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Choosing and Applying Fire-Retardant-Treated Plywood and Lumber for Roof Designs

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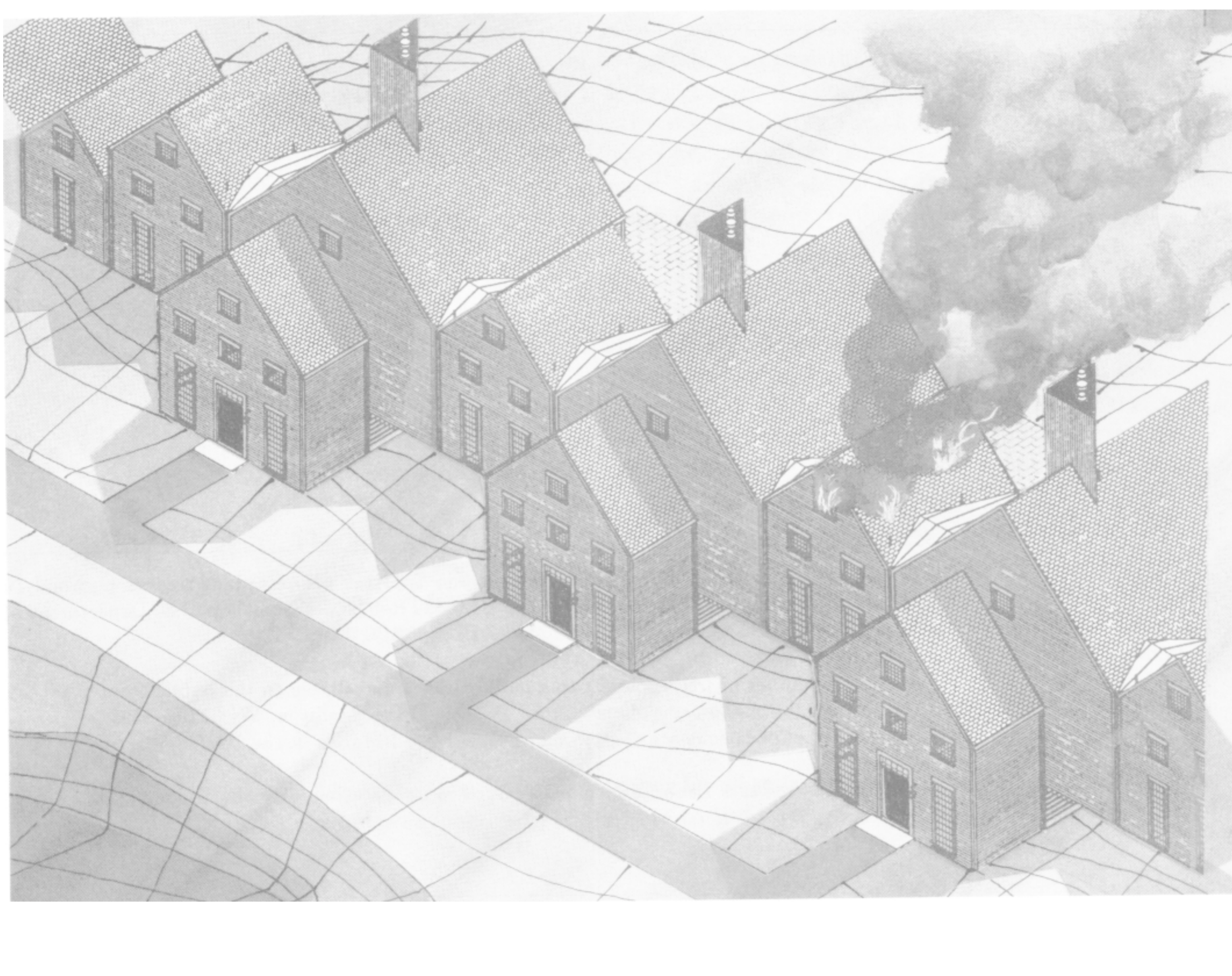

Abstract

Fire-retardant-treated (FRT) plywood used as roof sheathing has exhibited strength degradation in some situations. The cause appears to be certain fire retardant chemicals that are activated under environmental conditions of high temperature and moisture content. This report describes how fire retardants are made, how they work, and what causes strength degradation of FRT wood. We present guidelines for selecting and using FRT wood and precautions to follow when designing roof systems with FRT plywood.

Keywords: Degradation, strength, flammability, moisture, plywood, fire retardant, roof

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Introduction

For certain applications, building codes and insurance companies permit fire-retardant-treated wood to be used as an alternative to noncombustible materials. Fire retardants drastically reduce the rate at which flames travel across the wood surface, thereby reducing the capacity of the wood to contribute to a fire.

In some situations, the use of fire-retardant-treated (FRT) plywood as roof sheathing has resulted in a problem: the wood loses strength through thermal degradation. Although available information indicates that the frequency at which this problem occurs is low in relation to the volume of FRT material in use, it also indicates that significant degradation can occur with some fire-retardant-treatment formulations, in specific installations, and under the right conditions. The combination of elevated temperatures caused by solar radiation, type of fire retardant chemicals, and moisture can prematurely activate the fire retardant to do what it is designed to do: lower the temperature at which thermal degradation occurs, thereby increasing the char and reducing the production of flammable volatiles. These chemical changes, which occur at temperatures lower than those at the roof covering-sheathing interface, are responsible for the strength degradation of FRT plywood used as roof sheathing.

Background

In the worst cases, roofs made with FRT plywood have required replacement. In these cases, the wood had darkened, was very brash and brittle, and crumbled easily. For the severely degraded roofs brought to our attention, service time has ranged from 3 to 8 years. The publicity generated from the problem has raised serious questions about the causes and extent of wood degradation.

The magnitude of wood degradation depends on the particular fire retardant formulation used, the temperature levels attained in the roof system, and the presence of moisture. To select and use treated material appropriately, the consumer must know how a fire retardant treatment works, what chemicals are likely to cause wood degradation, and what factors contribute to the problem.

Objectives of Report

The aim of this report is to describe what is known about FRT plywood and the variables suspected to contribute to the strength degradation of treated wood.

This report describes

1. fire retardant treatments and their mechanism of action,
2. factors causing strength degradation of FRT wood,
3. research in progress on characterizing the degradation of FRT wood, and
4. guidelines on the selection and use of FRT plywood in the design of roof systems.

Fire Retardants and Their Mechanism of Action

Composition and Application of Fire Retardants

Chemical Constituents — The fire retardant treatments most commonly used for wood are combinations of inorganic or organic salts. Inorganic salts commonly incorporated in such treatments are monoammonium phosphate, diammonium phosphate, ammonium sulfate, ammonium polyphosphate, borax, and boric acid. A commonly used organic salt is guanylurea phosphate (LeVan 1984). These salts are cost effective and can be easily pressure impregnated into the wood; they are usually combined in various ways to improve the fire retardant formulation.

Because fire retardant treatments are proprietary formulations, their compositions are not published. For wood, most fire retardant formulations involve combinations of phosphorus- and nitrogen-containing compounds, which produce the greatest amount of fire retardancy with the least amount of chemical. Thus, compounds like ammonium phosphates are particularly effective.

Various chemicals are often added to the basic formulation of a fire retardant treatment to improve a particular attribute of the treatment. For example, some formulations may be buffered with borax to reduce the acidity of the treating solution, or substances such as corrosion inhibitors, stains, or mildewcides may be added.

Several companies manufacture commercial fire retardant formulations, and some manufacturers have many licensees. The chemical formulations of all fire retardant treatments, though proprietary, are on record with third-party inspection agencies.

Application — Wood must be impregnated with fire retardant chemicals as aqueous solutions to meet the approval of building codes in certain applications. The fire retardant chemicals are loaded into the wood at levels between 2.5 and 5.0 lb/ft^3 (4 and 8 kg/m^3), depending on the species of wood used and the intended application. For plywood, fire retardant treatments are impregnated into structural sheathing plywood manufactured under either PS 1–83 or the performance standard of the American Plywood Association (APA) PRP-108. These panels are bonded with adhesives qualified for exterior exposure. All treated wood should be dried after treatment to a moisture content of $\leq$ 19 percent for lumber and $\leq$ 15 percent for plywood in accordance with current American Wood-Preservers' Association (AWPA) standards C20 and C27 (AWPA 1987). Such material is designated as "kiln dried after treatment" (KDAT).

Mechanism of Action

Fire retardants work by altering the combustion chemistry of wood. They reduce the flammability of wood by (1) reducing the rate at which flames travel across the wood surface, thereby eliminating progressive combustion, and (2) reducing the rate of heat release. When FRT wood is subjected to high temperatures, the fire retardant chemicals lower the temperatures at which thermal degradation occurs, thereby directly altering the pyrolysis of wood, increasing the amount of char and reducing the amount of volatile, combustible vapors (LeVan 1984).

The best fire retardants for wood are acidic in nature. The acids catalyze the hydrolysis of carbohydrates to produce more char and less flammable volatiles. In tests with 21 different compounds, phosphoric acid was the most effective in reducing the amount of volatiles and increasing the amount of residual char, followed by mono- and diammonium phosphate and zinc chloride (Shafizadeh 1984).

Some wood species are more sensitive to acids than others. Softwoods are generally more chemically resistant to acids than hardwoods. Thus, to minimize the strength loss caused by acid hydrolysis, FRT plywood should always consist of soft wood veneer.

Types of Fire Retardants

Both interior and exterior fire retardant treatments are available. Most plywood is treated with Type A or Type B interior-type fire retardant formulations. These two kinds of treatments are categorized by their hygroscopicity (tendency to absorb moisture from the air), as measured by American Society for Testing and Materials (ASTM) standard test method D–3201, "Hydroscopic Test Properties of Fire-Retardant Wood and Wood-Base Products" (ASTM 1987). Type A FRT plywood is intended for use in environments where the relative humidity is less than 95 percent and where the wood is not exposed to weather, direct wetting, and recurrent condensation. Type B FRT plywood is intended for use in areas where the relative humidity generally does not exceed 75 percent (or where the equilibrium moisture content of untreated wood does not exceed 15 percent).

Exterior fire retardant treatment is classified by the fire performance of the treated wood after it is subjected to an accelerated weathering test, as measured by ASTM D–2898A (ASTM 1987). Exterior FRT plywood is used when the wood may be exposed to weather, direct wetting, recurrent condensation, or relative humidity of 95 percent or more or in any environment where high resistance to the leaching effects of moisture is desired.

Evaluation of Fire Retardants

Tests for Fire Performance — Third-party certification agencies evaluate fire retardants for fire performance. The primary test for evaluating fire performance is ASTM E–84, a 25-ft (76.2-m) tunnel flamespread test (ASTM 1988). All FRT

Table l—Standards for determining mechanical properties of plywood

ASTM test method [a]	Mechanical property	Reapproval date
ASTM D-2718-76	Rolling shear [b]	1986
ASTM D-2719-76	Shear through thickness	1981
ASTM D-3043-76	Flexure	1981
ASTM D-3044-76	Shear modulus	1986
ASTM D-3500-76	Tension	1986
ASTM D-3501-76	Compression	1986

[a] ASTM 1987.
bin-plane shear of plies.

plywood should bear an identification mark indicating flamespread classification, which is issued by the approval agency. To be classified as fire retardant, any wood product, when impregnated with chemicals by a pressure process, shall have a flamespread index of 25 or less when tested in accordance with ASTM E-84, "Standard Test Method for Surface Burning Characteristics of Building Materials" (ASTM 1988). For comparison, the flamespread and smoke index for noncombustible ceramic fiberboard is 0 and that for solid red oak panels is 100. For FRT material used in structural applications, the test is extended an additional 20 min, and material must show no significant progressive combustion and have a smoke-developed value of less than 25. In addition, the standard stipulates that the flame front of the treated wood shall not progress more than 10.5 ft (32 m) beyond the centerline of the burner at any time during the test.

Tests for Strength — Third-party agencies that evaluate fire performance do not evaluate FRT wood for strength properties. Strength properties for lumber under normal environmental conditions are determined using ASTM D–198–84 and ASTM D–4761–88. The standards for determining mechanical properties of plywood are listed in Table 1. The APA (1982) supplies span ratings for various grades of untreated plywood. The National Forest Products Association (NFPA) (1986) lists design values for untreated lumber in the National Design Specifications (NDS).

In the past, the NDS required a general 10-percent reduction in design stresses for FRT structural lumber relative to those for untreated lumber. After the new fire retardant chemical formulations with low hygroscopicity (Type A treatments) were introduced in the late 1970s and 1980s, the appropriateness of the generic 10-percent reduction was assessed. Subsequently, the generic factor was replaced with different adjustments, ranging from 0.80 to 0.90 depending on the performance property, for qualifying treatments. The NDS now states that FRT structural lumber "shall be assigned design values equal to the product of the adjustment factors in Table 2A and the design values otherwise permitted in this Specification when such lumber is identified by the quality mark of an approved inspections agency" (NFPA 1986). Appendix Q of the NDS provides a basis for assigning design values for lumber pressure-impregnated with fire retardant chemicals.

Prior to 1983, the APA recommended reductions of one-sixth and one-tenth in plywood design values for strength and stiffness, respectively, when FRT plywood was used. The APA currently recommends that design values for FRT plywood be obtained from individual FRT plywood treaters.

Uses of Fire-Retardant-Treated Wood

Fire retardant chemicals have been used for over 80 years to reduce the flammability of interior paneling, scaffolding, and dimension lumber and wood products used in the construction of military buildings and on naval ships (Eickner 1966). Use of these treatments for wood shakes and shingles is a more recent application. Certain building codes require or allow the use of FRT lumber as an alternative to noncombustible materials for walls and partitions. In 1960, some codes began to allow the use of FRT wood for roof sheathing and roof structural framing in certain types of building construction; previously, the use of noncombustible materials had been mandated for these roof applications.

Today, a major use of FRT plywood is as roof sheathing in multifamily dwellings at party-separation walls. In dwellings such as townhouses and condominiums, some building codes allow the use of 4 ft (12.2 m) of FRT plywood as roof sheathing at the party-separation wall in lieu of a fire-rated parapet extending above the roof line. The Building Officials and Code Administrators (BOCA) International provided for this substitution in 1979 and the Southern Building Code Congress, International (SBCCI) in 1982. Since then, the use of FRT plywood as a substitute for the parapet wall has increased dramatically. As this use has grown, reports of strength failures have increased. Most such failures have involved the new low-hydroscopic (Type A) treatments, the type of fire retardant treatment most commonly used since 1982. However, that most failures involve these new treatments may be only coincidental. Concomitant to the time the reformulations were implemented, the building codes allowed the substitution of FRT plywood for the parapet wall.

Using FRT wood has both advantages and disadvantages. The FRT wood is lightweight and economical. It can be cut and sized on site, easily nailed and refinished, and easily transported. The FRT wood has increased fire performance qualities. However, depending on the chemicals used, fire retardant formulations may increase the equilibrium moisture content of the wood and reduce the strength properties. Some chemicals corrode met al fasteners. As explained earlier, some chemical effects are activated at high temperatures and moisture levels and cause significant strength loss of the wood.

Causes of Strength Degradation of Fire-Retardant-Treated Wood

Problem

Under conditions of elevated temperature, some FRT wood many undergo acid hydrolysis (S. LeVan and J. Winandy, “Effects of fire retardant treatments on wood strength: A review.” In preparation.). Several signs can indicate wood degradation in structural applications: the wood may become brash, brittle, and crumbly and it often darkens; the roof may sag and appear uneven. When FRT plywood is used in conjunction with untreated plywood, the treated wood often appears darker. However, brown-rot fungi also cause wood to darken. The only way to distinguish between the effects of fungal decay and fire retardant degradation is to analyze the wood for the presence of fungal mycelia.

The majority of reported cases of strength degradation occurred when FRT plywood was used as roof sheathing. All codes allow FRT plywood in roofs of buildings where wood construction is permitted. However, FRT plywood has generally been used as a substitute for a parapet wall between attached multi-family units. Other locations include institutional buildings, such as nursing homes, schools, and prisons, where entire roof assemblies may be constructed of FRT wood and plywood. A few problems have been reported with trusses using FRT structural lumber in roof systems, but these cases have been infrequent and are under investigation. Because trusses are not likely to be subjected to the same severity of environmental conditions as roof sheathing, we expect that trusses would not undergo the same extent of strength reduction. However, because trusses do experience elevated temperatures, truss designers must be aware of the potential for degradation of FRT wood.

Variables Affecting Wood Degradation

Temperature — The increased sensitivity of some fire retardant formulations to elevated temperatures renders the wood more prone to failure if used in an environment of extreme temperatures. The strength and stiffness of wood decrease when wood is heated for long periods. The location and angle of the roof, plus the high absorptivity of most roofing materials, make the roof an ideal solar collector. As the roof covering collects solar radiation and holds this as heat, the surface temperature of the plywood sheathing rises. Temperatures can reach as high as 170°F (77°C) at the interface of the roof covering and roof sheathing (Heyer 1963). The sustained elevated temperatures that occur at the interface of the roofing material and plywood sheathing may activate the fire retardant mechanism.

Moisture — The role of moisture in the degradation of FRT plywood is uncertain. In general, thermal degradation of cellulose is accelerated by the presence of moisture (S. LeVan and J. Winandy, "Effects of fire retardant treatments on wood strength: A review." In preparation.). Excess moisture may accumulate in the wood during on-site exposure (wood left uncovered during construction) or be transferred from the interior of the building (from bathroom, kit then, and laundry facility). Because of seasonal variation, the moisture content of the wood may be higher in winter and spring. This may necessitate the use of additional ventilation to ensure adequate airflow to control excess moisture in the attic or roof plenum when FRT materials are used. Roof sheathing usually experiences the lowest moisture content during summer and the highest during winter. However, the relatively short period during which high temperatures and moisture conditions occur can have a synergistic accelerating effect on the rate of degradation.

Fire Retardant Chemicals — Some chemicals initiate acid hydrolysis at lower temperatures than do other chemicals. Past research on individual fire retardant chemicals showed that the temperature at which degradation begins depends on the type of chemical (Tang 1967). Degradation was initiated at the lowest temperature for wood treated with monoammonium phosphate ($NH_4H_2PO_4$) and at the highest temperature with sodium borax ($Na_2B_4O_7$). Monoammonium phosphate caused the most residual char and aluminum chloride ($AlCl_3$) the least. This implies that strength degradation probably occurs with only a few chemicals–those that have not been buffered and have the potential to produce acids under conditions of high temperature and moisture content. However, we do not have enough data to identify which chemicals are the culprits in the current cases of degraded FRT plywood.

The combination of chemicals (such as combinations that buffer the treating solution or encapsulate the fire retardant chemical) can alter the pH and acidic strength of the treating solution while retaining the effectiveness of the fire retardant chemical. Again, we do not yet know which combinations affect strength in the presence of elevated temperatures.

Research on Fire Retardants

Substantial research is underway to more fully understand the reaction of fire-retardant-treated wood in various environments over time. Research at Forest Products Laboratory is aimed toward identifying the failure mechanisms of FRT wood, chemicals that contribute to wood degradation, temperature levels at which degradation occurs, influence of moisture content, correlation between these factors and the rate of degradation, and effect of cyclic exposure of wood. We are currently testing approximately 7,000 specimens to learn the effect of six generic fire retardant chemicals and various environmental exposures (four temperature levels, two moisture content levels, and eight exposure periods) on the mechanical properties of the wood. Tests include static bending, chemical analysis, and nondestructive evaluation using sound transmission. We anticipate that some research results will be available by fall 1989 and additional exposure data by fall 1990. Member companies of the National Forest Products Association are studying a methodology for evaluating the effect of fire retardant treatments on the mechanical properties of wood at elevated temperatures and moisture contents. This evaluation is expected to be completed by summer 1989. Information obtained from these studies will provide a basis for a test protocol for obtaining information on the strength reduction characteristics of FRT plywood subject to high temperatures and moisture contents. We anticipate that a taskforce of ASTM Committee D–7 on Wood (D 07.06.04) will develop a test standard based upon these research efforts.

In addition, the National Association of Home Builders has established a taskforce to apprise its members of the problems encountered with FRT plywood, to provide legal assistance, and to disseminate research information as it becomes available.

Guidelines for Using Fire-Retardant-Treated Plywood

Design Considerations

Architects, design engineers, builders, and others must be aware of the potential problems of using FRT wood in severe environments. Specific design considerations include adjustments for temperature limitations, provision for adequate ventilation, and knowledge about the product, namely fire-retardant-treated wood.

Temperature — Design value adjustments for FRT wood are applicable to wood members used under normal ranges of temperatures and occasionally heated in use to temperatures up to 150° F (660 C). These adjustments are in addition to design value adjustments for temperature effects for untreated or treated wood used at above-ambient temperatures. The design specifications do not recommend that wood structural products be used in environments above 150°F (66°C).

Elevated temperatures caused by solar radiation can affect the performance of roofing materials. Reflective roofing materials absorb considerably less solar radiation than do absorbant materials, such as dark asphalt shingles. Shade can also significantly reduce the absorption of solar radiation.

Ventilation — Ventilation is essential in all construction to minimize excess relative humidity and to prevent condensation and moisture buildup. Good ventilation helps control the moisture content of roof systems. Because moisture cannot be flushed out of a roof plenum in the absence of air movement, ample intake and exit venting must be provided. Blockage of intake and exit vents by insulation must be avoided or corrected. Insulation that is attached directly to the roof sheathing or in close proximity prevents air movement and reduces the elimination of moisture from the sheathing.

Job-Site Precautions

All FRT wood for use in enclosed construction should be protected from wetting during storage and construction. The wood should be stored off the ground and under a roof or a waterproof cover that permits air to circulate under the stack. If the wood is wetted during construction, it should be permitted to dry before enclosure within the structural assemblies.

Normal carpentry practices apply to FRT wood: cutting, drilling, joining, and on-site sawing will not affect the surface-burning characteristics of the wood. However, lumber should not be ripped and milled on the job site since these processes may alter the surface-burning characteristics of the treated wood. Plywood can be cut or ripped without altering surface-burning characteristics.

Common sense should govern the handling of FRT wood. Dust masks and eye protection are recommended, and gloves will minimize the hazard of splinters. Those who handle FRT wood should not touch their face during use and should wash their hands after use.

Questions to Ask About Fire-Retardant-Treated Wood Products

Builders and others must make informed decisions on the use of FRT wood products. As we indicated, problems can occur in environments of high temperature and moisture content. Therefore, in selecting FRT wood, builders and designers should ask the following questions:

1. What temperatures and relative humidity (or moisture content) levels are expected in the application?
2. Can the exposure temperature and in-service moisture content of the product be minimized (for example, by using shade, using light-colored roofing materials, and increasing ventilation)?
3. What are the strength value reductions, if any, of individual fire retardant formulations for extended periods at expected temperatures and moisture contents?
4. Has a particular FRT product experienced strength degradation at expected temperatures and moisture contents?
5. Was the FRT wood dried to appropriate end-use moisture content at appropriate kiln temperatures?
6. Was the FRT wood protected from moisture on the job site until the building was closed in? If not, is a deliberate redrying period being provided before the FRT wood is sealed?
7. What are the recommended specifications of the FRT suppliers regarding types of fasteners and installation and serviceability of the wood?

In addition to these questions, two issues deserve special discussion. First, Should FRT wood be used in trusses, rafters, and other critical support members? Second, What should be done about FRT plywood or lumber already in use?

FRT Wood in Trusses and Rafters — Critical items for specifying FRT wood for trusses are similar to those for plywood. Certified design values for strength and corrosivity levels for given environmental conditions must be available from the fire retardant treatment producer or FRT wood supplier. The designer or builder must be able to characterize and control the environment in which the FRT wood will be used. In addition, the designer must be knowledgeable about the temperature and relative humidity ranges to be encountered and must design for control of these factors as needed.

A specific fire retardant should be avoided if the FRT wood manufacturer fails to supply information about the performance of the wood in a given situation. If knowledge of the acceptable performance of a particular FRT product over time is uncertain, we advise that the consumer choose another product or another way to provide fire protection (e.g., sprinkler, gypsum board).

FRT Wood Already in Use — If the structure has been designed and built to current specifications and the environment (temperature and relative humidity) is within specifications for FRT wood, the performance of the structure should be acceptable. However, if the environment is not within the specified range, the chance of degradation is greatly increased. In this case, the FRT product should be inspected regularly and frequently. If evidence of strength degradation exists, the FRT product should be replaced and steps taken to modify the environmental effects.

Concluding Remarks

Problems can arise when fire-retardant-treated wood is used as roof sheathing. Fire retardants are designed to lower the temperature at which thermal degradation occurs. This mechanism can be activated by elevated temperatures caused by solar radiation in combination with certain types of fire retardant chemicals and moisture. The resultant chemical changes are responsible for the strength degradation of the wood.

The consumer should make an informed decision about the use of FRT wood products. Knowledge about the strength properties of FRT products should be related to the final application and environment of the products. This approach can help circumvent the problems associated with FRT wood.

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Sources of Additional Information

Fire Retardant Treated Wood/
Chemical Manufacturers Council
7297 Lee Highway, Unit P
Falls Church, VA 22042
(703) 237-0900

Forest Products Laboratory
USDA Forest Service
One Gifford Pinchot Drive
Madison, WI 53705-2398
(608) 264-5673

National Association of Home Builders
15th and M Streets, NW
Washington, DC 20005
(800) 368-5242

National Forest Products Association
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Also contact individual companies that manufacture FRT plywood.

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