IV-F FIRE PERFORMANCE OF ORIENTED STRANDBOARD

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ABSTRACT

Wood-based composites represent a continuously increasing share of the wood products market. Commercial construction will be important for future expansion of the structural panels market. Use of engineered wood products as an alternative to traditional solid wood lumber is also increasing. A recent series of cone calorimeter tests evaluated the performance of several composite rim board materials, including three oriented strandboard (OSB) products, a com-ply product, a laminated veneer lumber product, plywood, and lumber. Although initial behavior was similar, the 300-s average heat release rates of the three OSB products were higher than those of the other products. Other results from the FPL cone calorimeter database for wood composites are also reviewed. With increased use of wood composites, the market for fire-retardant treatments of composites is likely to increase. Fire-retardant treatments for wood composites are briefly discussed.

INTRODUCTION

Oriented strandboard (OSB) "continues to be the hot product for North American producers, driven by strong demand, record-high prices and strong earnings" (IWMG 2006). Commonly used as floor, wall, and roof sheathing, its performance "has allowed OSB to gain entry into new markets, including materials-handling applications, the structural insulated panel industry, do-it-yourself projects, wood I-joists products, and industrial applications such as furniture, and trailer hers" (APA 2000). With this increased use of OSB, concerns about its fire performance and interest in developing and marketing treated OSB products have also increased. One objective of this paper is to summarize efforts at the USDA Forest Service, Forest Products Laboratory (FPL), to characterize the fire performance of OSB and other composite products and investigate options for treating OSB for improved fire performance.

MARKET FOR OSB

Understanding potential markets for fire-resistive OSB requires an understanding of North American housing and light-commercial construction markets. In construction, the term "structural panels" refers to softwood plywood or OSB panels produced with specific performance properties and intended for engineered uses (ANSI 2004). Structural plywood can be produced under prescriptive standards (ANSI 1995) or, like OSB, under generic performance-based standards (ANSI 2004). In 2004, the domestic U.S. structural panel market exceeded 35 × 10^6 m^3 and included construction, manufacturing, packaging, and other markets (APA 2005) (Fig. 1).

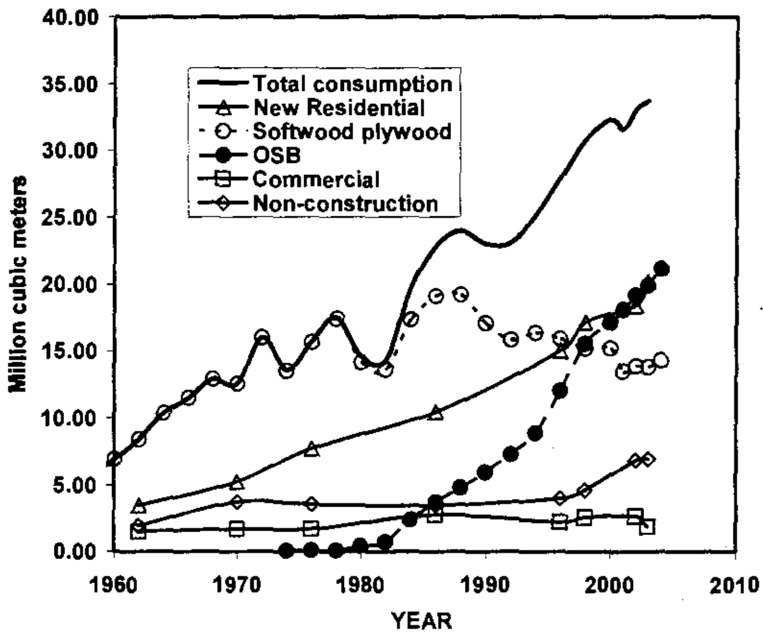
These data show that construction—new residential, residential maintenance, and commercial—represents over 80% of the total structural panel market. Over the past 30 years, a dramatic shift occurred in the structural panel market. Prior to 1990, structural plywood dominated the market. After adoption of ANSI PS-2 (ANSI 2004) in 1992, massive OSB production capacity slowly came on line. Reasons for this development include reduced availability of large-diameter trees for plywood production and corresponding increased economies of high-yieldow-waste utilization and utilization of smaller diameter trees. Accordingly, the structural panel market changed and is now dominated by OSB (Fig. 1). During this same period, two other market trends enhanced the significance of OSB. First, use of composites relative to use of solid lumber has grown from a (25–30):(70–75) ratio 30 to 40 years ago to (≥50):(≤50) today (Freedonia 1999). Second, average new home size in the United States almost doubled, from 410 m^2 in 1962 to 715 m^2 in 2004 (McKeever 2006). So the use of engineered wood composites has grown 3 to 4 times faster than the use of solidwood.

Schuler and Adair (2003) recognized that most of the structural panel market may be too focused on residential construction. They concluded that any real future market growth for structural panels will be in commercial–or "non-residential"–construction because residential construction and maintenance markets are virtually saturated by lumber and structural panels. In their market assessment of the potential for OSB products in office furniture and door manufacturing, Tabarsi and others (2003) noted that any slowdown in the growth of housing starts could prove detrimental to OSB manufacturers who rely heavily on this market alone. We also believe that significant future growth in the structural panel market will be outside domestic residential markets. Thus, the OSB market must expand in either commercial construction or non-construction markets, such as manufacturing, packaging, or other non-tradtional uses. In the past 5 years, the nonresidential OSB market actually declined from 1.68 to 1.18 × 10^6 m^3 (APA 2005).

A critical requirement for construction materials used in either commercial or multi-family-residential markets is controlled fire performance.

FIGURE 1

HISTORICAL U.S. STRUCTURAL PANEL MARKET
(MCKEEVER 2002,2006)



To maximize the potential commercial market, fire-retardant-treated (FRT) OSB should comply with the definition for FRT wood in building codes and other specifications. This would allow FRT OSB to be used where codes currently allow FRT wood to be used as an alternative to noncombustible materials or otherwise prescribe a design option that involves FRT wood. Such definitions for FRT wood generally allow chemical treatment by impregnation or other means during product manufacturing. Surface-applied treatments are unacceptable. American Wood-Preservers' Association (AWPA) standards exist for pressure treatments of plywood (C27) and lumber (C20) with fire-retardant (FR) chemicals, but similar standards are lacking for treated panels based on strand, flake, particle technologies, such as OSB. A standard comparable to the mechanical properties standards ASTM D 5664 (lumber) and ASTM D 5516 (plywood) must be developed for OSB and similar products.

Two FR-treating processes seem plausible. The first involves the incorporation of FR chemicals on the particles/flakes/strands/fibers just before, during, or after the resin- and wax-blendmg processes. However, research to date has not completely addressed all the problems associated with FR chemicals interfering with the resin curing process during and immediately after hot-pressing. Another issue of in-process FR treatment may be the loss of both production time and materials when the manufacturer alternately converts between production of untreated OSB and FRT

OSB. The second type of process—a post-treatment process—may be more acceptable, with less risk for OSB producers.

Given the state-of-the-art and hyper-economic competitive nature of the structural panel market, OSB producers will likely adopt FR treatments only if they are convinced that engineering performance properties and serviceabiliity characteristics will not become compromised more than those of a comparable FRT-plywood panel. As OSB continues to supplant plywood as the dominant structural sheathing panel in North American construction, we believe that the lack of code-recognized FR chemicals and standardized treatment processes for OSB is a hindrance to expanding the OSB market in multi-family residential and commercial construction as a replacement for plywood. Actually, FRT plywood may be losing market share. Micklewright (1997) predicted the FRT plywood market at just over 106,000 m^3. However, a recent FRT plywood market report predicted it at only 63,700 m^3 (Vlosky 2006). In 2004, the total consumption of coniferous plywood was 14.67×10^6 m^3 (Howard 2006). Although the existing FRT panel market is a fraction of the structural panel market, the fact that we do not have a viable FR-treatment technology for OSB is a significant problem in aggressively pursuing the OSB market for multi-family residential and commercial construction. The development of FRT OSB products may also improve the export marketing of OSB.

UNTREATED OSB

The U.S. regulatory test for surface burning behavior of building products is the 7.32-m tunnel test (ASTM E 84). Limited E 84 flame spread data on OSB and other composite products is available in the public domain. Data for ASTM E 84 flame spread indexes (FSIs) in the American Wood Council (AWC) compilation (AF&PA 2002) on flame spread performance of wood products are listed in Table I.

These test results were provided to AWC by APA–The Engineered Wood Association. The AWC data compilation also includes results for particleboard and plywood products. Three commercial flakeboard products were tested in an ASTM E 84 tunnel furnace in a study of an experimental structural flakeboard made from Douglas-fir forest residue (Holmes and others 1979). Surface densification was suggested as a possible reason for the lower FSI of experimental flakeboard compared with the three commercial products (Table 1). In another study of an experimental structural flakeboard, a 30-mm-thick red oak structural flakeboard and a 28-mm-thick plywood were tested in a ASTM E 84 tunnel apparatus (White and Schaffer 1981). The 110 average FSI for the flakeboard was comparable to the historic 100 FSI value for red oak flooring and higher than the 55 FSI for the plywood.

Surface burning behavior is only one of the fire performance properties that can impact the proper use and successful marketing of wood products. The other major fire performance requirement is fire resistance to flame penetration or burn-through.

TABLE 1

AVAILABLE ASTM E 84 FLAME SPREAD INDEX DATA FOR OSB, WAFERBOARD, OR FLAKEBOARD

Product	Thickness (mm)	FSI	Source
OSB or waferboards	8	127 to 138	AF&PA 2002
OSB or waferboards	11	86 to 150	AF&PA 2002
OSB or waferboard[a]	13	74 to 172	AF&PA 2002
OSB or waferboard[a]	19	147 to 158	AF&PA 2002
Commercial flakeboards[b]	13	127, 147, 189	Holmes and others 1979
Experimental flakeboard[c]	13	70, 72	Holmes and others 1979
Experimental flakeboard[d]	30	110	White and Schaffer 1981

[a] With exterior glue (Exposure 2 or exterior). [b] Three different commercial products.
[c] Made from Douglas-fir residues. [d] Made from red oak.

Burn-through resistance of OSB panels is discussed in an APA publication (APA 1998). The most recent FPL publication on fire resistance of OSB relates to rim boards (White 2003) of three OSB products, a plywood, a veneer and wood fiber composite (Com-Ply), and a laminated veneer lumber (LVL) product. Linear char rates of the five products ranged from 1.45 to 1.52 min/mm. A char rate of 1.58 min/mm is generally assumed for wood subjected to ASTM E 119 fire exposure. These rim board products were subsequently tested in the cone calorimeter at FPL to assess their combustibility. The results are presented in the following section.

CONE CALORIMETER TESTS OF UNTREATED OSB

At FPL, the cone calorimeter is the test method used to evaluate combustibility and surface burning characteristics of untreated and treated wood products (White and Dietenberger 2004). The cone calorimeter method for determining heat release rate (HRR) is described in ASTM E 1354 and ISO 5660-1. The primary result from the cone calorimeter test is a HRR curve over the duration of the test (Figure 2). Seven products were tested in the cone calorimeter study of rim board products, including three 29-mm-thick OSB products, a 24-mm-thick southern pine plywood, a 27-mm-thick Douglas-fir Com-Ply product, a 31-mm-thick Douglas-fir LVL product, and 37-mm-thick Douglas-fir solid sawn lumber. The OSB products designated “A” and “C” were of mixed hardwoods. The OSB designated as “B” was southern pine. The first six products were tested in the previous study on fire resistance of rim board products (White 2003). The Com-Ply product had five layers, including the 2 face veneers, 2 wood fiber layers, and a veneer center layer. The plywood and LVL had 7 and 11 layers of veneers, respectively.

TABLE 2

TIMES FOR OBSERVED IGNITION OF TEST SPECIMEN

	Ignition Time for Four External Heat Flux Levels							
	OSB A		194.8		32.8		38.6	
Product	**OSBA**	**194.8**	**32.8**	**38.6**	**16.6**	**18.7**	**13.0**	**10.2**
OSB A	194.8	32.8	38.6	16.6	18.7	13.0	10.2	7.1
OSB B	305.7	3.6	66.3	7.8	19.8	3.7	13.2	7.6
OSB C	156.6	23.0	42.8	2.8	16.2	8.4	11.1	14.1
Plywood	249.6	34.0	33.6	11.2	18.9	14.8	8.1	17.7
Lumber	515.4	9.9	41.5	8.8	18.3	16.0	10.5	10.6
Corn-Ply	556.9	6.1	34.8	27.6	18.6	23.8	10.1	47.9
LVL	345.5	47.4	43.8	18.1	17.3	3.8	8.5	18.2

FIGURE 2

HEAT RELEASE RATE CURVES FOR DOUGLAS-FIR RIM BOARDS
(LVL, COM-PLY, AND LUMBER)

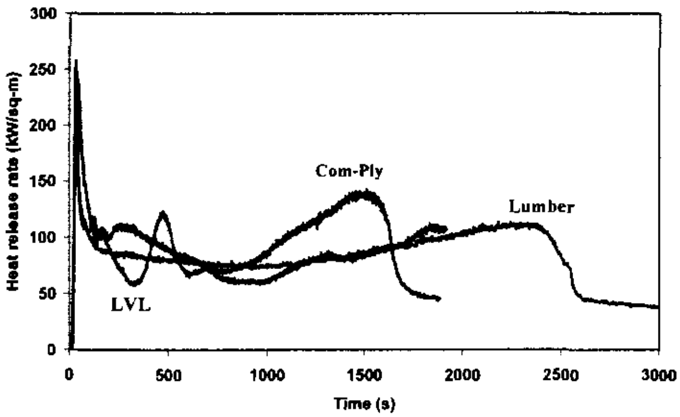


TABLE 3

PEAK HEAT RELEASE RATE OF RIM BOARD PRODUCTS

	Peak Heat Release Rate for Four External Heat Flux Levels							
	20 kW/m²		35 kW/m²		50 kW/m²		65 kW/m²	
	Mean		**Mean**		**Mean**		**Mean**	
Product	(kW/m²)	**CV**(%)	(kW/m²)	**CV**(%)	(kW/m²)	**CV**(%)	(kW/m²)	**CV**(%)
OSB A	168.5	7.4	162.9	7.0	198.6	4.3	252.2	2.8
OSB B	192.6	7.0	164.3	6.2	191.4	5.6	233.7	2.4
OSB C	170.5	8.1	181.2	5.5	217.8	2.8	284.1	1.1
Plywood	134.8	6.4	141.5	4.1	179.5	12.3	238.0	4.4
Lumber	134.6	10.8	182.8	8.2	201.9	1.0	233.5	7.4
Corn-Ply	132.0	14.4	129.5	13.1	223.4	29.7	221.1	27.1
LVL	130.7	6.6	177.0	26.4	245.2	18.6	224.7	13.9

TABLE 4

AVERAGE HEAT RELEASE RATE FOR 300 S AFTER OBSERVED IGNITION OF TEST SPECIMEN

	Average Heat Release Rate for Four External Heat Flux Levels							
	20 kW/m²		**35 kW/m²**		**50 kW/m²**		**65 kW/m²**	
Product	**Mean** (kW/m²)	**CV**(%)	**Mean** (kW/m²)	**CV**(%)	**Mean** (kW/m²)	**CV**(%)	**Mean** (kW/m²)	**CV**(%)
OSB A	134.1	10.6	131.6	6.0	163.2	2.6	192.9	1.7
OSB B	152.1	4.0	138.1	4.2	163.1	5.6	192.8	4.0
OSB c	138.0	6.6	157.5	6.1	187.9	1.5	225.2	1.4
Plywood	113.6	2.6	117.5	4.6	157.4	9.4	171.4	11.0
Lumber	103.7	14.1	114.8	2.7	136.9	4.9	160.2	3.3
Corn-Ply	104.0	10.2	93.8	22.8	140.3	18.6	162.9	14.3
LVL	103.0	5.3	124.0	19.2	162.2	9.3	167.6	7.7

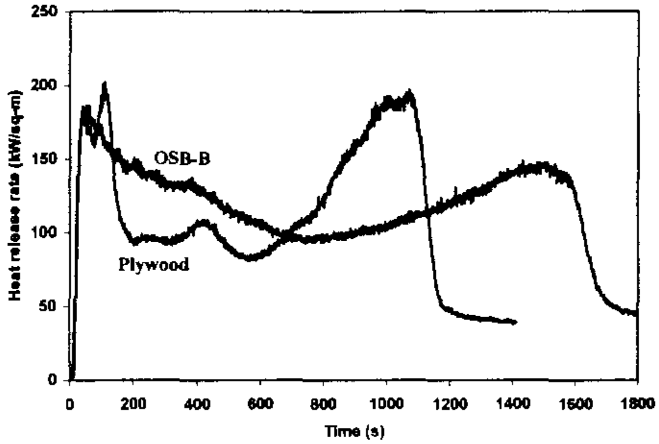
We tested the specimens in the horizontal orientation with the retainer frame (without the wire grid) over the test specimen. The electric spark igniter was placed above the test specimen until sustained ignition of the test specimen was observed. The four heat flux levels were 20, 35, 50, and 65 kW/m². Tests were usually terminated after 1,800 s, prior to the decrease of HRR to minimal levels. Times for sustained ignition (Table 11) for the different rim board products were comparable at the higher heat flux levels, whereas times were greater for the three Douglas-fir products (solid sawn lumber, Com-Ply and LVL) at the 20-kW/m² exposure.

Curves for the three Douglas-fir rim board products were typical for wood, showing an initial increase to a peak HRR, then a drop to a steady-state heat release rate, followed by a second peak as the final portion of the specimen is consumed (Fig. 2). Peaks after the initial peak likely reflected the layered construction of the LVL and Com-Ply. For reporting purposes, the heat release curve is often reduced to single numbers using the initial peak HRR (Table 3) and averages of HRR over a set time, such as 60, 180, and 300s (Table 4) after ignition of the specimen is observed. Although there were some differences in peak HRR, rankings of the seven materials were not consistent for the four heat flux levels (Table 11). The three OSB products had higher average peak HRR than those of the other four materials at the 20-kW/m² exposure (168 to 192 kW/m² for the OSB products compared with 130 to 135 kW/m² for the other materials). At the 65-kW/m² exposure, average peak HRR for southern pine OSB (B) (234 kW/m²) was slightly less than the average value for southern pine plywood (238 kW/m²). Averages for 300 s after observed ignition showed consistency in higher HRR for the three OSB products compared with the other four products (Table III). On average, the HRR for 300 s of the three OSB products were 24% to 36% higher than for the Douglas-fir solid sawn lumber. Non-OSB rim board products showed a rapid drop in HRR after the initial peak HRR (Figures 2 and 3). With the OSB products, the reduction in HRR after the initial peak HRR was more gradual (Fig. 3).

Although the higher HRRs reflect higher mass loss rates, the higher densities of the OSB products means that there are smaller differences in the linear char rate values discussed earlier.

FIGURE 3

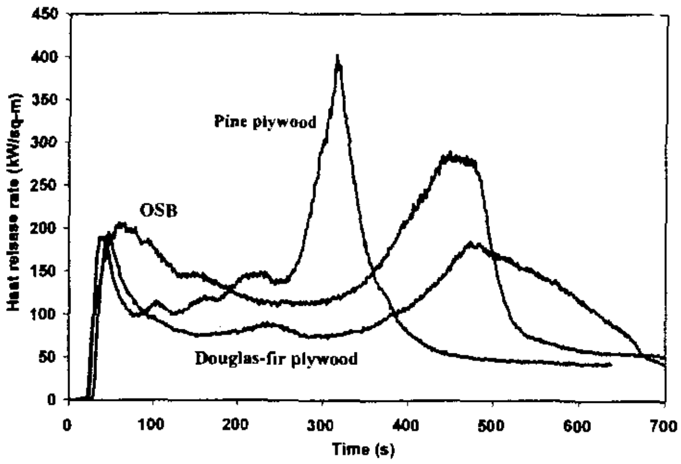
HEAT RELEASE RATE CURVES FOR THE SOUTHERN PINE PLYWOOD AND OSB RIM BOARDS



A 13-mm-thick OSB was one of the materials included in a wood industry material bank for fire research that was created in the late 1980s. Other materials included 11-mm-thick southern pine plywood and 12-mm-thick Douglas-& plywood. Tests on the materials included ASTM E 906 (Ohio State University method) HRR tests ("ran 1992), room-corner tests (Tran and Janssens 1991, White and others 1999), and cone calorimeter tests (Tran 1992, Grexa and others 1996). In addition to HRR, cone calorimeter tests of the OSB and other materials were used to examine ignitability of the materials (Dietenberger 2004) and smoke development (Dietenberger and Grexa 2000). In FPL cone calorimeter tests of the three panel products (OSB, southern pine plywood, and Douglas-fir plywood), the heat release curves (Figure 4) were similar to those obtained in tests of the rim board products (Figure 3). In other cone calorimeter tests of these products (Grexa and others 1996), average effective heat of combustion values were 12.2 MJ/kg for the OSB and 12.7 MJ/kg for the Douglas-& plywood. Corresponding total heat release values were 83.2 MJ/kg for the OSB and 57.3 MJ/kg for the Douglas-fir plywood.

FIGURE 4

HEAT RELEASE RATE CURVES FOR 13-MM-THICK PANEL PRODUCTS



The estimated ASTM E 84 FSI was 120 for the southern pine plywood and 175 for the OSB in the wood industry material bank (White and others 1999). In room-corner tests using a 100-kW propane burner and test materials on walls only (White and others 1999), times for flashover as indicated by flames out the door were 189, 324, and 520 s for OSB, southern pine plywood, and Douglas-fir plywood, respectively. In another series of tests, output of the propane burner was changed from 40 to 160 kW at 300 s. In room tests using this 40/160-kW burner and test materials on walls only (Tran and Janssens 1991), times for flashover as indicated by flames out the door were 266, 344, and 380 s for OSB, southern pine plywood, and Douglas-fir plywood, respectively. Test data on this OSB product were included in the database used to develop an analytical model for initial flame spread (Dietenberger and White 2001).

FIRE-RETARDANT-TREATED OSB

Fire-retardant-treated wood is usually required to meet several criteria based on mechanical properties, corrosion potential with metal fasteners, and flame spread. For plywood and lumber, these requirements are in their respective AWPA standards. Many commercial FRT plywood products have been standardized or accepted by building codes and are commonly commercially available. This technology was recently reviewed Ayrilmis and others (2005).

REQUIREMENTS

A non-comprehensive list of composite product requirements might include requirements for flame spread, hygroscopicity, and mechanical properties. Fire-retardant-treated wood must have an ASTM E 84 flame spread index of ≤ 25, show no evidence of significant progressive combustion when the standard test is continued for an additional 20-min period, and show no progress of the flame front more than 3.2 m beyond the centerline of the burner at any time during the test. When materials of low hygroscopicity are needed, the material must have equilibrium moisture content of ≤ 28% when tested in accordance with ASTM D 3201, which specifies a relative humidity of 90% ± 3% and a temperature of 27°C ± 2°C. Further, when used as roof sheathing, which is commonly exposed to high thermal loads due to solar radiation, it must be tested for the effects of treatments and elevated temperatures on strength properties (ASTM D 5664 for lumber, D 5516 for plywood, or an equivalent methodology). If OSB is to increase market share in the commercial construction materials market, it must meet these or similar fire-performance requirements.

ENHANCING FIRE PERFORMANCE

If strand/flake/fiber-based wood composites such as OSB are to compete effectively with other structural panels such as plywood in the commercial or multi-family construction markets, several challenges need to be addressed. One of the greatest challenges of developing a technology for enhanced fire performance of OSB is that physical and mechanical properties of OSB are significantly reduced by swelling incurred during water-based post-production pressure-treatment processes. Many traditional adhesive resin–FR chemical technologies have been evaluated (Johnson 1964, Laufenberg and others 1986, Leao and others 1995, Liu and others 1992, Luo and others 2004, Winandy and others 2006). Traditional wood composite resins, such as urea- or phenol-formaldehyde or polymeric diphenylmethane diisocyanate, and traditional FR chemicals commonly used for solid wood, such as ammonium phosphate, various borates and boric acid complexes, and organic phosphates (such as guanylurea phosphate), have been studied. At the required resin-chemical loading levels, most combinations are either not equal in flame spread and mechanical performance or not cost competitive with FRT plywood. One significant issue is that pre-processing treatments may inhibit adhesive resin cure by interactions with traditional FR-treatment chemicals (Bergin 1963, Schaeffer and others 1966, Vick and others 1996). Still another issue related to resin–FR chemical interactions is the effect of hot-press temperatures on eventual effectiveness of the FR in meeting flame-spread requirements.

Accordingly, many new treatment options have been investigated. Vapor-boron treatments have been investigated as an alternative to liquid-boron treatments (Tsunoda 2001, Hashim and others 1997). Development of a post-production, non-swelling pressure treatment based on super-critical fluid technology has been considered (Acda and others 1996, Morrell and others 1993, Muin and Tsunoda 2004, Oberdorfer and others 2000). Surface-applied treatments have also been investigated (Shen and Fung 1972, Subyakto and others 1998), but the longevity and long-term practical effectiveness of surface treatments have not been proven. Acetylation also holds potential (Vick and Rowell 1990, Vick and others 1991), but again insufficient technical experience and current economics hamper the rapid commercialization of these technologies.

CONCLUDING REMARKS

Continued growth in the OSB structural panel market will probably occur in residential construction, but the rate of growth is not expected to increase and may even slow as residential sheathing markets become more saturated by OSB. Thus, we predict that significant portions of future growth will need to occur in other markets, such as the multi-family-residential, commercial construction, or nonconstruction markets (manufacturing, packaging, or other nontraditional uses) if the massive growth of the OSB market is to be maintained, An important requirement for total penetration of the commercial market is fire performance equivalent to that of current FRT lumber and plywood.. Strand-, flake-, particle-based composites such as OSB are often not capable of withstanding the pressure-treatment process and still retaining necessary engineering performance properties. Thus, future OSB market growth in commercial construction requires development of technologies to enhance its fire performance on par with FRT plywood.

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