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FIRE-RETARDANT-TREATED WOOD: RESEARCH AT THE FOREST PRODUCTS LABORATORY

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This paper describes the research program underway at the USDA, Forest Service, Forest Products Laboratory, Madison, Wisconsin, that was designed to examine mechanisms of thermal-induced degradation in fire-retardant-treated lumber and plywood. It also reviews results from our research program on chemical, mechanical, and nondestructive evaluations of untreated and fire-retardant treated wood exposed to elevated temperatures.

INTRODUCTION

North American building codes sometimes require the use Of wend treatcd with fire retardant (FR). For nearly 50 years, FR-treated lumber and plywood have been successfully used in structures exposed to temperatures less than 40°C. However, over the past 4 to 6 years, a significant number of roof sheathing failures have occurred in multifamily dwellings and nonresidential commercial buildings that have utilized FR-treated plywood as roof sheathing (1). The most often-cited failure is out-of-plane buckling, but numerous cases have been reported of workers breaking through panels or of roof sheathing failures under snow loads. The National Association of Home Builders estimates that replacement costs for these failures will exceed US$2 billion. Based on these reported failures, it appears that some FR formulations are undergoing thermal decomposition caused by elevated temperatures induced by solar radiation. When used as roof sheathing, structural wood-based materials are periodically exposed to temperatures as high as 80°C. At these temperatures, some commercial FR. formulations are causing thermal-induced strength degradation and some formulations are not. Fire-retardant-treated materials experiencing thermal degradation darken in color, have an appearance similar to dry rot, crumble easily when abraded, and often exhibit excessive cross-grain checking.

The USDA Forest Service, Forest Products Laboratory (FPL), has initiated a multidisciplinary research effort to address concerns related to the thermal-induced degradation of FR-treated wood materials. The following list gives the accomplishments and goals of the FPL research program on the degradation of FR-treated wood materials.

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Engineering Properties	Defined the impact of kiln-drying after treatment(7)
	Proposed interim design guidelines (5)
	Established correlations between FR chemicals and steady-state exposure temperature (3)
	Developed and evaluated a new ASTM test method for FR plywood exposed to elevated temperatures and humidity (6)
	Compared the effects of cyclic exposure temperatures (paper in preparation)
Chemistry	Identified thermal-induced compositional changes (3)
	Proposed thermal-induced degradation mechanism and reviewed literature (4)
In-Place Evaluation	Establish baselines for acoustic nondestructive evaluation (paper in preparation)
	Establish fundamental concomitant property relationships (paper in preparation)
Serviceability	Described problems with FR-treated plywood roof sheathing (2)
	Develop predictive models for performance (Research in progress)
	Develop predictive roof temperature models (Research in progress)
	Identify the impact of plywood quality factors on thermal performance (Research in progress)
	Identify the impact of processing factors on thermal performance (Research in progress)
	Establish laboratory-field performance correlations (Research in progress)

The objectives of this paper are to summarize our results to date and to describe our current research activities.

CHEMICAL EFFECTS

Initial investigations indicated that field problems resulted from thermal-induced acid degradation of wood carbohydrates by the acidic FR chemicals (4). More comprehensive work has now shown that the proposed acid degradation mechanism was valid (3). This research has also shown that the relative effects of many FR treatments can be classified by the type of FR chemical employed and the time-temperature combination required to convert the FR formulation into its acidic form. The relative effects of untreated controls and four FR formulations exposed for various durations at 82°C, then equilibrated to constant weight at 20°C-65% relative humidity (RH) and tested, are shown in Figure 1. Monoammonium phosphate (MAP), an inorganic salt, was a major chemical component used in the FR-treated plywoods that have experienced thermal-induced roof-sheathing failure. Phosphoric acid (PA) is the acidic dissociated form of MAP. Guanylurea phosphate-boric acid (GUP) and dicyandiamide-phosphoric acid-formaldehyde-(DPF) represent commercial interior and exterior organic FR salts, respectively, Each FR chemical accelerates wood strength loss when compared to untreated controls (CTL), but PA and

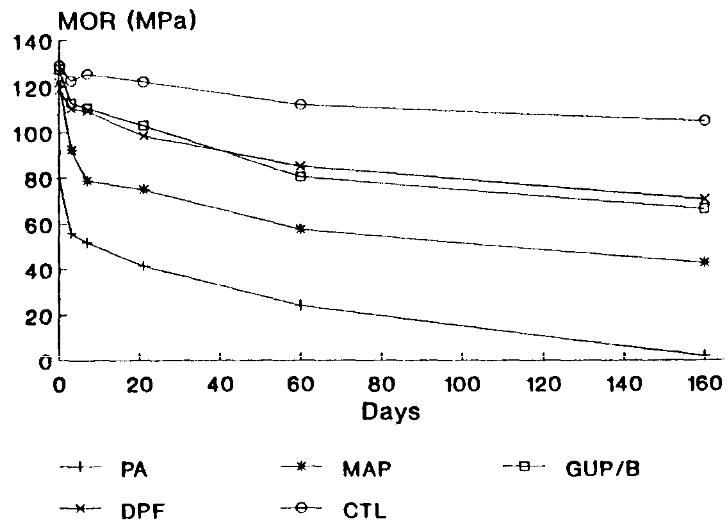

Figure 1 Effects of four fire retardants on bending strength of 16- by 35- by 305-mm clearwood specimens exposed to steady-state exposure at 82°C (180°F) and 50% RH (CTL = untreated; PA = phosphoric acid; MAP = monoammonium phosphate; GUP = guanylurea phosphate; DPF = dicyandiamide–phosphoric acid–formaldehyde).

MAP have significantly greater effects than either organic salt (Fig. 1). Note that permanent thermal degradation eventually occurs for both treated and untreated materials exposed at 82°C. Furthermore, it appears that after thermal-induced degrade has initiated ($\leq$ 21 days exposure) and eventually stabilized (> 21 days exposure), the rate of strength degradation is similar between treated and untreated materials even though the strength values of these materials are greatly different.

TEMPERATURE AND RELATIVE HUMIDITY EFFECTS

As exposure temperature, relative humidity, and duration increase, mechanical properties are progressively reduced. The influence of these variables on bending strength are shown for untreated plywood exposed at 54°C--79% RH, 65°C-75% RH, 77°C--79% RN, and 77°C-50% RH (Fig. 2) and for MAP-treated plywood (Fig. 3). From these data, four results are apparent (6):

1. Before exposure to elevated temperatures, the MAP-treatmrnt process causes an initial reduction in strength compared to untreated plywood.

2. The rate of strength degradation of untreated and MAP-treated plywood increases as exposure temperature increases.

3. The rate of strength degradation of untreated and MAP-treated plywood increases as relative humidity increases.

4. The rate of change over time of exposure in bending strength appears constant for any treatment-temperature combination.

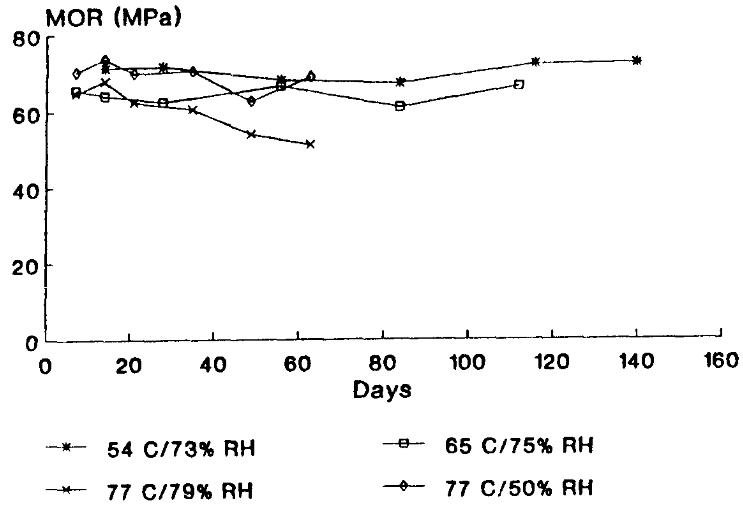

Figure 2 Effect of exposure to various temperatures on modulus of rupture (MOR) of untreated plywood.

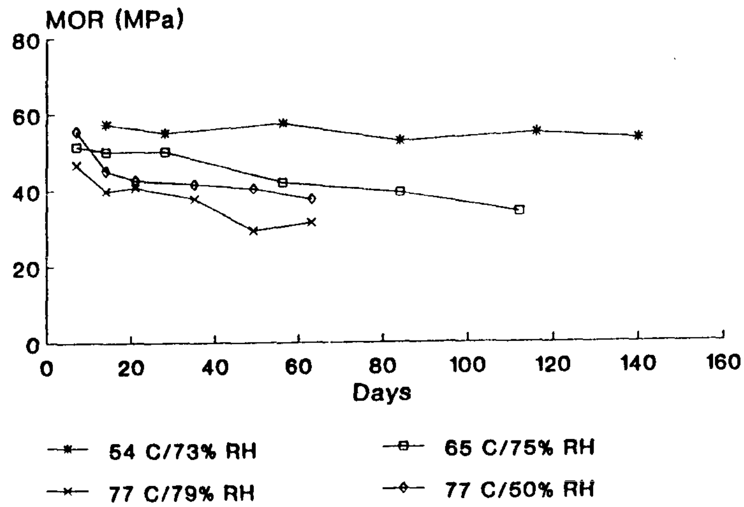

Figure 3 Effect of exposure to various temperatures on modulus of rupture (MOR) of monoammonium phosphate-treated plywood.

This last result of a constant trend was previously reported for untreated, MAP-treated, and several other FR formulations. Data from two reports imply that strength loss proceeds at a constant rate dictated primarily by temperature (3,6).

As relative humidity increases, the rate of strength loss at elevated temperature increases. However, the effect of relative humidity (Fig. 2 and 3) does not appear to be as influential as the effect of the temperature of exposure (6). Additional research is now examining the effects of thermal exposure at higher moisture content levels.

CYCLIC AND STEADY-STATE EXPOSURE

In the field, sheathing temperature and moisture exposures are cyclic. The effects of cyclic thermal exposure are currently being evaluated on a cumulative time-at-temperature basis.

THERMAL STABILITY

Several years ago, it was recognized that a standard test method was needed to verify accept able performance of commercial FR treatments periodically exposed to elevated temperatures. A standardized method for evaluating the potential of proprietary FR treatments to promote thermal-induced strength loss when exposed to elevated temperatures is in draft form and is currently being considered by the American Society for Testing and Materials D-7 Committee on Wood. This draft standard was developed by a joint plywood industry-treating industry-FPL task group. The standard would provide a testing methodology that compares the relative performance of proprietary commercial FR treatments with untreated material for use in environments exposed to elevated temperatures, In this methodology, at least 75 days of thermal exposure at 77° C -67% RH is recommended as sufficient to indicate products or treatments that are susceptible to thermal-induced degradation (6). This recommendation implicitly assumes that the performance of a treatment at $\geq$ 90°C will be similar, but slightly accelerated, to its performance at 77°C. Based on our work to date (3,6), we have found no evidence contrary to that assumption.

Although steady-state exposure to elevated temperature is theoretically quite severe, 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 77°C-79% RH and 82°C–50% RH is much less than the magnitude of the degradation often experienced in the field. Thus, we believe that some other significant processing variable may also be involved in field failures. Possible variables could be a lack of required kiln drying, excessive redrying kiln temperatures, or partial amounts of FR chemicals that are initially even more deleterious to strength (e.g., phosphoric acid). We are currently studying each of these possibilities.

NONDESTRUCTIVE EVALUATION

In our investigations, two nondestructive evaluation (NDE) techniques have shown considerab!e promise. One technique utilizes the relationship between force required to withdraw a screw from FR-treated plywood and its remaining bending strength. This technique is easy to interpret, would require relatively low deverlopment costs, and should be readily received by building inspectors. Stress wave NDE techniques have also yielded excellent results. Strong correlative relationships have been observed when stress wave characteristics such as attenuation and speed wave were compared with residual strength. However, considerable effort needs to be devoted to overcome boundary condition problems associated with application of stress wave techniques to in-place members.

DESIGN OPTIONS

Strength reductions related to thermal-induced degradation have recently been encountered with the use of some FR treatments for plywood roof sheathing. Based on the unacceptable performance of some FR formulations, FR-treated materials should not he considered an interchangeable commodity item. New test methods may soon be available to differentiate between various proprietary commercial FR treatments.

Some FR formulations have decomposed at elevated temperatures induced by solar radiation, causing thermal degradation of the treated plywood. Therefore, the limit of permanent thermal stability for FR-treated material should be assumed to be no greater than 55°C unless specific data documenting stability at higher temperatures is presented to the designer. It is the responsibility of the designer to anticipate the temperatures and relative humidities in a structure and then to consider the available options.

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