Enhancements to performance: design for fire resistance

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Abstract

The structural integrity of new engineered wood products in a fire will be critical for their acceptance in the 21st century. This paper gives examples of past and current research and the available design tools to improve the fire-resistance performance of engineered wood products. Improved fire resistance can be achieved by appropriate engineering design. Models under development will also improve the ability to maintain fire safety as the building materials of the future are developed.

Introduction

In a fire, it is important that the structural members of a building continue to retain their structural integrity. We expect the walls and floors to confine the fire to the compartment of origin. Fire resistance is the ability of structural members and assemblies to resist the effects of a fully developed fire. The fire resistance or fire endurance hourly rating for building code purposes is obtained by testing an entire assembly according to ASTM E 119 (2). Three criteria govern the failure of a test assembly in ASTM E 119 structural integrity, excessive temperature rise on the unexposed side, and flame penetration. The fire exposure severity specified in ASTM E 119 represents a post-flashover fire in which there is full involvement of the room or compartment in the fire (flashover is complete fire involvement of the compartment and flames coming out the doors and windows).

Traditional heavy timber construction has a reputation for superior fire resistance performance. For heavy timber construction, building codes specify the sizes of the wood members rather than the required fire-resistance ratings. Unprotected steel members are known to fail, while structural wood members continueto maintain their structural integrity. Traditional light-frame wood construction is generally considered to have acceptable fire resistance, particularly when protected with gypsum board.

Many questions have been asked about the fire-resistance performance ofthewide array of new engineered wood products. Individuals in the fire services have concerns about the safety of trusses and I-beams (4,22). In addition, questions often are asked about the performance ofadhesives in the various composite products.

The fire safety of new engineered wood products will be an important issue affecting their acceptance in the 2Ist century. Two primary fire safety issues affecting the continued acceptance of engineered wood products are their ability to contain a fire in a concealed space and maintain structural integrity in a post-flashover fire.

Unprotected sandwich panels are an example of a product with unsatisfactory fire performance as a load-bearing member. In the early 1970s, the Forest Products Laboratory (FPL) conducted a series of studies on the fire performance of load-bearing structural sandwich panels constructed using 6-mm- (1/4-in.-) thick plywood (8,13). The cores were either foam plastics or paper honeycomb. The panel performance as a load-bearing wall in the ASTM E 119 wall furnace was poor. Failure times were 3 to 6 minutes. In other FPL tests of sandwich panels with metal faces, failure occurred in less than 1.5 minutes (34).

To evaluate the significance of these failure times, full-scale structures were constructed and tested using wood cribs as the combustible contents. The two side walls of the 5- by 7-m (1.5- by 2-ft.) structures were loaded. Using sawn-wood studs and 6-mm- (1/4-in.-) thick lauan paneling as the interior finish, the initial wall failure occurred at 25.5 minutes, or 7.5 minutes after flashover occurred in the structure. Life safety within the compartment is a possibility before flashover.

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In three tests of unprotected sandwich panels, initial failure of structural integrity occurred between 4.75 minutes before flashover to 1.5 minutes after flashover. Clearly, the fire safety performance of these unprotected load-bearing sandwich panels is not acceptable. However, early failures by flame penetration or excessive temperature were not observed. For sandwich panel walls in which the sandwich panel is not supporting the loads, flame penetration or excessive temperature would be the failure criterion of interest.

For cases such as unprotected sandwich panels, we need to develop ways to improve the fire safety performance to a satisfactory level. The fire-resistance performance of wood assemblies can beenhanced by improving structural components, providing thermal protection, or incorporating components in an assembly.

Structural components

The engineered wood product is likely to be a structural component; therefore, it is reasonable to begin by improving the fire performance of the structural component. Some examples of structural components follow.

Examples of previous research to improve the fire performance of structural components include the Corn-Ply stud, large timber or glued-laminated beams, and metal-plate-connected (MPC) trusses.

Com-Ply studs and joists are products with particleboard cores and veneer facings, developed by the USDA Forest Service, Southeastern Forest Experiment Station in the 1970s (16). Corn-Ply studs were intended to replace sawn studs and joists. In an unpublished study, walls with Com-Ply studs were tested at the FPL. A wall with 2 by 4 sawn studs (nominal 2- by 4-in., actual 38- by 89-mm) and 6-mm- (1/4-in.-) thick plywood as the interior paneling failed at 21.2 minutes. In the initial series of wall tests, a Com-Ply stud wall with 6-mm- (1/4-in.-) thick plywood interior paneling failed at 11.3 minutes. The Coni-Ply wall with 9.5-mm- (3/8-in.-) thick regular gypsum board as the interior finish failed at 23.2 minutes. In these initial tests, the veneer facings on the narrow edge were 4 mm (1/6 in.) thick. The core was a randomly oriented particleboard. After these initial tests, the Southeastern Forest Experiment Station conducted additional exploratory tests. As a result, they modified the Com-Ply stud by increasing the thickness of the veneer facings to 6 mm (1/4 in.) and changing the core to oriented flakeboard. When this modified Com-Ply with 6-mm- (1/4-in.-) thick plywood as the interior paneling was tested, structural failure occurred at 26 minutes or 4.8 minutes better than the sawn lumber stud wall. The load in all the tests was the same. The load represented a typical loadingonanexteriorwall in the first storyofatwo-story house (8). Design load values for the Corn-Ply studs were not available. Exploratory testing showed that the stud stiffness was a factor in the fire performance.

The second example of past work on the endurance of a structural component is large wood beams and columns. A considerable amount of work has been done on predicting the fire endurance of large wood beams and columns, particularly glued-laminated beams (21). In the United States and Canada, a code-approved procedure calculates the fire endurance rating of an unprotected large wood member (minimum dimension of ≥152 mm (≥6 in.) (1,15). The equations in the procedure were developed by T.T. Lie (14). The procedure allows for variations in the cross-sectional dimensions of the member and the load as a fraction of the full design load. (The effective length of a column is also an input into the equations.) Thus, the procedure can be used to calculate the effect of adding sacrificial wood to improve the fire endurance rating of large wood members. Other procedures are available to calculate smaller members such as floor joists (21,24,29,33).

Glued-laminated members are made from different laminates of lumber. Different grades of lumber are used within the beam to optimize the load-bearing capacity. To allow for charring of a high-grade tension laminate, the code procedure requires the laminate next to the extreme tension laminate to be of the same grade. A procedure developed by Bender and Schaffer and others (3,23) can be used to fully evaluate the effects of individual laminates on fire endurance.

The third example is the MPC trusses. A fire endurance model for a single MPC wood truss was developed by the University of Wisconsin-Madison and the FPL (32). The model provides for input of the load-bearing capacity of the individual wood and metal plate components of the truss. The mechanical properties are degraded as a function of surface and center temperatures. As part of a continuing study, the model is being used to investigate the failure mechanisms of MPC trusses and possible ways to make the failure in a fire more gradual and ductile.

Performance data

In addition to the previous examples, factors affecting the fire-resistance performance of structural components include charring rates, fire-retardant treatment, adhesives, and connections. Factors that affect charring rate include density, species, moisture content, and severity of fire exposure. The charring of wood has been extensively studied (20,21,26,31).

The Southeastern Forest Experiment Station evaluated Com-Ply members dipped in fire retardants. The fire-retardant treatment tended to reduce the fire endurance time. Although some fire retardants may reduce the charring rate (19), fire-retardant treatments of structural members are generally considered to have little effect on the fire endurance time in standard tests. In tests where flame penetration through joints in the wood is a factor (e.g., a solid wood wall), fire-retardant treatment of the wood may improve the fire endurance rating. A fire-retardant treatment will also reduce the contribution of the wood components to the spread of a fire in a concealed space.

Data on the effect of adhesives in fire resistance are limited. As noted in the *Wood Handbook* (9), available information indicates that laminated members glued with phenol, resorcinol, or melamine adhesives are at least equal in their fire resistance to a one-piece member of the same size. Laminated members glued with casein have slightly less fire resistance than sawn lumber of the same size. Tests also suggest that fire performance is reduced with polyvinyl adhesives (18). When the charring is perpendicular to the glueline, charring rate may increase slightly when the charring has progressed past a glueline.

Most work on the fire performance of connections has been done on heavy timber construction. Connections for heavy timber construction are briefly discussed by Schaffer (21). Carling (5) reviewed a large amount of the available literature. As part of the development of the fire endurance model for a single truss, the performance of the metal plates at elevated temperature was evaluated. An FPL research paper is being prepared on this work.

Thermal protection

The most common way to improve the fire resistance of engineered wood products is to provide thermal protection. Generally, the protection is either a protective membrane of the assembly or direct protection of the structural component. General rules on the effect of changes in the thermal protection are discussed by Harmathy (12). Thermal protection is most commonly provided by gypsum board. Fire protection is provided by a range of gypsum products including regular unrated gypsum board, fire-rated gypsum board known by its generic designation of Type X, and a more advanced fire-rated gypsum board generally referred to as Type C.

Gypsum board is an effective way to improve fire resistance. In the FPL tests on structural sandwich panels discussed previously, protection of the sandwich panels with gypsum board or a fire-resistive coating was able to make the fire performance of the load-bearing sandwich panels equivalent to that of traditional light-frame construction. In full-scale structure tests, initial failure of sandwich panels protected with 13-mm- (1/2-h.) thick Type X gypsum board did not fail until 6.25 minutes after flashover.

A sandwich panel with a fire-resistive coating failed at 24.9 minutes in a standard ASTM E 119 test. The sandwich panels with 13-mm- (1/2-h.-) thick Type X gypsum board failed at 23.0 and 24.5 minutes. The corresponding unprotected sandwich panel failed at 3 minutes, and the wood frame with 6-mm- (1/4-in.-) thick plywood paneling failed at about 20 minutes.

Protective membrane

Fire-rated assemblies can be found in listings such as those published by the Gypsum Association (11) and by Underwriters Laboratories (27). In the additive method of calculating the fire-resistance rating of a sawn stud or joist floor (25,29), the contributions of various protective membranes are listed and added to the time assigned to the structural members. Protective membranes are generally attached directly to the structural member or to metal channels that are attached to the structural members.

The Truss Plate Institute and individual companies of the MPC truss industry have made a considerable effort to develop cost-effective, fire-rated truss assemblies. Proprietary products include the FR-System of Lumbermate (6) and the TrusGard System of Truswal Systems.

Direct protection

Unlike steel construction, direct protection is not generally used to provide fire-rated wood members. For new construction, the fire endurance of a large wood member can effectively be obtained by increasing the dimension of the member. For rehabilitation, an alternative way to increase the rating for an existing large wood member is sometimes needed. Unfortunately, listings for fire-rated wood members coated with a fire-resistive coating or covered with gypsum board or other fire-resistive board products are not available. Research was done on the potential of fire-resistive coatings (17) and fire-resistive board products to provide direct protection. The FPL tested various fire-retardant and fire-resistive coatings on plywood in a small fire-resistance furnace (28,30). Recent work on the effect of direct protection of gypsum board on the charring rate of wood was reported by Gardner and others (10).

Assembly effect

Except for large beams and columns, the standard ASTM E 119 test for fire resistance specified by the building codes is a test of an assembly. The individual components of the assembly are not tested or assigned a rating. Thus, any advantages gained by incorporating the components in an assembly will be recognized by the rating system. The major disadvantage of this situation is the enormous cost of ASTM E 119 testing and the need to retest the entire assembly when some aspect of the desired construction assembly is different from the assembly that was tested.

One aspect is the presence of insulation. Depending upon the type of assembly, type of insulation, and location of the insulation within the assembly, insulation can either decrease or increase the fire-resistance rating. Although insulation may protect components on its unexposed side, insulation will likely increase the rate of temperature rise of materials on its tire-exposed side.

To gain increased flexibility in fire-rated wood construction as well as increased understanding of the potential ways to increase the fire ratings, considerable effort is being made to develop theoretical models for fire-rated wood assemblies. The MPC truss model is part of this effort. The single-truss fire endurance model is currently being expanded to a truss system model. A fire endurance model for an unprotected sawn joist assembly based on NFPA System 1 (7) has been developed. Improved heat transfer models for protected assemblies are under development.

These fire modeling efforts are largely being done by the members of the North American Wood Products Fire Research Consortium. The consortium members include the American Plywood Association, the Canadian Wood Council, the FPL, Forintek Canada Corp., and the National Forest Products Association.

The construction details of the assembly can be a factor in the spread of a fire in a concealed space. Appropriate fire stopping and draft stopping can confine the area of fire spread (25). One option to improve fire safety is the use of sprinklers. Fire-retardant treatment of the combustible materials (framing, sheathing, insulation) can reduce the contribution of the materials to the spread of the fire. The integrity of the protective membrane should be maintained during construction to insure that the performance in the field reflects the protection provided in the standard test.

Concluding remarks

As we already have seen in the 20th century, the structural integrity of engineered wood products in fires will be critical for their acceptance in the 21st century. As we continue to develop new engineered wood products that use natural resources more efficiently, fire safety concerns will become increasingly critical. The development of engineered wood products should include consideration of their fire performance. Improved fire-resistance performance can be achieved by engineering design. Models under development will improve our ability to maintain fire safety as we develop the building materials of tomorrow.

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