were attached with two 64-mm-long by 3.3-mm-diameter (2.5-in.-long by 0.131-in.-diameter) nails placed into the end of each joist. The subfloor was 18-mm- (23/32-in.-) thick OSB nailed to the joists using 64-mm-long by 3.3-mm-diameter (2.5-in.-long by 0.131-in.-diameter) nails spaced approximately every 300 mm (11.8 in.) along the joists.

To isolate the fire endurance of the joist, the underside of the subfloor was coated with an intumescent to prevent the subfloor from failing before the joists. The 1.2-m- (3.9-ft-) wide subfloor was cut to 0.99 m (3.25 ft) long and was installed with the strength direction perpendicular to the joists.

Intermediate-Scale Test Method

Intermediate-Scale Furnace

The interior dimensions of the furnace used at the USDA Forest Service, Forest Products Laboratory are approximately 0.99 m wide by 1.83 m long by 1.27 m tall (3.25 ft wide by 6 ft long by 4.17 ft tall). The furnace is lined with approximately 150 mm (5.9 in.) of ceramic fiber insulation on the vertical sides and 100 mm (3.9 in.) of refractory cement on the bottom. The outside of the furnace is covered with a steel skin. The top of the furnace is open to allow a specimen to be placed on the top. Heating is provided by eight diffusion flame natural gas burners located in the floor of the furnace with combustion air supplied through 17 tubes, each 75 mm (3 in.) in diameter. Nine of the tubes are distributed through the floor of the furnace with four more in each end wall of the furnace, just above the furnace floor. An exhaust port is located approximately in the middle of one of the large walls and is connected to a chimney. The top edge of the furnace is a water-cooled tube, and there are two approximately 50-mm- (2-in.-) wide square glass viewports in the wall opposite the exhaust.

Approximately 300 mm (11.8 in.) below the top edge of the furnace, there are ports for six thermocouples sheathed in 21.3-mm (0.8-in.) OD by 15.8-mm (0.6-in.) ID Inconel pipes (Special Metals Corporation, New Hartford, New York, USA).

Loading Apparatus

Figure 1 illustrates the specimen and loading apparatus. Steel bearing plates were installed on the bottom of the ends of each specimen. The plates were 6 mm (0.24 in.) thick, 100 mm (3.9 in.) wide, and 495 mm (19.5 in.) long. Each plate was attached with two #10 by 38-mm- (1.5-in.-) long screws in each joist and four screws in each rim board. Steel plates were used rather than a wooden sill so that the ends would be unconstrained in the axial direction by resting on 70-mm- (2.76-in.-) diameter steel rollers.

The bottom of the specimen rested approximately 50 mm (2 in.) above the top edge of the furnace to allow the specimen to deflect during the test. This left an open space approximately 290 mm (11.4 in.) high between the bottom of the sub floor and the top of the furnace. This space was filled with stacked 150-mm- (5.9-in.-) wide and 50-mm- (2-in.-) thick pieces of mineral wool insulation (Roxul/Rockwool 60, Rockwool Group, Hedehusene, Greater Copenhagen, Denmark). The insulation was placed in such a way that it would not support the specimen throughout the test.

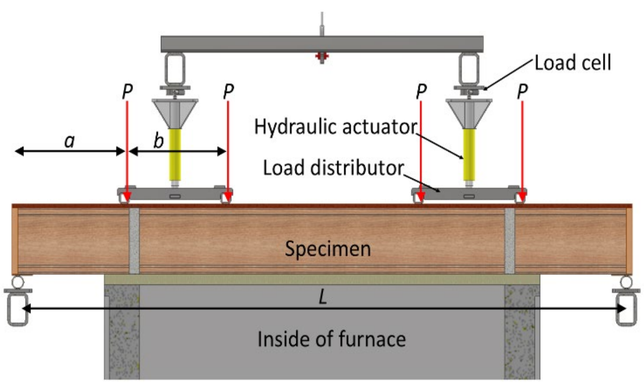

Figure 1—Specimen assembly in the furnace with the loading apparatus above the specimen (*a*, distance from end of specimen to outside point load; *b*, distance between outside point load and inner point load; *P*, load at each point; *L*, length of specimen).

A loading frame with two hydraulic actuators was installed above the specimen. Each actuator pressed on steel framing members that distributed the load from the actuator through two square steel tubes, 50 mm (2 in.) wide with a 6-mm- (0.24-in.-) thick wall and 600 mm (23.6 in.) long, placed on the top of the subfloor perpendicular to the joists. This setup applied an equal load to each joist at four points along its length. The two inner load points were 483 mm (19 in.) from the center, and the other two load points were an additional 508 mm (20 in.) toward the ends. The hydraulic actuators were powered by a hydraulic pump with a manual pressure control valve.

Loading Calculations

The WIJMA method for fire resistance testing requires each floor joist member to support a load corresponding to 50% of its full ASD bending design load.

For solid-sawn lumber, the maximum bending design load can be found in table 4 of the 2018 National Design Specification (NDS) supplement (AWC 2017). The maximum allowable bending stress for a select structural Hem-Fir 2 by 10 is given as 9.7 MPa (1,400 lbf/in^2).

For the I-joists, the maximum bending moment specified from the manufacturer was used to calculate the maximum bending stress:

$$\sigma_B = \frac{M_{max}(d)}{I} \quad (1)$$

where σ_B is the bending stress, M_{max} is the maximum allowable bending moment, d is the depth, and I is the moment of inertia of the I-joist.

Limitations of our laboratory prevent true distributed loading. As an approximation, 4-point bending was used. To account for the distributed mass of the specimen and the externally applied point loads, a combined loading scenario was calculated by

$$\sigma_B = \sigma_p + \sigma_w \quad (2)$$

where σ_p is the stress from the applied point loads and σ_w is the stress from the distributed load from the mass of the specimen.

The contribution to the maximum bending stress from the 4-point loads can be calculated by

$$\sigma_p = \frac{P(2a+b)d}{I} \quad (3)$$

where *P* is the load at each point, *a* is the distance from the end of the specimen to the outside point loads, *b* is the distance between the outside point loads and the inner point loads, *d* is the depth of the joist, and *I* is the area moment of inertia of the joist (Fig. 1).

The contribution of the distributed specimen mass can be calculated by

$$\sigma_w = \frac{(m/L)L^2 d}{I} \quad (4)$$

where *m* is the mass of the specimen, *L* is the length of the specimen, *d* is the depth of the specimen, and *I* is the moment of inertia of the specimen.

Combining the previous equations results in the following equation for the applied load at each loading point:

$$P = \frac{\sigma_p I}{d(2a+b)} \quad (5)$$

Test Procedure

Prior to testing, the mass of the entire specimen was determined and used to calculate the applied load. Moisture content measurements were taken in three locations on each joist using an RDM-3 pin-type moisture meter (Delmhorst Instrument Company, Towaco, New Jersey, USA). The specimen was photographed including the visible faces of both joists to document the location of any knots or defects that may contribute to failure.

Prior to the start of each test, the data recording was started with the data acquisition system and the desired load was applied to the specimen with the hydraulic actuators and then immediately released. Then, the load cells and string potentiometer were set to zero before being loaded again.

After the load was applied, the furnace and a timer were started simultaneously. The data acquisition and control system regulated incoming natural gas to control the furnace to the standard fire curve described in ASTM E119 (ASTM 2014). The data acquisition system recorded the furnace temperature, the specimen temperatures, the load at each actuator, the deflection, the fuel flow rate, and the time.

Additional visual and auditory observations were recorded manually. The load was monitored throughout the test, and adjustments were made manually as needed.

Tests were terminated after the specimen failed (could no longer support load) or when the deflection was so great that flames escaped through the edges of the assembly. At that point, gas flow was terminated and the loading frame was removed from the furnace so the specimen could be removed. The specimen was extinguished after being removed from the furnace.

Results

Time–Temperature Curves

The time–temperature curves for the various tests are presented in Figure 2a. Because the temperature was computer-controlled, successive replicates were very similar.

During the first 15 min, the standard fire curve has a rapid temperature increase that can be difficult to maintain. The temperature in the furnace was below the standard curve until 3.66 min, at which point the temperature overshot the standard curve before approaching the standard curve again near the 15-min mark. The area under the time–temperature curve represents the total amount of thermal energy applied

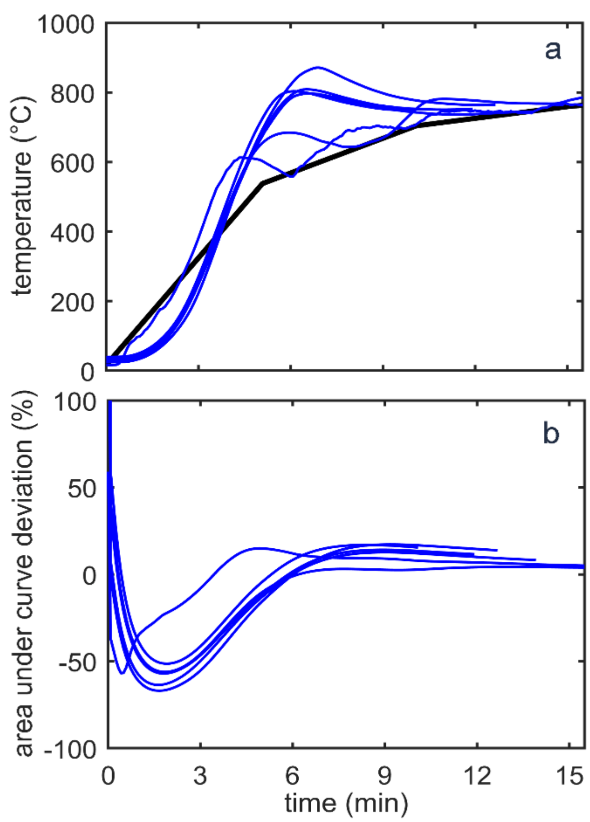

Figure 2—(a) Time–temperature curves for the different replicates. The solid black curve represents the standard fire curve; (b) deviation from the standard curve for the different replicates.

to the specimen. The difference in the area under the curve applied to the specimen and the standard fire curve can be seen in Figure 2b. For most replicates, the area under the curve was under the standard curve until 6 min into the test, when it leveled off near zero.

In Figure 2, there are two curves that show significant deviations from the remainder of the replicates. These specimens were tested with a more responsive temperature feedback loop. Failure times with the more responsive fire curves fell within the boundaries of the other tests. The area under the curve for these tests still exhibited a 50% deviation from the standard curve in the early testing, similar in magnitude to most of the tests.

Deformation as a Function of Time

The main results of the test can be seen in Figure 3, which shows the deformation of the floor assemblies as a function of time for the four different treatment groups. The positive controls, that is, systems that were known to pass the AC14 tests are the two graphs on the top (a and b), and the negative control and experimental treatment are the two graphs on the bottom (c and d).

Both positive control systems exhibited similar behavior. In these systems, deformation increased gradually with time until a sudden failure occurred. Although the data in Figure 3 stop at the failure point, the raw data exhibited a large decline in the *y*-axis at this point. This failure mechanism was similar in both the solid-sawn joists and the protected I-joists.

In contrast, both the negative control unprotected I-joists and the I-joists protected with the experimental intumescent coating exhibited a "knee" in the deformation−time curve after which the deformation rapidly increased until failure. This knee in the curve was attributed to a failure in the web material that caused the top flange of the I-joist to assume the entire bending load of the assembly.

Although the I-joists with the intumescent coating exhibited a load−deformation curve similar to that of the unprotected I-joists, the time to failure was much greater than that for the unprotected I-joists. The similarity in the load-deformation curve to that of the unprotected I-joists suggests that the I-joists protected with intumescent coating also exhibited a web failure. The time to failure of the intumescent coating was between that of the unprotected and OSB-protected I-joists. The increased time to failure compared with the unprotected I-joists indicates that the coating was providing effective protection to the web, although a more comprehensive solution would be needed to reach the AC14 criteria of 15.5 min.

Comparison with Full-Scale Test Data

The major goal of these tests was to see if this intermediate-scale test could be used to screen new technologies before investing in a full-scale fire resistance test. Figure 4 compares the results (failure times) of the intermediate-scale test with other test data. In Figure 4, the range of observed failure times is represented by a green box for each of the

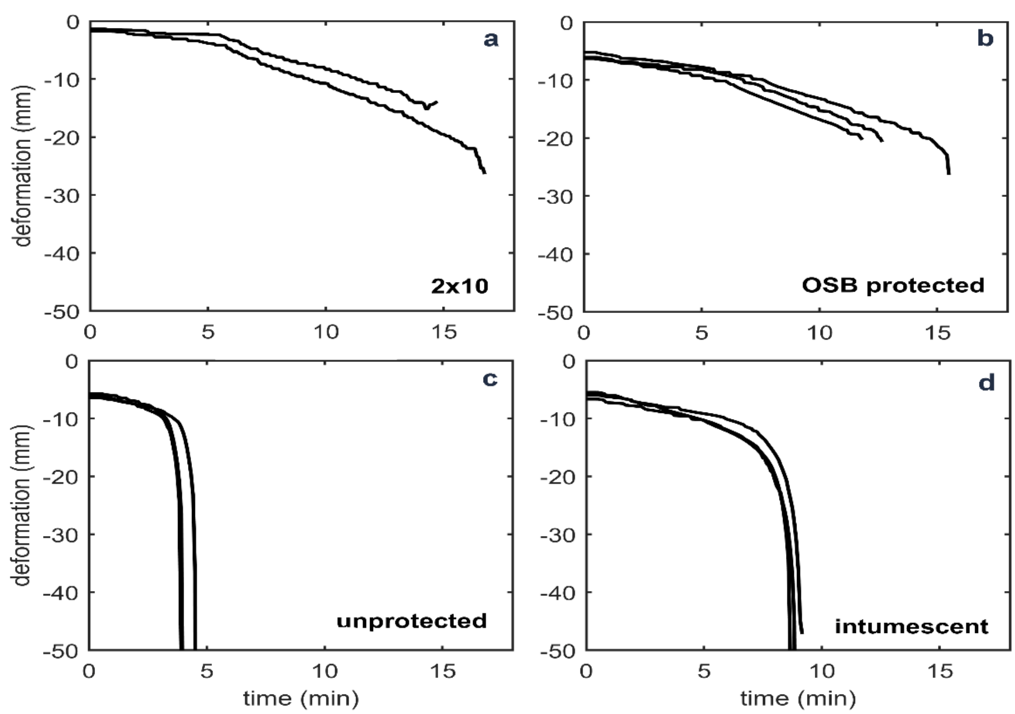

Figure 3—Deformation−time curves for the four different treatment groups: (a) positive control — solid-sawn 2 by 10 joists; (b) positive control — I-joists with OSB-protected webs; (c) negative control — unprotected I-joists; (d) experimental I-joists with an intumescent coating on the web.

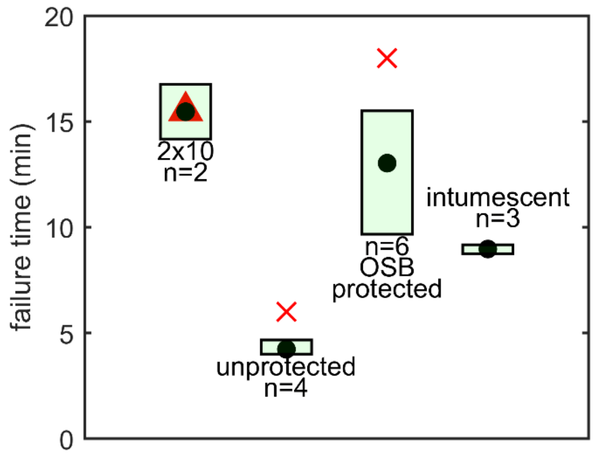

Figure 4—Failure times for the different treatments in the intermediate-scale test compared with calculated or tested full-scale assemblies. The black dot represents the average time to failure for the different treatments. Green boxes represent the range of failure times. The red x's represent full-scale test data. The red triangle is the calculated failure time of the solid-sawn joists using the TR10 calculation.

four treatment groups we examined. The mean failure time is represented by a black circle, and full-scale test data are represented by red ×'s. The full-scale test data for the unprotected I-joists were found in a published report on the fire service response hazards (Kerber and others 2012). The full-scale test failure time for the OSB-protected I-joists was provided from an industry partner (data not available). Although we could not find literature on solid-sawn 2 by 10 joists loaded to 50% of the ASD load, the calculated failure time of 15.5 min from Technical Report 10 (TR10), developed by the American Wood Council, is illustrated in Figure 4 with a red triangle (AWC 2021).

For tests with full-scale test data available to compare, it appears that the intermediate-scale tests resulted in a lower time to failure than that of the full-scale test. The average failure time of the OSB-protected I-joists was 13 min in the intermediate-scale test compared with 18 min in the full-scale test. The difference of 5 min in failure times represents a 38% underprediction. For the unprotected I-joists, the mean intermediate-scale test failure time was 4.23 min compared with 6 min for the full-scale test. The difference of 1.77 min represents a 44% underprediction in failure times.

Load Dependence of Solid-Sawn Joists

To examine how load affected the time to failure, tests were run with solid-sawn 2 by 10 joists at 100% of the design load in addition to the tests at 50% as specified in the AC14 standard. These tests were compared with TR10 calculated failure times (AWC 2021).

The TR10 method applies the nonlinear char rate of wood to the three exposed sides of the joist to calculate the reduced cross section of the member (AWC 2021). The following equation gives the effective char depth a_{eff} for an exposure time using the standard nonlinear char rate constant (β_t) of 1.365 mm/min$^{0.813}$:

$$a_{\mathrm{eff}} = \beta_t t^{0.813} \tag{6}$$

where t is time in minutes.

Appendix B in TR10 gives the equation for the design stress ratio for a fully braced joist:

$$R_s = 2.85 \frac{S_f}{S_s} \tag{7}$$

where R_s is the design stress ratio and S is the section modulus. The subscripts f and s refer to the final and initial states, respectively.

Expanding the initial section modulus term and the reduced section modulus term after subtracting a depth of a_{eff} from the three exposed faces leads to

$$R_s = 2.85 \left(\frac{b - 2a_{\mathrm{eff}}}{b} \right) \left(\frac{d - 2a_{\mathrm{eff}}}{d} \right)^2 \tag{8}$$

where the b is the joist width and d is the depth.

Although Equations (7) and (8) cannot be solved analytically, they are easily solved iteratively. When solved with the standard dressed dimensions of a nominal 2 by 10 (b = 38.1 mm, d = 235 mm), a failure time of 15.5 min is found when using a design stress ratio of 0.5 (50% of allowable load) and a failure time of 11.2 min is found using a design stress ratio of 1.0 (100% of allowable load). These and similar values are tabulated in TR10 appendix B for common joist sizes. The calculated failure times are compared with measured failure times in Figure 5.

As with Figure 4, the green boxes in Figure 5 represent the range of observed failure times, the green circles represent the average (mean) failure time, and the red triangles represent the calculated failure time from TR10. The mean failure times were equal to or greater than the calculated failure time. For the 100% design load tests, only one of the seven replicates failed before the calculated failure time of 11.2 min.

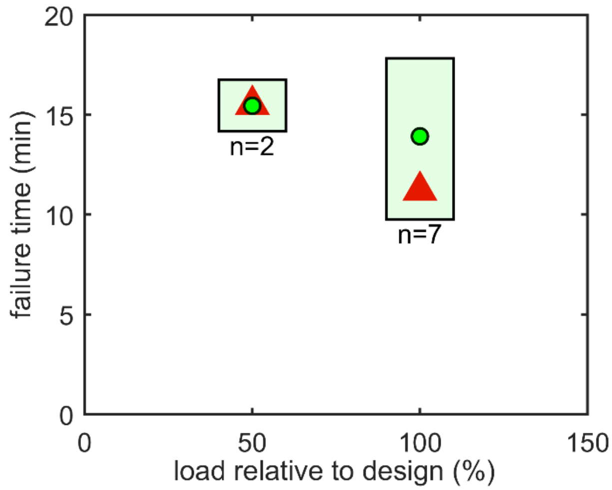

Figure 5—Comparison of the measured failure times for solid-sawn 2 by 10 joist assemblies with the failure times calculated using TR10. The mean failure times are shown as green circles, and the range of failure times is represented by the green box. Calculated failure times are shown as red triangles.

Discussion

This study evaluated the effectiveness of an intermediate-scale test method for floor framing members, particularly wood I-joists. Differences were observed in the failure modes between solid-sawn dimension lumber floor joists and unprotected I-joists with a web failure (Fig. 3). Two different web protection strategies were examined. The OSB-protected webs exhibited a similar failure mode to the solid-sawn joists, whereas the webs protected with an intumescent coating exhibited a failure similar to the unprotected I-joists. Qualitatively, at least, the test method appears to be able to detect web failures in the I-joists.

Ideally, an intermediate-scale screening test would have an equivalent failure time to the full-scale test it is designed to predict. In this study, failure times in the intermediate-scale test were about 38% to 44% less than failure times in the full-scale test where data were available for comparison (Fig. 4). However, for solid-sawn joists, failure times were greater than or equal to the calculated failure times from the TR10 analysis. Although the data were somewhat inconclusive, the intermediate-scale test apparently underpredicted the fire resistance of floor framing members when compared with a full-scale test. One potential explanation for the difference between the methods is that the composite effect plays a much larger role in the full-scale test than it does in the intermediate-scale test.

Even though the intermediate-scale test had a lower fire resistance time than the full-scale test, it does appear to have utility as a screening test. The load-deflection curves can easily identify a web failure, and failure times at the intermediate scale can be compared with each other to identify the most promising prototype. Based on data in Figure 4, it may be worth trying a full AC14 test if the failure time is within 40% of the necessary 15.5 min.

Conclusions

A new intermediate-scale test was developed to evaluate the fire resistance of floor framing members. The goal of the test was to develop a low-cost screening method for the ICC-ES AC14 evaluation criteria. Load deformation curves from the intermediate-scale test could identify web failures. However, the failure times in the intermediate-scale test were between 38% and 44% less than those of the full-scale tests (where comparable data were available). The intermediate-scale test method appears to have utility in ranking different experimental web protection technologies for wood I-joists. However, the exact failure times from this test method appear to be less than what one would expect in the full-scale test.

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Literature Cited

ASTM. 2014. ASTM E119. Standard test methods for fire tests of building and construction materials. West Conshohocken, PA: American Society for Testing and Materials.

ASTM. 2021. ASTM D6874. Standard test methods for nondestructive evaluation of wood-based flexural members using transverse vibration. West Conshohocken, PA: American Society for Testing and Materials International.

AWC. 2017. NDS supplement: national design specification: design values for wood construction. 2018 edition. Leesburg, VA: American Wood Council. https://www.fp-supply.com/cmss_files/attachmentlibrary/AWC-NDS2018-Supplement-ViewOnly-171027.pdf

AWC. 2021. Calculating the fire resistance of wood members and assemblies. Techincal Report No. 10. Leesburg, VA: American Wood Council. 137 p. https://awc.org/wp-content/uploads/2021/12/awc_tr10_20210209_awcwebsite.pdf

Brannigan, F.L. 1989. A primer on truss roofs. Why truss roofs are hazardous for firefighters. Firehouse. March.

Dietenberger, M.; Hasburgh, L.E.; Yedinak, K.M. 2021. Fire safety of wood construction. In: Wood handbook: wood as an engineering material. General Technical Report FPL-GTR-282. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: Chapter 18. https://research.fs.usda.gov/treesearch/62268

Green, D.; Kretschmann, D.E. 1991. Lumber property relationships for engineering design standards. Wood and Fiber Science. 23: 436-456. https://www.fpl.fs.usda.gov/documnts/pdf1991/green91c.pdf

Grundahl, K. 1992. National engineered lightweight construction fire research project: technical report: literature search & technical analysis. Quincy, MA: National Fire Protection Research Foundation. 256 p. https://www.sbcindustry.com/sites/default/files/uploads/attachments/node/128/nfprf_report_wtca_version.pdf

ICC. 2019. ICC-ES AC14. Acceptance criteria for prefabricated wood I-joists. Birmingham, AL: International Code Council Evaluation Service. 52 p.

ICC. 2021. 2021 International Residential Code (IRC). Washington, DC: International Code Council.

Kerber, S.; Samuels, M.; Backstrom, B.; Dalton, J. 2012. Fire service collapse hazard floor furnace experiments. Northbrook, IL: Underwriters Laboratories.

Leichti, R.J.; Falk, R.H.; Laufenberg, T.L. 1990. Prefabricated wood I-joists: an industry overview. Forest Products Journal. 40(3): 15-20. https://www.fpl.fs.usda.gov/documnts/pdf1990/leich90b.pdf

Loferski, J.R. 2015. Light-frame building construction with 2 by 4 lumber–the “new” old building system of American housing. In: Proceedings of the 21st Internationales Holzbau-Forum IHF 2015. Garmisch-Partenkirchen, Austria, December 1-3, 2015.

Routley, J.G. 1989. How wood trusses perform during a real fire. Fire Journal. January/February.

White, R.H.; Schaffer, E.L.; Woeste, F.E. 1983. Replicate fire endurance tests of an unprotected wood joist floor assembly. Wood and Fiber Science. 16: 374-390. https://wfs.swst.org/index.php/wfs/article/view/1223

WIJMA. 2019. Establishing fire equivalency for floor framing members to unprotected 2x10 dimension lumber or equal-sized structural composites lumber. Boise, ID: Wood I-Joist Manufacturers Association. 8 p. https://i-joist.org/wp-content/uploads/2019/06/6_4_19-AC14-ES-Reference.pdf

Zelinka, S.L.; Bourne, K.J. 2022. Intermediate-scale laboratory method to qualify heat-delaminating adhesives for use in cross-laminated timber. Forest Products Journal. 72: 216-225. https://doi.org/10.13073/fpj-d-22-00031

Zelinka, S.L.; Bourne, K.J.; Bechle, N.J.; Rammer, D.R. 2021. Intermediate-scale test developed to screen adhesive fire performance in glued-laminated timber before full-scale testing. Research Note FPL-RN-0397. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Protects Laboratory. 4 p. https://research.fs.usda.gov/treesearch/62854