FLAME RETARDANCY OF WOOD: PRESENT STATUS, RECENT PROBLEMS, AND FUTURE FIELDS

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In: Lewin, Menachem, ed. Recent advances in flame retardancy of polymeric materials: Proceedings of 3rd annual BCC conference on flame retardance; 1992 May 19-21; Stamford, CT. Norwalk, CT: Business Communications Company, Inc.; 1992:250-257.

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ABSTRACT

In response to specific and immediate research needs, the Forest Service-Forest Products Laboratory is conducting several studies that pertain to the present and future status of fire-retardant-treated (FRT) wood and fire-resistive coatings. These studies include the degradation of FRT plywood, the potential use of fire-resistive coatings to protect wood trusses, and the development of a combined preservative-flame-retardant treatment for wood shingles.

DEGRADATION OF FIRE-RETARDANT-TREATED PLYWOOD

For nearly 50 years, fire-retardant-treated (FRT) plywood and lumber have been used successfully in structures exposed to temperatures up to 100°F (37°C). Some immediate loss in strength caused by the drying of FRT wood has been recognized (Winandy and others 1988, Winandy 1991). Ten years ago, two major model building codes allowed the use of FRT plywood roof sheathing as a substitute for a fire-rated parapet wall between multifamily dwellings. Since that time, some cases of strength failure in FRT plywood have been reported. These failures were due to thermal degradation of the FRT plywood induced by elevated temperatures; some fire-retardant formulations cause treated wood to be more susceptible to thermal degradation. The National Association of Home Builders (1990) has estimated that replacement of these failed roof sheathings may exceed $2 billion.

Past Research

When wood "burns," it actually undergoes thermal degradation that evolves gases that are quickly oxidized. The result is combustion *or* "burning." The remaining parts of the wood that are not consumed constitute the char. Fire retardants work by lowering the temperature at which the wood thermally degrades. When this degradation occurs at a low temperature, less combustible gases are released and more char is formed. However, thermal degradation can be brought on prematurely by exposing the FRT wood to elevated temperatures. When thermal degradation occurs, the chemical components of the wood are hydrolyzed, causing a loss of strength in the wood. LeVan and Winandy (1990) and LeVan and Collet (1989) described the suspected mechanism that causes strength loss.

Not all fire-retardant formulations have undergone thermal degradation in the field, and not all plywood treated with such formulations has undergone such strength failures. LeVan and others (1990) examined the effects of six fire-retardant formulations (phosphoric acid, monoammonium phosphate, borax/boric acid, organic phosphate salt, amino resin system, organic phosphate ester) on the bending properties of solid wood. Specimens were treated with a formulation and then redried at low temperatures (≤ 120°F (≤ 48°C)). After redrying, the treated specimens and untreated controls were exposed to conditions of 80°F (26°C) and 30% relative humidity (RH), 130°F (54°C) and 73% RH, or 180°F (81°C) and 50% RH for 3 to 160 days. The modulus of elasticity (MOE), modulus of rupture (MOR), and work to maximum load (WML) were calculated based upon the results of destructive testing. The specimens treated with phosphoric acid were severely degraded, and the MOR and WML at 130°F (54°C) and 180°F (81°C) were reduced to 10%-50% compared to that of untreated specimens. The specimens treated with monoammonium phosphate also showed substantial thermal degradation, although not as severe as the specimens treated with phosphoric acid. Specimens treated with the other fire retardants were less degraded than specimens treated with monoammonium phosphate or phosphoric acid.

The chemical analyses of the degraded wood showed similar trends for each fire-retardant formulation, indicating the same mechanism was probably responsible for the degradation of the wood (LeVan and others 1990). The extent of the strength loss of the monoammonium-phosphate-treated wood was less than expected based upon known field failures (APA 1989). It was therefore theorized that other factors such as post-treatment redrying temperature or elevated moisture contents affected the rate of degradation and strength loss.

An Arrhenius-based kinetic model was shown to partially predict the rate of thermal degradation in mechanical properties for FRT softwood plywood exposed to elevated temperatures (Winandy and others 1991). These efforts contributed to the development of an ASTM Emergency Standard (ASTM ES 20-91) (ASTM 1991a).

Current and Future Research

Several studies at the Forest Products Laboratory (FPL) are aimed at evaluating the current and future serviceability of FRT plywood. In one study, parameters for nondestructive evaluation are being correlated to actual mechanical properties derived from destructive testing methods. Another ongoing study is examining the factors that influence the degradation of FRT wood, such as redrying temperatures, moisture content, and various fire retardant components. Another study is correlating the results of laboratory experiments on thermal degradation with field results. The results of these and other studies will be used to develop a model that can be used to estimate the remaining service-life of FRT plywood roof sheathing.

FIRE-RESISTIVE COATINGS FOR WOOD

New technologies provide both new opportunities and new problems in the use of wood for construction. The performance of truss assemblies in the standard ASTM E 119 test (ASTM 1991b) was reviewed by Schaffer (1988) in a recent *Fire Journal* article. However, these standard test results failed to allay concerns about the field performance of the truss assemblies (Brannigan 1988, 1989; Routley 1989). Firefighters and others are mainly concerned about the sudden collapse of the floor or roof. The critical importance of proper quality control and maintenance of the ceiling membrane could be reduced by improving the fire performance of the truss itself. In commenting on the controversy, Cutter (1990) raised the issue as to whether the metal gusset plates could be covered with an insulating barrier.

Past Research

White (1984, 1986) found that fire-resistive coatings can provide significant protection to wood exposed to ASTM E 119 conditions. Richardson and Cornelissen (1987) showed that flame-retardant paints could provide significant increases in the fire resistance of heavy timber roof systems. In other studies, which included only one or a few tests, the results were mixed. Some results are reported by Yiu and King (1989) and Tan (1988).

Current Research at FPL

A joint FPL-University of Wisconsin (UW) Project on improved fire resistance of metal-plate-connected wood trusses addresses the concerns about the intrinsic fire safety of trusses. Our objective is to identify and evaluate technical innovations that will improve the fire resistance of wood truss systems without involving the ceiling membrane. The fire-resistive coatings and other proposed technical innovations will be evaluated in a tension apparatus large enough to accommodate a 4.5- by 7-ft (1.4- by 2-m) furnace.

The significance of the component performance in the overall performance of a truss will be evaluated by the input of the component experimental data into a fire endurance model developed by FPL and UW-Madison (White and others, in preparation; Shrestha 1992). The fire endurance model is also able to identify the failure mechanisms of the wood truss systems.

The coating and wood industries still need to obtain certified fire ratings for the truss designs. This will require full-scale ASTM E 119 tests.

Once verified by these standard tests, the models and data in this project will provide the capability to expand the ratings to a wider range of assemblies.

outlook

Innovations identified in the FPL-UW research may have the potential for broader applications in wood construction. In addition to trusses, coatings are potential solutions to other fire safety problems, such as alternatives for FRT plywood in roof applications and rehabilitation of existing wood structures to current code requirements. The introduction of coated wood products as an alternative to FRT plywood roof sheathing has shown the market potential for such coatings. The high cost of ASTM E 119 tests, the limited application of test results resulting from the lack of accepted methods to design for appropriate coating thicknesses, and the economics of coatings as opposed to gypsum board have apparently hindered the marketing of coatings specifically for obtaining required fire ratings with wood members. It is hoped that the FPL-UW study as well as the continued development of other fire endurance models for wood assemblies will facilitate the availability of fire-resistive coatings for wood construction.

COMBINATION OF FIRE RETARDANT AND PRESERVATIVE TREATMENTS

Decay-resistant and FRT wood products are commonly used in many applications. Several fire-retardant and preservative combinations are even effective for interior uses. However, successful exterior use of a combined fire-retardant-preservative treatment has yet to be developed. The major problem with such an exterior combined treatment is that most combinations of fire retardants and preservatives are chemically incompatible. Moreover, most fire retardants are susceptible to leaching from moisture when exposed to outdoor conditions. Additionally, many leach-resistant preservatives impart an unacceptable color to the wood.

Past Research

Several approaches have been taken to producing a combined fire-retardant-preservative treatment. One method has been to modify an existing ground contact preservative treatment by adding fire-retardant chemicals. Chromated copper arsenate (CCA) has been a popular leach-resistant preservative. Although CCA treatment tends to have no negative effects on flame spread, it does have a tendency to glow after the initial heat source is removed. (Bruce 1956). The modification of CCA with zinc and phosphorus to reduce its glowing tendency led to the development and testing of a commercially practicable, fixed, waterborne fire-retardant preservative for fence posts (McCarthy and others 1972). The treatment consisted of a preservative combination (zinc, copper, chromium, arsenic, and phosphorus) with adequate leach-resistant, decay-resistant, and fire-resistant properties; however, the effectiveness of this treatment as a preservative was reduced by the modification. Other factors, such as the green color of CCA-treated material and concern over the toxicity of the components of CCA, may also have precluded the widespread use of fire retardants with modified CCA.

Organic phosphorus fire retardants were added to creosote or penta-petroleum solutions to improve the fire retardancy of treated railroad bridges (Collister 1963). The applications of creosote-treated lumber are more limited than those of lumber treated with other preservatives, and problems with the penetration of triaryl phosphate have been noted (Collister 1963).

Another method has been to use conventional fire retardants that have good decay resistance and to fix the chemicals in the wood. Jain and Cedercreutz (1961) developed a combined fire-retardant-preservative treatment that contains boric acid, zinc chloride, copper sulfate, and sodium bichromate. Although decay results were favorable, the treatment was not leach-resistant. Purushotham and others (1963) found that a mixture of monoammonium phosphate, boric acid, zinc chloride, copper sulfate, and sodium bichromate had both good fire performance and decay resistance, but again leaching was a problem. Dev and Kumar (1982) attempted to fix a combined fire-retardant-preservative treatment (monoammonium phosphate, boric acid, zinc chloride, copper sulfate, and sodium bichromate) in the wood by exposure to a gaseous reagent. This reduced the amount of chemical that leached from the wood, but the fire performance was still less than desired.

Gyarmati and others (1975) combined ammonium sulfate, diammonium phosphate, borax, and sodium fluoride for use as a fire-retardant-preservative, but leach resistance was not addressed. Ermus and others (1977) found that a mixture of cupric sulfate, borax, ammonium sulfate, and boric acid imparted decay resistance to wood and gave good fire performance as a result of the supposed formation of insoluble copper berates.

Juneja (1972) developed a leach-resistant fire retardant consisting of urea, dicyandiamide, phosphoric acid, and formaldehyde (UDPF) in a molar ratio of 1:3:4:8. Juneja and Shields (1973) found that this fire retardant offered decay resistance to yellow birch strips against *Lenzites trabea* when the retention was 14.2%. Despite the fact that UDPF was heat cured to fix the resin in the wood, leaching was still a problem. Juneja and Calve (1977) examined the effect of curing on the leachability of UDPF and found that even at very high curing temperatures (302°F (l50°C)), >70% of the phosphorus and >50% of the nitrogen impregnated in the wood was lost as a result of leaching. A major problem is that the phosphoric acid is not bound in the polymer itself but is only associated with the polymer through an ionic bond.

LeVan and Holmes (1986) evaluated several fire retardants for exterior use and found that UDPF-treated shingles suffered from reduced fire performance after 5 and 10 years of outdoor weathering. The UDPF-treated shingles did not suffer from burning brand failures, but the results of flame spread tests worsened over the course of exposure. LeVan and Holmes hypothesized that the fire performance would be reduced because the treated shingles had not been heat cured. Gardner and others (1983) examined wood treated with Pyroguard H[1] (a mixture of UDPF and a proprietary preservative additive) and found that some leaching did occur, especially of phosphorus. Alexiou and others (1986) concluded that Pyroguard H was an effective fire retardant in boards of *Pinus radiata.* Unpublished work performed at the FPL supports the leaching of phosphorus from UDPF-treated wood, regardless of the curing time and temperature (Sweet and Tran, in preparation).

Advances have been made in the area of deposition of insoluble inorganic compounds. Wood has been treated with a cation-containing solution and then an anion-containing solution that forms insoluble products that precipitate in the solid wood. Yasuda and Ota (1987) treated wood with a calcium chloride solution, then a sodium hydroxide solution, to form insoluble calcium hydroxide. The wood was then treated with sodium aluminate and sodium sulfate to precipitate the mineral known as ettringite ($Ca_{12}A1_{24}(OH)_{24}(S0_4)_6.5H_20$).

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[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

This precipitate is insoluble, and Yasuda and Ota claim that the treated wood showed good resistance to insects and had good fire performance. Hirao and others (1987) claimed good fire performance by treating wood with calcium chloride and then sodium carbonate, thus precipitating calcium carbonate in the wood. Ota and others (1988) treated wood with barium chloride and then diammonium phosphate, precipitating dibasic barium phosphate. The authors claim that the treated wood showed good fire performance and resistance to insects. Wood strips were treated by Ishikawa and Adachi (1991) with a barium chloride and boric acid solution. The wood was then impregnated with a diammonium phosphate and boric acid solution, and finally bonded together with a water-resistant adhesive. Ishikawa and Adachi claim the resulting product had good fire performance and was termite resistant.

Current Research

The wood shake and shingle industry has traditionally used western redcedar as the source for their products. As western redcedar has become unavailable, interest has arisen in using less durable wood for shakes and shingles. As a result of concern over the potential contribution of untreated shakes and shingles to spreading a fire, a combined fire retardant-preservative treatment would address both issues. A study is currently underway at FPL to find preservatives that are compatible with leach-resistant fire retardants. Fourteen preservatives have been tested for compatibility with eleven fire retardants. Most combinations have been incompatible. Of the compatible combinations, the most promising combination has consisted of an amino resin fire retardant and a patented, commercially available preservative. This combined system is currently in the patent application process, and a full ASTM E108 fire test is planned for the spring of 1992. If the results of the fire test are satisfactory, the combined system will be licensed to a company that is ready to market the product.

outlook

The use of a combined fire-retardant-preservative system would be of great value for almost any exterior use of wood where there is concern over the potential contribution of the wood to spreading a fire. A sizable percentage of the 321 million board feet (770,400 m^3) of preservative-treated lumber produced (1987 data) could be treated with a combined system. The most promising approaches are in *situ* deposition of insoluble inorganic compounds and organic polymers that include nitrogen and phosphorus in the polymer chain.

Other developments that may create a demand for combined fire-retardant-preservative systems are new specifications for fire-rated shingles and other wood products, environmental concerns about some existing preservatives and fire retardants, and the growing demand for knowledge about wood species that are not decay-resistant.

CONCLUDING REMARKS

Wood and wood products are important building materials in both residential and nonresidential construction. For most applications, wood does not need to be treated for flame retardancy. For applications where a higher level of fire safety is desirable or necessary, fire-retardant-treated (FRT) wood or wood products provide a viable alternative to traditional noncombustible materials. Despite the current problems involving FRT plywood roof sheathing, the need for flame-retardant wood products will continue in the 1990s. There are significant potential markets for-combined fire-retardant-preservative treatments and fire-resistive coatings. To improve the effective utilization of our wood resources, the Forest Products Laboratory will continue its active research program in developing, evaluating, and improving fire protection technologies for wood and wood products.

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