

# DEGRADATION OF FIRE-RETARDANT-TREATED PLYWOOD: CURRENT THEORIES AND APPROACHES

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**P**remature deterioration of plywood roof decking which has been treated with fire-retardant chemicals has rendered roofs across the United States structurally unsafe and has catapulted cost estimates for potential damage and replacement of damaged plywood into the billions of dollars (U.S.). The historical and economic development of chemical formulations, building code allowances and cost-saving alternatives to parapet wall construction in multifamily dwellings has dramatically increased the production and usage of fire-retardant-treated (FRT) plywood since 1982. At the same time, industry practices and inherent shortcomings in FRT plywood design may have spurred the proliferation of FRT problems which manifest themselves after the fact.

Documented evidence indicates that certain FRT plywood roof sheathing suffers ominous reductions in strength and performance within several years of installation in the typical environmental exposures of a roof. Many factors—including chemical selections, treatment processes, job-site precautions, ventilation and insulation provisions, humidity and moisture considerations—may come into play.

Initial test results, preventive measures, prescribed alternatives and innovative building code responses are already in development.

## KEYWORDS

Acid-catalyzed dehydration, fire retardants, kiln drying, multifamily dwellings, plywood, strength, thermal degradation.

## INTRODUCTION

A roof over one's head is an accepted requirement of rudimentary living and a symbol of security and protection. The basic integrity of sloped roofs is rarely questioned by the average property owner unless leakage develops or energy considerations exist. The possibility of roofs actually failing is seldom contemplated. The advent of plywood roof decking treated with certain fire-retardant chemicals has altered the focus. On many properties these roofs can no longer be expected to sustain a person's weight, a heavy snow, or even normal design loads. Heralded as a cost-effective safety measure, some fire-retardant-treated (FRT) roof decking has actually become a safety hazard. The National Associa-

tion of Home Builders (NAHB) reported<sup>1</sup> that "by mid-1988 it became apparent that a large scale problem was developing with FRT plywood roof sheathing that was deteriorating to an unsafe condition within several years" of installation. Their findings concluded that the problem "poses unknown hazards in terms of plywood durability and strength." In fact, premature deterioration of plywood roof decking which has been treated with certain fire-retardant chemicals has rendered roofs across the country structurally unsafe, and has catapulted cost estimates for potential repair/replacement of damaged plywood into the billions of dollars (U.S.).<sup>2</sup>

## HISTORICAL AND ECONOMIC DEVELOPMENT

The United States military was among the first to use FRT plywood. Initially used over 80 years ago in military buildings, blimp hangars and naval ships, the plywood was originally treated to impart a degree of flame resistance by altering the combustion process of the wood to curtail flame spread.

Chemical formulations changed over the years, due to many technical and economic forces. By the late 1970s and early 1980s, FRT wood was an acceptable alternative to non-combustible construction in certain applications. These developments spurred greater demand and wider acceptance for FRT plywood. By the early 1980s, FRT use in the United States increased dramatically as a result of a variety of these factors.

As early as 1960, various building codes began to allow for the substitution of FRT plywood for noncombustible materials in roof sheathing and roof structural framing. FRT plywood later became recognized as a viable alternative to parapet walls in the provision of fire breaks at the roof in conjunction with fire-separation walls in multifamily dwellings. Beginning in 1979, changes were made in various building codes to provide for such use.

FRT plywood roof sheathing used in lieu of parapets was eventually sanctioned by almost all model building codes (with the exception of the Uniform Building Code), which typically specify FRT for a minimum width of 121.92cm (4 ft.) on each side of fire-rated walls and for 60.96cm (2 ft.) on each side of chimneys in multifamily dwellings. The usage

of FRT offered a less-costly alternative to parapet wall construction. It also helped to avoid leakage-related maintenance problems, aesthetic drawbacks and design limitations of parapet wall usage. The FRT was lightweight and could be cut and sized on the job site; it could also be easily nailed, refinished and transported.

Widely accepted by the building industry, FRT plywood used as roof sheathing has been primarily used in the eastern half of the United States in areas governed by the Standard Building Code, the Basic National Building Code or the One and Two Family Dwelling Code. Predominantly employed as roof sheathing in attached townhouses and apartments, it has also been used under certain local codes in some single-family dwellings (such as those located with 152.4cm (5 ft.) of another residence).

The American Plywood Association (APA) is on record as becoming aware of premature failures for the first time in 1986.<sup>3</sup> However, reports indicate that some knowledgeable persons in the FRT industry were aware of a potential problem as early as 1983.<sup>4</sup> In recent years, there have been known incidences of workmen being badly hurt while fixing deteriorated areas. As of 1989, the NAHB reported that some FRT plywood had deteriorated within only a few years of installation to the point that it would not support the weight of a person.

The NAHB reported that approximately 34,875,000 square meters (375,000,000 sq. ft.) of potentially defective FRT plywood roof sheathing 0.9525cm (3/8 in.) thick was used through the end of 1988. Estimated usage could exceed 55,800,000 square meters (600,000,000 sq. ft.) As a result, over one million dwelling units could be affected at a minimum repair cost in excess of \$2,000 (U.S.) each.<sup>5</sup>

### THE MECHANISM OF FIRE RETARDANCY

Chemical processes throughout the fire-retardant wood industry utilize the same basic technical philosophy. Chemicals are pressure-impregnated into the wood to alter the wood's combustion chemistry in an attempt to prevent flaming combustion. The end result is intended to cause the wood to char (turn to charcoal) without flame spread, and to reduce the release of heat and volatiles (combustible vapors) from the material. Fire retardants reduce the rate at which flames travel across the wood surface, thereby reducing the capacity of the wood to contribute to a fire.<sup>6</sup>

The choice of chemicals can substantially alter performance and resultant benefits or detrimental side effects. Acidic materials appear to be the most effective in achieving the desired level of fire retardancy. Phosphates and sulfates also work well and are generally cost effective. Inorganic salts are the most common chemicals used for fire-retardant wood.<sup>7</sup> Softwood veneers are preferred since they are generally more chemically resistant to acids than hardwoods and can help to minimize strength loss in the treated wood.

### SHORTCOMINGS IN DESIGN—THE DEGRADATION PROCESS

Problems became evident early on with the rusting of nails and corrosion of other metal fasteners used in FRT wood. As a result, the usage of ammonium sulfates was discontinued. Subsequently, ammonium phosphate salts became the basis of most treatments. Organic compounds were then ad-

ded in an effort to lock the salts into the wood structure and raise the threshold temperature at which the fire-retardant degrading reaction begins. Buffering was employed to neutralize the acids as they were formed.

Documented evidence now indicates that certain FRT plywood roof sheathing suffers from severe strength loss and deterioration within several years of installation in the typical environmental exposures of a roof.<sup>8</sup> Reports of strength failures have shown a marked rise since the increase (through code revisions) in FRT plywood usage in lieu of parapet walls and the common application of new low-hygroscopic treatments in the early 1980s.

Deterioration of the FRT plywood is visually recognizable. Interior views of attic spaces have confirmed that the underside of the wood darkens significantly (see Figure 1). A characteristic dark, reddish-brown, charred appearance is often evident. Although quite similar to the visual characteristics of rot, tests have confirmed that no fungi are present. Such discoloration is even more apparent on the top side of the FRT roof sheathing which is covered by the roof shingles. This darkening is often accompanied by localized white staining caused by the accumulation of fire-retardant chemicals, such as salts.

Severe deck deflections (warpage) are often apparent within a few months of installation (see Figure 2). The roof may sag, appear uneven and actually buckle in waves. Physically, the wood appears brittle and delaminated. It may become brash and crumbly, and can crack or shear when stressed. Audible cracking (which has been likened by fire department officials to "walking on potato chips") is often apparent under foot traffic.

The chemical actions that initiate fire retardancy at higher temperatures also appear to be responsible for degradation of the plywood at lower temperatures. In essence, it appears that elevated temperatures may actually activate the chemical process designed to resist flame during fire. These elevated temperatures occur either when the FRT plywood is kiln dried after application of the chemicals and/or when the FRT plywood is exposed to elevated temperatures existing in attic spaces as well as between the plywood roof sheathing and the shingles.

Chemicals (such as phosphoric acids) are released from the treated wood. This acid-catalyzed dehydration reaction results in destruction of some of the carbohydrates (one of the chemical constituents of the wood), severely degrading the wood over time—often to the point at which it cannot retain sufficient strength for the life of the structure. The acid-catalyzed dehydration reaction can substantially reduce (below accepted design/code standards) the safety and stability of the roofs within a few years of construction. In addition, the degraded strength, including fastener pullout resistance, of the charred plywood can cause and/or contribute to roof leakage problems. As an example, warpage of the deck can lift the shingles, allowing water to enter under them. Wind can also get under the lifted shingles, causing shingle blow-off.

As an example, visual examination of untreated plywood roof sheathing indicates that no major problems are generally observed in environments manifesting temperatures of approximately 93.3°C (200°F). However, recent analyses indicate ominous reductions in the flexural (bending) strength and performance of some FRT plywood sheathing. As an example, strength reductions over time of 50 percent and

more have been reported at 82.2°C (180°F) by the U.S. Forest Products Laboratory.<sup>9</sup>

In recent field investigations of an FRT problem,<sup>10</sup> reductions of as much as 90 percent and more were noted in the flexural (bending) strength of FRT plywood sheathing which was in place for a period of less than five years. Data was provided that, while the ultimate rupture stress for untreated Southern Yellow Pine can be expected to be near 702.2 kg/cm (10,000 psi), fire-retardant-treated Southern Yellow Pine in this instance exhibited rupture strength of as little as 70.2 kg/cm (1,000 psi) and less within that short time span. Such sheathing could be expected to be brittle and subject to fracture under relatively small live loads on a roof deck and to be especially weak when subject to concentrated loads such as foot traffic.

Strength reductions and material degradations may be even more dramatic in installations using FRT plywood which might have been treated and dried quickly (at high temperatures) by the treaters. These drying practices which might have been employed to meet growing demand may possibly result in material damage within a few months of exposure within the roof environment.

The Forest Service of the United States Department of Agriculture (USDA) has performed ongoing research through its Forest Products Laboratory in Madison, Wisconsin. In an attempt to simulate the in-place conditions of a roof system over a period of several years, testing of thousands of samples of various FRT chemicals has been performed after exposure at varying temperatures and relative humidities.

Although it appears that initial strength loss of the FRT plywood begins with the treatment (and subsequent drying) of the plywood, various factors can serve to accelerate the ongoing process.

Degradation appears to increase as temperature increases. As an example, at 82.2°C (180°F), it appears that organic acids experience a longer delay in activation. For the influence of various fire-retardant chemicals at various temperatures, refer to Forest Products Laboratory, research paper 498.<sup>11</sup>

High temperatures related to solar gain may be involved. The temperatures at the interface between the shingles and roof deck can be in excess of 76.7°C (170°F). Minimal (or nonexistent) ventilation or dark-colored shingles can exacerbate this condition. Dark (especially black) shingles are solar collectors which naturally absorb more heat. Since ventilation requirements in building codes were established to control moisture, not heat, there is also some concern that these ventilation requirements may not be sufficient to adequately reduce plywood temperatures and, therefore, may be inadequate to assist in preventing the FRT plywood degradation process.

The amount of heat transferred to the deck can be increased in cases where felt is not installed between the shingles and deck, or where insulation or radiant barriers are improperly placed against the underside of the deck. Minimal attic space ventilation, minimal shade, and the particular location or angulation of the roof deck may result in greater heat absorption. The rate of thermal degradation may also be accelerated by the presence of moisture, although its role in the process is uncertain and appears to be minimal at best.

## INDUSTRY STANDARDS AND GUIDELINES

FRT plywood is produced through a process similar to that employed by the wood preservative treatment industry. However, while the preservative industry is subject to well-established standards and procedures, there are minimal FRT guidelines. These guidelines include flame-spread certification and American Wood Preservers Association (AWPA) standards (C20 and C27) for redrying.<sup>12</sup> Industry consensus standards for assessment of FRT performance under "normal" service do not exist. FRT formulations are proprietary.

Wood manufacturers produce the plywood. This plywood is certified to meet various requirements such as those of the American Plywood Association (APA) which is based in Tacoma, Washington. The material is marked to meet standards for structural performance and building code requirements.

The wood treaters purchase plywood from the manufacturer or other distributor. The material is then treated with the fire-retardant chemicals. Subsequently, the treated wood is kiln dried by the treater or is shipped to another company for drying. The finished product is treated for flame spread as well as smoke and volatile release to meet building code requirements. The standard agencies which support the testing methodology include the American Society for Testing and Materials (ASTM), the National Fire Protection Association (NFPA), Underwriters Laboratory (UL) and Factory Mutual (FM). However, agency evaluations of fire performance do not include evaluation of strength properties for the FRT wood. Even the APA currently recommends that design values for strength and stiffness of FRT plywood should be obtained from individual FRT plywood treaters.<sup>13</sup>

Moreover, manufacturers and treaters have long known that the initial strength of wood was reduced by the application of fire-retardant chemicals. Research has indicated that the typical application of these chemicals will result in a minimum strength reduction of between 10 to 20 percent.<sup>14</sup> As previously discussed, the percentage reduction in strength can increase dramatically in the case of certain, in-place, fire-retardant plywood roof sheathing.

Nonetheless, fire tests were consistently performed immediately after treatment and drying to confirm effective fire-retardancy at temperatures in excess of 204.4°C (400°F). However, historically, no long-term tests were performed at moderate temperatures (such as those found in routine application environments) to monitor ill-effects that may occur over time. While offering no means of pre-diagnosis before materials are typically applied, such practices spurred the proliferation of FRT problems which manifest themselves after the fact.

In 1987, the APA Board of Trustees formally withdrew its recognition of "interior fire-retardant treatment of any structural wood panel."<sup>15</sup> In fact, the APA has gone so far as to indicate that they will not renew recognition until a test protocol is established that will restore confidence in the long-term integrity of FRT pressure-impregnated treatments. It appears that they believe most FRT treatments will fail at different rates depending on thermal load and duration of exposure.

Nonetheless, at least one treater maintains that "it is the sole responsibility of the building owner or his agent . . . to

provide ample ventilation to control wood temperature and moisture content." The treaters contend that "the specifier should evaluate the acceptability of the product for each application."<sup>16</sup>

Treaters warn against using their product under conditions of inadequate ventilation, excessive humidity, and other "improper" design conditions. Some caution against exposure to direct wetting. Others state that certain FRT products are not to be used as roof sheathing directly under dark-surfaced roofs, in tropical or subtropical locations, or in structures in which excessive heat and/or moisture may be anticipated. Few actually define the temperature and humidity limitations.

Clearly, industry consensus standards and guidelines regarding service life performance testing and design criteria are needed.

### CORRECTIVE ACTIONS

Research and industry involvement appear to brighten the future for the FRT industry. The USDA Forest Service continues to perform in-depth research through its Forest Products Laboratory in Wisconsin. In addition, a committee has been established to develop a test method for evaluation of the problem. A protocol screening test method is being considered as an emergency standard by the ASTM. If accepted as such, a standard will then be in place for evaluating various treatments and will bring some needed consensus test standards to the industry.

Involved parties include the wood preservers, the American Plywood Association, the U.S. Department of Agriculture, the American Society for Testing and Materials, and the Building Officials and Code Administrators International (BOCA). The NAHB Task Force on Fire Retardant Treated Plywood has forwarded its appraisal of the problems encountered with FRT plywood and has disseminated available research information. Nonetheless, much remains to be done in formulating a national compendium of recommendations for the FRT industry.

On the local fronts, building authorities have also responded. In April 1989, building officials in Fairfax County, Virginia, imposed a ban on the use of FRT plywood products without proper certification (by a professional engineer) of their durability or integrity after application. Certain manufacturers have received acceptance of certain FRT plywood products after submission of appropriate technical data to county officials. The county has reportedly applied similar requirements to several other FRT lumber products. Officials have responded similarly in Florida. Prior to acceptance of an FRT product, the Palm Beach County Building Department also requires builders who use FRT to provide certified performance documentation.

### FIELD INSPECTIONS AND PREVENTATIVE MEASURES

All roofs suspected of having fire-retardant-treated plywood should be inspected by a professional who is familiar with the problem. Most of the roofs affected are between two and eight years of age. An inspection of these roofs should be made from both inside the attic space and on the roof deck. The urgency of inspection is clearly illustrated in a warning issued by one Maryland builder to its homeowners which advised "extreme caution" and recommends that no one get on the roofs until a thorough inspection has been completed.<sup>17</sup>

Certainly, if FRT plywood is present, reinspection should be performed every year. Problems should be monitored closely and all signs of deterioration documented. If the circumstances warrant, a qualified professional should obtain representative samples and perform strength tests. Microscopic examination and analysis may also be indicated.

Preventive measures are possible. As an example, the application of light-colored shingles may help to somewhat lessen the detrimental effects of heat on the FRT plywood roof sheathing.

Although attic ventilation may be but a secondary factor in the degradation process, preventative medicine in the form of improved ventilation is also highly recommended to reduce the attic temperature. Research indicates that a minimum of 0.30m<sup>3</sup>/minute per square meter (1.5 cfm per square foot) of attic floor should be provided.<sup>18</sup> Consideration should also be given to power ventilation equipment, such as fans.

At least one FRT manufacturer underscores the importance of adequate roof ventilation and proper insulation practices to prevent excessive wood temperatures (over 65.6°C or 150°F) in the roof sheathing/framing and moisture build-up in the wood. The manufacturer stresses that "this requires significantly more ventilation than the amount specified by most building codes, and it requires that the entire underside of the roof be washed with a uniform flow of outside air." The same manufacturer cautions that "failure to provide adequate ventilation can result in buckling, bowing, strength loss and roof failure."<sup>19</sup>

Job-site precautions are equally important. The FRT plywood should be stored off the ground and protected from rain during storage and construction. There should be adequate ventilation around the wood stack and, if wetted, all FRT plywood should be permitted to dry properly before it is enclosed within structural assemblies.

Most important, all bad roof decking should be replaced. If replacement must be made with FRT plywood, only top-quality products should be used. An investigation of the treatment process and appropriate material selection may limit plywood damage and replacement costs in the long term. Not all fire-retardant treatments may be subject to degradation to the same extent. Indeed, it is possible that more expensive treatments that use buffers (such as borax), organic, and/or milder, and less acidic, chemicals may be less prone to material degradations in the roof environment and to subsequent strength reductions. However, even some of these treatments have experienced limited problems to date.

Informed decisions must be made on the use of FRT plywood. An investigation of reported manufacturer problems should be undertaken prior to the selection and application of any additional materials. Consumers may also wish to investigate specific warranty provisions from FRT manufacturers. As an example, 40-year warranties may accompany some of the newer FRT products which utilize organic compounds. In all cases, consumers should avoid a specific FRT product if the manufacturer cannot supply information as to the performance of the wood in a given situation. The Forest Products Laboratory advises that, "if knowledge of the acceptable performance of a particular FRT product over time is uncertain," the consumer should "choose another product or another way to provide fire protection."<sup>20</sup>

Problems can also be circumvented with alternative construction methods. Since late-1988, Montgomery County, Maryland, has required the installation of sprinkler systems in lieu of FRT plywood in newly-constructed multifamily dwellings. A true noncombustible roof deck can also be used. This can be achieved through the installation of metal decking.

The placement of water-resistant, fire-rated, gypsum sheathing 1.59cm (5/8 in.) thick under untreated plywood decking offers yet another option. This gypsum may be placed between the trusses or rafters and may be secured through the use of wood blocking and/or clips (see Figure 3). Consideration should be given to using the shortest possible roofing nails for shingle application so that the gypsum is not unnecessarily broken. However, applicable standards regarding fastener lengths/penetrations, such as those recommended by the National Roofing Contractors Association (NRCA) and the Asphalt Roofing Manufacturers Association (ARMA), should not be compromised.

A return to the practice of parapet wall construction may be made as well. In fact, several building code authorities (such as those in New York State) recommend that fire walls extend through the roof deck to eliminate the need for FRT plywood. A common wall with a two-hour fire rating can be constructed in conjunction with a parapet. A double wall, each with a one-hour fire rating, offers yet another alternative.

In addition to some of the relatively-new gypsum materials, other alternative products are also in development. These include flame-retardant coatings on plywood and polymer plastic laminates applied to wood. Although such applications and composites may currently be cost prohibitive, future advances may offer viable—and economical—construction innovations.

### PROGNOSIS FOR THE FUTURE

The formulation of standard test protocols should provide greater assurance that FRT products can maintain integrity in intended applications. It appears that confidence in FRT product usage will only be attained when the treaters and manufacturers can document proven performance properties and provide valid span tables and life expectancies for their products.

Input from the U.S. Forest Products Laboratory and the National Forest Products Association will be essential in delineating suspect treatment formulations and appropriate precautions for FRT product usage. In conjunction with building code revisions and third-party monitoring and certification, the current dilemmas with FRT plywood may be successfully resolved.

Although problems may have been evident to some industry professionals since 1983, the manufacturing of fire-retardant-treated plywood has increased geometrically each year. Had the industry responded when the problem originally surfaced, it may have been possible to substantially reduce—by as much as 80 percent—the current estimated repair costs to correct a widespread problem. Consideration of chemical formulations, treatment/drying processes, temperature limitations and ventilation provisions must be made by designers, builders and consumers. An understanding of the FRT product, and its strength properties, in intended applications and environments is critical to informed decision making and successful prospects for the future.

### ACKNOWLEDGMENT

The artistic assistance of Larry E. Baer, architect of Engineering and Technical Consultants, Inc., in Columbia, Maryland, is acknowledged with gratitude.

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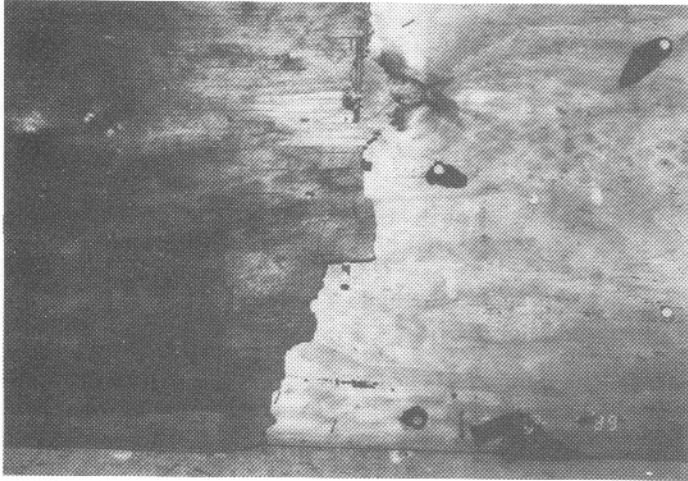


Figure 1 Comparison of FRT plywood vs. untreated plywood.



Figure 2 Excessive deflection of FRT plywood decking.

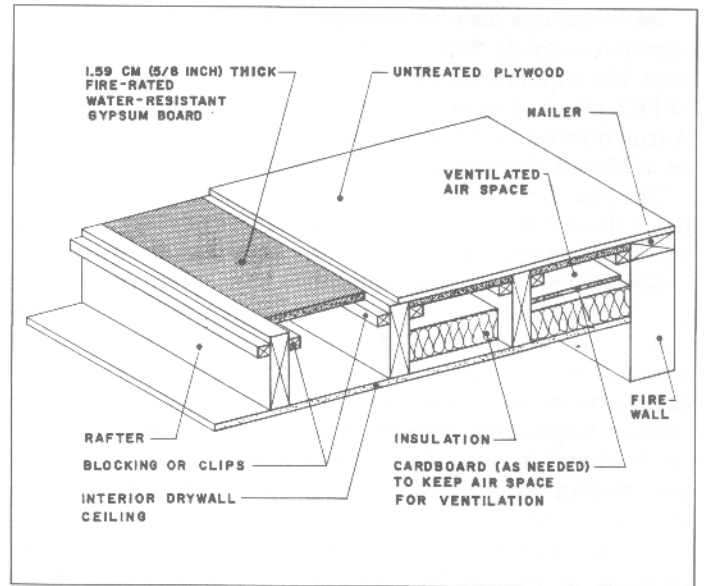


Figure 3 Installation of gypsum under untreated plywood roof decking.