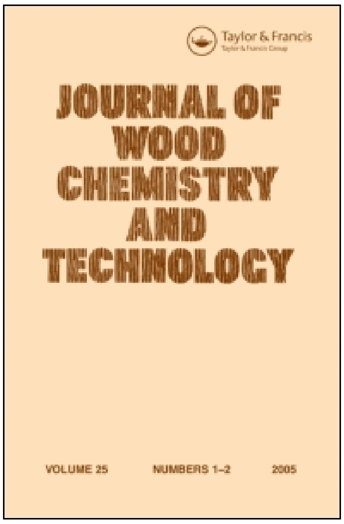

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IMPROVED FIRE RESISTANCE FOR INTERIOR WOOD PANELS

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ABSTRACT

The background for considering decorative wood panels in the overall evaluation of materials and products which may contribute to fire hazard is briefly reviewed. State-of-the-art approaches to fire resistance for these products are summarized, with reference to the broader subject of fire retardants for wood. Some areas for potential development, and specific research needs are suggested.

INTRODUCTION

On the basis of data compiled by the National Fire Data Center of the U.S. Fire Administration for the period 1977-1980, specific materials and products commonly used in residential structures have been identified* as potential contributors to fire hazard. It has also been postulated that significant opportunities for new approaches to improved fire resistance may exist for these products, and that these may be re-

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vealed by examining each product category with a focus on the end-use, and on the type of fire hazard encountered. Interior wood panels are among the products selected by the Agency* as requiring consideration. This paper presents a brief summary of the state-of-the-art materials and technology now available, and a realistic appraisal of potential future developments for improving the fire resistance of interior wood panels.

Flammability and fire resistance are broad terms which acquire significance only with reference to definitions of exposure, environment, specific aspects of the burning processes, and methods of testing. In the present discussion, the term "flammability" is used to denote the tendency of a material to ignite on exposure to an externally imposed heat source; "flame resistance" refers to decreased flammability of a material as measured by accepted test methods, and the term "flame retardant" is applied to chemical compounds or systems which decrease the flammability of a material in which they are present. The relative hazard addressed is the one resulting from ignition of a specified material or product and subsequent flame spread. Potential hazards from smoldering, or flameless combustion, from smoke evolution and from toxic products of combustion are important considerations, but are beyond the scope of this review.

In the context of these definitions, it is evident that for a specific product the manner of exposure to external heat sources, the probable mode of ignition, the probability of ignition and potential flammability hazard depend on many factors related to design and to materials' interactions, as well as on the material itself and on its chemical composition. In principle, the effects of these factors on the flammability behavior of materials and products should be reflected in the test methods used for their evaluation and in applicable specifications and standards. As a practical matter, however, the problem of developing laboratory test methods which can accurately measure specific properties related to flammability, or provide valid simulations of behavior in fire exposure, is exceedingly complex, and essentially unresolved. Available methods are, at best, relative measures of flammability, and indicative of probable differences in use. Correlation of test results with performance of materials in a fire remains elusive for most products and exposures. Thus, flammability of materials can generally be defined only in relative terms, with reference to specific test methods, and with great caution in the prediction of rankings and potential hazards.

The fire retardants discussed below are reportedly in commercial use at this time. Those mentioned as possibilities for future development are believed to have potential practical significance, and to require modest changes in processing technology. Advanced materials developed for specialized products or applications, and approaches considered to be purely experimental are not included. In brief, the materials for improved fire resistance of interior wood panels discussed below are based on state-of-the-art technology, and they are defined as those which would retard flame propagation and/or enhance the probability of extinguishment if ignited by exposure to burning materials in their proximity.

FIRE RETARDANTS FOR WOOD

There exists a profound dichotomy between the historical evolution of application of fire retardants to wood, which dates back several centuries, and the progress of scientific knowledge on the thermal degradation and combustion of cellulose, which has advanced at rapid pace in recent decades. The chemistry of fire retardants for cellulose, and the mechanism of their effectiveness have also been investigated in depth. Nevertheless, a gap remains between the progress of research on the flammability of cellulose and of wood, and the application of new concepts in the development of specific new products designed to improve the fire resistance of wood-based materials. Several excellent reviews are available on the broad subject of fire retardants for wood, but it is often difficult to derive from them the principles, results, and guidelines needed for appraising the technology available for specific product categories.

The purpose of this paper is to focus on problems and opportunities in fire retardant treatments for a specific category of wood products--namely, those employed for decorative interior panels in residential structures, offices and public occupancies. The position of these products in the overall production and utilization of wood-based products is shown in Table 1 (adapted from Ref. [1]). While decorative panels constitute but a small fraction of the market for wood-based products, the flammability behavior of products used for interior finish is closely scrutinized by regulatory agencies on a state and local level. The potential fire hazard posed by exposed interior panels is related to ignition and flame propagation upon exposure to a material burning in proximity to the panel. The probability of decorative paneling materials being first to ignite on direct contact with an ignition source is low because of the flat surface, low surface area and the design attitude of the product in use.

TABLE 1

Wood Products--Production and Applications

(Adapted from Reference [1])

	Approximate Production Million Square Meters	Major Applications
Particle board (3/4-inch basis)	325	Sheathing, Underlayments, Mobile home decking *Paneling Door cores, Furniture
Hardboard and Insulation board (Building fiberboards) (1/8-inch basis)	713	Lap and panel exterior siding *Interior panels and furniture (high density)
MDF (Medium density fiberboard composite) (3/4-inch basis)	45	Furniture and cabinets
Softwood plywood (3/8-inch basis)	1832	Subflooring, roofing, siding
Hardwood plywood (surface measure) - (imported-356) (domestic-134)	490	*Decorative panels, furniture and cabinets
Lumber	90 (cubic meters)	Structural members (low rise construction) Flooring, trim, and doors.

The level of fire resistance of the materials may be defined, for example, by a Flame Spread Index, determined by the ASTM-E-84 test method, or by a critical energy flux necessary to propagate the flame, measured by the radiant panel test (ASTM-E-162).

The state-of-the-art for improving fire resistance of wood-based materials in decorative panels is reviewed here with the above considerations in mind.

The study of fire retardant (FR) treatments for wood began in the Seventeenth Century, for the purpose of decreasing the fire propensity of wood used in ships and in theaters. About two hundred years later, many useful inorganic compounds had been identified, and some of them are in commercial use to this day. In spite of this long history of awareness, commercial production of wood treated with fire retardants has remained low, and motivated primarily by the necessity to comply with regulations--rather than by a voluntary drive towards improved fire safety. The reasons for the slow growth of FR-treated wood products are essentially economics, and, also, the undesirable effects of known FR treatments on product properties. The critical properties of wood, and the extent to which these are affected by FR treatments have been discussed in several technical publications of value [2,3,4,5]. They are mechanical properties, moisture response (hygroscopicity) and dimensional stability, properties related to fabrication requirements such as machining, glueing characteristics, and adhesion of surface coatings (painting), and resistance to environmental degradation. In the case of interior decorative panels, emphasis must be placed on fabrication requirements, dimensional stability, adhesion of surface coatings and aesthetics, while effects on mechanical properties and on resistance to outdoor exposure are less important.

<u>Technology for Treating Wood with Fire Retardants</u>.

In terms of processing technology, approaches for the treatment of wood with fire retardants may be classified as follows:

(a) Integral dispersion: incorporation into fibers or particles before these are assembled into fabricated products (e.g. hardboards, plywoods, particle boards). A viable method is, for example, the dry-forming of pre-impregnated fiber [6].

(b) Impregnation of preformed product with aqueous solutions of flame retardant compounds, for example, inorganic salts or organic monomers capable of polymerization reactions in situ.

(c) Coating--generally in conjunction with paints or clear varnishes. Coatings may be either water-based or solvent-based, and either intumescent or non-reactive [7].

Chemical impregnation processes are more frequently used for new materials; coating is the only viable approach for the treatment of existing structures, but may not be accepted without inspection by code authorities [2].

A descriptive summary of methods for treating wood products with fire retardants is presented in Table 2. In principle, all methods are applicable to decorative panels, in which outdoor exposure is not contemplated, and leach resistance of the fire retardants is not needed. As a practical matter, the approach or process of choice is determined by the material, the FR chemical system, the manufacturing technology, and the performance specifications or requirements.

The chemical systems used for impregnation treatments are based almost exclusively on inorganic compounds, long known for their fire retardant effectiveness in wood and in cellulose [2,3]. Specific formulations have been developed as a result of experimental investigations of performance properties in treated products, coupled with considerations of processing and economics. For example, zinc chloride is a good fire retardant,

TABLE 2

Methods for Application of Fire Retardants to Wood Products

Method of Treatment	Remarks	Examples of Chemical Systems Used
Surface application (penetrating liquids or solutions) Immersion, simple impregnation	Methods do not result in adequate retention of FR chemicals when leach resistance is needed	Formulations of inorganic salts (e.g. ammonium sulfate or phosphate, zinc, chloride, borates, etc.)
Vacuum pressure impregnation	Involves vacuum treatment in autoclave, introduction of FR solution, application of air pressure, and drying	-do-
Integral dispersion	Involves incorporation of FR chemicals into fiberboards, hardboards and particle boards during fabrication.	-do-
Coating (non-reactive)	Thick coating is required (5 to 6 times the amount required for decorative purposes)	Chlorine-containing polymers formulated with antimony oxide (oil-based paints)
Intumescent Coatings	Formulation applied is capable of forming a cellular char (intumescing)	Carbon-producing ingredient (e.g. carbohydrate) with Lewis acid (e.g. phosphorus compound), binder and other ingredients.

but tends to increase smoke development under some conditions; ammonium sulfate is used because of its low cost and good fire retardant effectiveness, boric acid is especially effective in preventing afterglow; ammonium phosphates and phosphorus compounds provide good flame resistance and also inhibit afterglow; sodium dichromate is added to inhibit corrosive effects of the formulation. Typical formulations of fire retardants used commercially for treatment of wood products are documented in the Standards of the American Wood Preservers Association (AWPA) [8]. Some examples illustrating the use of specific components mentioned above are [9]:

Type B	Zinc chloride	65.2%
	Ammonium sulfate	10.0%
	Boric acid	10.0%
	Sodium dichromate	14.8%
Type C	Diammonium phosphate	10.0%
	Ammonium sulfate	60.0%
	Sodium tetraborate (anhydrous)	10.0%
	Boric acid	20.0%.

In contrast to these formulations of well known inorganic compounds, fire retardant treatments based on coating processes are more numerous and complex. They are designed to protect the substrate through the presence of fire retardants in the exposed surface of the product (non-reactive coatings) and/or through a capability for bubbling and swelling (intumescing) with formation of an insulating cellular char layer when the material is exposed to elevated temperature.

Non-reactive coatings do not generally provide the same degree of fire protection as intumescent coatings, because thick coatings--up to 5 or 6 times thicker than those used for decorative purposes--are needed for adequate effectiveness, and this requirement poses serious limitations. The most important non-intumescent FR coatings are those based on chlorinated alkyd resins. In some instances, chlorinated diacids (e.g. tetrachlorophthalic anhydride) are incorporated into the coating resin. In others, fire retardant additives may be used, providing that they do not impair coating properties, and that they are compatible with the paint vehicle. Chlorinated paraffins and other halogenated additives are used in oil-based paints, generally in conjunction with antimony oxide, or mineral fillers.

Inorganic FR coatings based on silicates with additives or fillers such as asbestos, chalk, etc., have been proposed [4]. When heated, the silicates form a stable, frothy crust, insulating the underlying substrate from heat exposure.

Water-based, non-intumescent FR coatings have not been developed to a significant degree to date.

In the case of intumescent coatings, several components are needed, including a carbon-producing ingredient, or "carbonific",typically a carbohydrate or a polyol; a Lewis acid such as a phosphorus compound which can catalyze dehydration; a component evolving large amounts of non-flammable vapor when heated, or "spumific", typically a nitrogen compound such as urea, guanidine, or dicyandiamide; and a binder, generally a chlorinated resin binder [10,11]. Intumescent coatings, in contrast to non-reactive coatings, require only a thin coating to provide a significant level of fire resistance to the substrate. However, they have other limitations: The first of these is a relatively high cost, and there are also technological problems. On one hand, high loadings of the intumescent components in the formulation are needed, and these may impair the properties of the coating; on the other hand, the necessary ingredients of the paint formulation may interfere with the intumescent properties of the system, because the reactivities of the system components must be precisely synchronized to attain the desired results.

A meaningful comparison of impregnation processes and coating processes for improving the fire resistance of decorative wood panels cannot be attempted without reference to specific products, requirements, and test methods. Assuming that comparable levels of fire resistance could be attained with available technology, the impregnation approach offers the advantage of producing a "permanent" modification--subject only to the deterioration of ageing and use, without necessitating renewal as in the case of treatment by application of surface coatings.

Examples of Commercial Processes.

A great deal of the information on formulations and processes developed in industry for fire-resistant wood products is considered proprietary, and thus is not available. Some illustrative treatments reported to have commercial significance for interior panels, which can be considered indicative of current trends are summarized in Table 3, with pertinent references. The technology developed at the Eastern Forest Products Laboratory (Ottawa/Ontario) has been commercialized in Canada and in the U.S.A. and is well documented in the technical literature.

In the case of intumescent coatings, the composition of commercial products is not generally disclosed. Selected manufacturers of components and of formulated products are listed in Table 4, and representative formulations are available from manufacturers' technical literature and from review papers [10,11].

TABLE 3

FR Treatments for Interior Wood Panels

Source	Method of Processing/Application	Chemical Composition/Class	Refs.
Eastern Forest Product Lab., Ottawa, Ontario Hoover Universal Company	Surface coatings	Melamine/urea/ or Dicyandiamide resins and phosphoric acid	[1,2,3]
Hooker Chemical Co. (Developmental)	Surface application (brush or coat)	Aqueous solution of organo-phosphorus compounds	[4]
Humphrey Chemical Co.	Vacuum Pressure Impregnation	Zinc ammonia Borate complex	[4,5]
Koppers Industries (NON-COM)	Surface coatings	Organic phosphates (with melamine resin)	[4]
AGL, Ltd. (SILPRO)	Impregnation (dual process)	Insoluble metal silicates formed in situ	[4,6]

(1) S.C. Juneja and L.R. Richardson, Forest Products J. 24(5), 19 (1974); British Patent 1,389,898

(2) USP 3,832,316 (1974)

(3) USP 3,887,511 (1975)

(4) Private communication; see also D.S. Baker, Chem. Ind (London) 74 (1977)

(5) USP 3,524,761 (1970)

(6) USP 3,974,318 (1976).

TABLE 4

Intumescent Coatings and Paints

Source	Formulation Components	Reference(s)
National Starch and Chemical Corp. and Dover Chemical Corp.	• Ammonium Polyphosphate (e.g. Phos-Check P/30-Monsanto) • Melamine • Dipentaerythritol • Chlorinated Paraffin • Vinylacetate Copolymer Latex (binder-National Starch Resyn 5000)	[1,2]
American Vamag Company	N.A.	[2,3]
Ocean Chemicals Inc.	N.A.	[2]

(1) H.L. Vandersall, Journal of Paint Technology 39 No. 511, 494 (1967).

(2) Private communication.

(3) U.S. Testing Laboratory Report No. 77444-3, to American Vamag, January 15, 1980, Surface Burning Characteristics of Building Materials.

Potential Developments.

There are several areas where improvements can be realized in the technology of fire-resistant wood panels.

The first is the development of FR systems for approaches based on chemical impregnation, in which undesirable effects on the properties of treated wood can be minimized. This should include consideration of organic FR chemicals specifically tailored for the application, and departure from formulations of long established, economical, but not necessarily optimal, inorganic FR compounds. Cooperation of chemical manufacturers with wood products' producers is essential for progress in this area.

Another potentially rewarding approach is the development of new methods of treatment, utilizing the advances in manufacturing technology realized by producers of hard board, fiber boards and plywood. This would expand the range of FR systems that could be used, and reduce the cost of treatment through economies in processing.

Innovative approaches to the formulation of coatings, particularly intumescent coatings, are another area in which development work would be productive. In this area, several experimental approaches have shown promise. For example, a non-conventional system has been reported [12] in which a single compound, a substituted benzene sulfonamide, can act as intumescent agent in concert with a resin binder (vinyl chloride - vinylidene chloride copolymer), specifically selected to match the thermal properties of the intumescent agent and to provide the synchronized reactivity needed for effective fire retardance. Another conceptually related experimental system employs a polysulfide/epoxy resin binder with the ammonium salt of 4-nitroaniline sulfonic acid [13]. Intumescent coatings in which the elements of intumescence are incorporated into the binder itself have also been disclosed: Reaction of triphenyl phosphite with an epoxy resin has been shown to provide excellent intumescent coatings [14].

New developments based on existing knowledge and technology are possible, and within reach. However, economic justification and incentives for continuing industrial activity are severely limited because of the relatively small production volumes involved, and the motivation for pursuing the development of products of improved fire safety is provided primarily by the pressure of regulations.

Research needs for the total spectrum of fire resistant wood products have been outlined with emphasis on the requirements of lumber and structural members [5]. Research on test methods, on treatments for decreasing the evolution of smoke and toxic combustion products, and for increasing resistance to fire penetration, is relevant to the specific problem of fire resistant decorative panels. More specific research objectives for these products include the identification of efficient fire retardant compounds for impregnation or integral dispersion treatments which can be applied at low concentrations, decreasing undesirable effects on processes and properties; non-conventional intumescent coating compositions in which reactions of the carbon-producing component, dehydration catalyst, and nitrogen-containing ingredient are more effectively integrated; and the utilization of technology developed for specialized applications (e.g. high performance coatings) for improving the fire performance of wood panels.

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