Fire-Retardant-Treated Wood: Effects of Elevated Temperature and Guidelines for Design

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Abstract

Fire-retardant-treated wood is an important component of nonresidential commercial and multifamily constructions. Research has shown that not all fire-retardant-treated wood exhibits similar performance attributes. Some formulations may cause thermally induced degradation of the wood in service. This paper briefly discusses the causes of the strength reductions and presents tentative guidelines for using fire-retardant-treated lumber and plywood.

Introduction

Building codes sometimes require the use of fire-retardant (FR)-treated wood. FR-treated lumber and plywood have been successfully used in structures exposed to temperatures <100°F for nearly 50 years. However, over the last 4 to 6 years, a substantial numter of failures have occurred in multifamily dwellings and nonresidential commercial buildings that have used FR-treated plywood as roof sheathing (APA, 1989). Based on these reported failures, it is apparent that some FR formulations are undergoing thermal decomposition due to elevated temperatures induced by solar radiation. It also appears that other formulations are not experiencing this same thermal-induced degradation. Those experiencing thermal degradation turn a dark brown with a dry rotted-like appearance, crumble easily when abraded, and often exhibit excessive cross-grain checking. A more complele description of the problem of failure in FR-treated plywood used as roof sheathing is presented by LeVan and Collett (1989). The thermo-chemical factos involved in the ongoing strength-reduction problem of FR-treated plywood at elevated temperatures and a proposed chemical mechanism have been presented by LeVan and Winandy (1990).

FR-treated plywood was accepted by Building Officials and Code Administrators (BOCA, 1988) and Southern Building Code Congress (SBCCI, 1988) model building codes for use as roof sheathing in 1979 and 1982, respectively. Because of the regional nature of building codes, this problem is most common in the eastern United States on nonresidential commercial construction and on multifamily dwellings built without parapet walls since 1980. When the problem of thermally induced degradation of FR-treated plywood develops, it requires costly roof replacement. The National Association of Home Builders estimates that replacement costs for the failed material will exceed $2 billion (NAHB, 1989). Depending on the local building code, replacement requires removing the roofing material and degraded roof-sheathing, followed by installation of thermally stable FR-treated plywood, untreated plywood with gypsum underpayment, or new composite roof sheathing materials employing plywood, fiberglass, and gypsum. Applying new rooting material is the final step. The estimated cost of such a task is around $2,000 to 3,000 per 1,000 ft^2 (NAHB, 1989).

High Kiln Temperatures Reduce Strength

Based on the work of many investigators, we now know that most FR treatments initially reduce strength from between 10 to 25%, and that the magnitude of these reductions varies with the FR treatment and the property being considered (Winandy, 1988). This work has consistently shown that the temperature used in kiln drying FR lumber and plywood after treatment is one of the factors most responsible for the magnitude of these strength reductions in FR-treated material. Accordingly, American Wood Preservers Association (AWPA) Standards, C-20 for FR-treated lumber and C-27 for FR-treated plywood, both require that the kiln temperature after treatment be limited to < 160°F until the average moisture content (MC) of the FR-treated material is <25% (AWPA, 1989).

Research Results

Initial investigations suggested that field problems resulted from thermally induced acid degradation of wood carbohydrates by the acidic form of the FR (LeVan and Winandy, 1990). More comprehensive work has now shown that the proposed acid degradation mechanism was valid, and that the relative effects of many FR treatments can be classified by the type of FR employed and the time-temperature combination required to convert the FR formulation into its acidic form (LeVan et al., 1990). Figure 1 illustrates the relative effects of untreated controls, as well as three FR formulations exposed for various durations at 180°F, then equilibrated to constant weight at 74°F/65% relative humidity (RH) and tested.

Monoammonium phosphate (MAP) is an inorganic salt FR that was a major chemical component used in the FR-treated plywoods now experiencing roof-sheathing failure. Guanylurea phosphate/boric acid (GUP) and Dicyandiamide phosphoric acid formaldehyde (DPF) rep. resent commercial interior and exterior organic FR salts, respectively. Each FR accelerates wood-strength loss when compared with untreated controls (CTL), but MAP has a significantly greater effect than either organic salt. It is important to note that permanent thermal degradation eventually occurs for both treated and untreated materials exposed at 180°F. Furthermore, it is noteworthy that after thermally induced degradation has initiated (<21 days exposure) and eventually stabilized (>21 days exposure), the raw of strength degradation is similar between treated and untreated materials, even though there arc large differences in strength.

Additional research using untreated and MAP-treated plywood was performed at 130°F/73% RH, 150°F/76% RH, 170°F/79% RH, and 170°F/50% RH. The results indicate that MAP-treated plywood is lower in bending strength than untreated plywood at all temperature and, as temperature increases, the rate of strength degradation is similar between untreated and MAP-treated plywood. It was also noted that as relative humidity increased at 170°F, the rate of strength degradation increased. However, the effect of relative humidity did not appear to be as influential as the effect of the temperature of exposure.

While steady-state exposure to elevated temperature is theoretically quite severe, from a practical standpoint the results of steady-state testing appear less severe than field experience. This observation is based on the fact that the level of degradation in mechanical properties and wood composition induced by steady-state laboratory exposures of 170°F/79% RH and 180°F/50% RH is far less than the magnitude of the degradation often experienced in the field. Thus, another significant variable may be involved infield failures, such as lack of required kiln drying, excessive kiln temperatures during redrying, or partial amounts of an FR chemical that is initially even more deleterious to strength (e.g., phosphoric acid, which is the acid form of MAP).

To verify acceptable performance of commercial FR treatments, most FR formulator/treaters arc currently testing their proprietary FR treatments using a draft test protocol, which was developed by a joint plywood industry/treating industry/USDA Forest Service, Forest Products Laboratory task group. This draft test protocol provides a standardized testing methodology that quantifies the relative performance of proprietary commercial FR

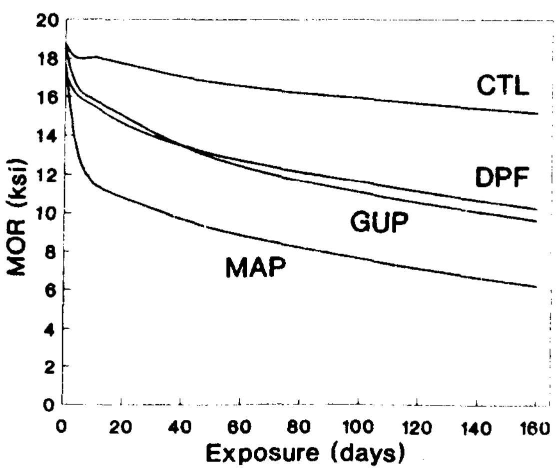

Figure 1. Effects of three fire retardants on bending strength of 0.625- x 1.375- x 12-in. clearwood specimens exposed to steady-state exposure at 180°F (82°C) and 50% RH (CTL = untreated control, MAP = monoammonium phosphate, GUP = guanylurea phosphate, and DPF = dicyandiamide phosphoric acid formaldehyde).

treatments where exposure to elevated temperatures is expected. This protocol has recently been submitted to the American Society for Testing and Materials (ASTM) for consideration as a consensus standard.

In addition to the test protocol, the AWPA committees that are responsible for the redrying temperature limitations in AWPA Standards C20 and C27 arc currently considering a further modification to these redrying temperature limits. The proposed limits would altogether restrict redrying temperature to 160°F for interior FR formulations. Exterior FR formulations would also be limited to 160°F until the specimens reach <19% MC, at which time an elevated curing temperature would be allowed.

Tentative Guidelines for using Fire-Retardant-Treated Lumber and Plywood

Based on laboratory research and field experience, it appears that differences between field- and laboratory-induced property degradation rates are related to the formulation of the FR chemicals used, adequacy of kiln drying after treatment, and severity of the drybulb and wetbulb depression temperatures employed in the redrying process. The overall effects of these FR chemicals and redrying temperatures could also be amplified by the temperatures experienced during initial kiln drying prior to FR treatment. Such an interactive effect from initial kiln drying has been noted for chromated copper arsenate (CCA) preservative treatments (Barnes et al., 1990; Winandy et al., 1990, unpublished data).

Designers should pose the following questions to suppliers of FR-treated materials that are intended for exposure to elevated temperatures, such as in roof decks. These questions are not intended to be totally conclusive. For each specific use, additional design matters will also require careful consideration.

1. Does the FR formulator/treater warranty the FR-treated material for the intended use?

2. What are the initial effects of FR formulation on wood strength, wood stiffness, and fastener corrosion that are certified by the FR formulator/treater and its relevant third-party inspection agency?

3. Has the FR-treated material proposed for the use in question been tested at elevated temperature? **A** draft test protocol has been developed and is currently being considered for adoption as the ASTM standard. Until ASTM adopts a standard, results generated from the draft test protocol may represent the best available method to certify acceptable performance.

4. Has an approved third-party inspection agency certified compliance with all existing standards, processing, and testing proecdures? These procedures would include AWPA C20/C27, ASTM E 84 (ASTM, 1989), compliance with chemical formulation and post-treatment drying tempera-

tures employed in developing the original certification, and new test protocol for assessing ongoing temperature-induced strength degradation.

5. Was the FR-treated material dried after treatment to <15% MC for plywood and <19% MC for lumber, levels specified in AWPA Standards C27 and C20, respectively? These moisture content levels are required for proper structural performance, especially for avoiding fastener corrosion.

6. Will adequate precautions be used during shipping and at the job site to prevent moisture from rewetting the FR-treated material? If exposed to moisture, will appropriate drying be required before using the FR-treated material?

Summary

ER-treated wood has been used for nearly 50 years in the United States. Since FR treatments reduce wood strength, consideration must be given to strength reduction in the design process. However, additional strength reductions relate to thermal degradation have recently been encountered with the use of some FR treatments for plywood roof sheathing. Based on the unacceptable performancc of some FR formulations, FR-treatcd lumber and plywood should not be considered as interchangeable commodity items. Architects and engineers must be aware that not all FR-treated wood possess similar properties and performance constraints. New test methods are being developed to differentiate between various proprietary commercial FR treatments. It is the specific responsibility of each designer 10 anticipate the temperatures and relative humidities expected to be encountered in a structure, and then to consider the available options. These decisions will directly affect selection of the proper materials for that structure. Consideration of the above-mentioned questions and attention to other relevant environmental factors specific to each intended use will result in a structure that performs as expected.

Finally, in its section on FR treatment durability, recent editions of the Wood Handbook (FPL, 1987) have stated that the chemicals used in FR treatments are thermally stable for short periods to temperatures up to 330°F. However, because of field problems and the results of recent research at the FPL, it has now become apparent that duc to overextended exposure, some FR formulations can undergo thermal decomposition due to elevated temperatures induced by solar radiation. Thus, the limit of permanent thermal stabilily for FR-treated material should be assumed to be closer to 130°F, unless specific data documenting stability at higher temperatures is presented by the formulator.

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