WOOD STRAND CEMENT BOARD

MATTHEW ARO
University of Minnesota Duluth Natural Resources Research Institute
5013 Miller Trunk Highway, Duluth, Minnesota, USA 55811

ABSTRACT

The weight, strength, and durability properties of plywood and oriented strandboard (OSB) have made them the dominant products for residential sheathing applications in North America. However, there exist particular geographic regions where prevailing conditions promote severe weathering, fungal growth, and insect attack – these areas, largely, have prolonged periods of high humidity, warm temperatures, and moderate to heavy rainfall.

Wood Strand Cement Board (WSCB), a class of recently-developed panels composed of long and thin wood strands bonded with Portland cement, may be less susceptible than plywood and OSB to severe weathering, fungal growth, and insect attack. WSCB panels exhibit good durability, structural strength, resistance to fire, and high resistance to rot, fungal decay, and attack by termites and other vermin. Further, they are easily nailable, exhibit excellent screw-holding capacity, and can be easily painted and stuccoed. Also, because WSCB panels adhere strongly to fresh concrete, they can be used for permanent shuttering of concrete walls, pillars, and floors, such as those found in basements.

This paper will briefly describe the history of wood-cement products and explain the attributes of the recently-developed WSCB panels and describe why this class of panels may be a viable substitute for plywood and OSB in areas that exhibit harsh end-use conditions.

KEYWORDS

Wood Strand Cement Board (WSCB); oriented strandboard (OSB); Wood-Wool Cement Board (WWCB); inorganic-bonded panels; cement-bonded panels

INTRODUCTION

Solid-sawn lumber has long been used as material for roof, floor, and wall construction. As the industry's product and process knowledge increased, more durable and effective panels were developed. In North America, veneer-based plywood is commonly used as sheathing material for residential home construction because it exhibits good strength and durability properties, installation ease, and improved structural resistance to wind and earthquake loadings compared to solid wood boards (Forest Products Laboratory 1999). In the early 1980s, a new class of structural panels called oriented strandboard (OSB) was developed, partly due to the shortage of quality timber such as large-diameter trees as well as economic incentives for using small-diameter, fast-growing species (usually aspen-poplar and southern yellow pine) (Chung *et al.* 1999). OSB is manufactured by consolidating oriented wood strands with an exterior-grade resin under heat and pressure to make a reconstituted wood product with engineered properties. OSB exhibits even better weight and strength properties than plywood and has become the dominant structural sheathing material in North America. In fact, the residential construction market accounts for 65% of all OSB used in North America (Adair 2004).

Growth in some structural applications is still limited, however, because of adverse environmental conditions prevalent in the regions in which they are applied. These particular environments can put many engineered wood materials, which are already susceptible to decay and moisture, into conditions above their acceptable limits (Baileys *et al.* 2003). In particular, the fluctuation of hygrothermal loads could cause physical deterioration in the wood material leading to attack by wood-decaying microorganisms such as mold, white rot, and brown rot fungi – particularly in outdoor applications (Chung *et al* 1999). Therefore, steps must be taken to ensure their protection from damaging environmental conditions during storage and construction.

The Partnership for Advancing Technology in Housing (PATH 1999) has identified four general strategies to improve product durability:

1. Improve the performance of existing products and materials;
2. Stimulate selection of more durable products and materials;
3. Minimize premature failure due to manufacturing and installation problems; and
4. Encourage preventative maintenance and early detection.

Following these guidelines, the industry has improved the performance of OSB, plywood, and other resin-bonded wood-based panels via the addition of wax for water repellency, utilization of different wood species for enhanced resistance to biological attack, addition of biocidal chemicals, and formulation of specialized resins.

Factors Influencing Service Life of Wood-Based Panels

Environmental Factors

Generally, high temperature and humidity levels are conducive to sustaining mold, decay, and stain fungi. Moisture can enter building envelope assemblies as liquid water through leaks and capillary action, and as water vapor through infiltration of humid air and water vapor diffusion (Morse and Acker 2006). Furthermore, architectural design changes using shorter roof overhangs and closer proximity of siding to the ground line increase the opportunities for moisture intrusion (Barnes and Kirkpatrick 2005). Further still, in some areas of the world, the use of building vapor membranes can decrease the ability of moisture to escape the building cavity (Morrell 2001). For prolonged exposure to conditions of over 80% relative humidity (RH), there is potential for mold growth on OSB, plywood, and other resin-bonded wood-based panels. Therefore, panels should be protected from this type of exposure.

In addition, cycles of wetting and drying can have a deleterious effect on panel durability. Product swelling can occur, which may make the panels more susceptible to cracking, subsequently reducing the integrity of the entire structure. The cracks can accelerate wetting and drying rates of wood products and alter a building envelope's long-term performance. Research shows that OSB's moisture-absorption capacity and thickness increases after each cycle of wetting and drying, and the time required to reach maximum moisture content is greatly reduced as the panels undergo subsequent wetting and drying cycles (Kumaran and Nofal 2000). As the panels absorb more moisture, there is increased susceptibility to mold, decay, and stain fungi.

Biological Factors

Wood decay is affected by wood moisture content and wood temperature. For the most part, decay is relatively slow at temperatures below 10 degrees Celsius (°C) and above 35°C (Forest Products Laboratory 1999), but fungal growth can rapidly occur between 20°C and 35°C (Walchli 1977). As expected, comparisons of different sites in terms of their average air temperature show a tendency for shorter service lives at warmer locations (Beesley *et al*. 1983; Augusta *et al.* 2004; Grinda and Cary 2004).

The United States Forest Products Laboratory has devised a climate index map (Figure 1) to predict relative decay hazard regions in the U.S. The map is based on the mean monthly temperature and number of rainy days, and primarily estimates the decay hazard of wood exposed above ground.

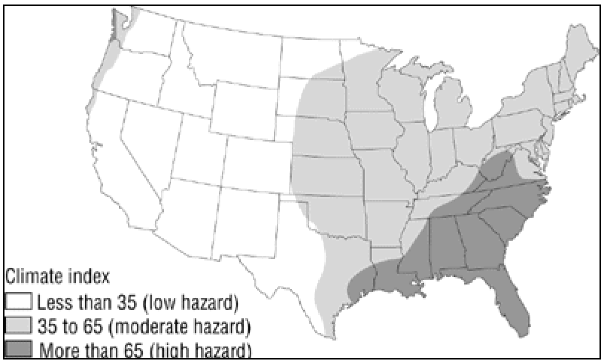

Figure 1 – Climate Index Map (Forest Products Laboratory)

Merrill *et al.* (1965) reported that fiberboard attacked by several mold fungi lost about 12-18% of its weight, resulting in a loss of strength of approximately 50%. Another study reported that conditions of 90% RH and 15-25°C produced remarkably rapid fungal growth on eight different types of wood composite boards (Wang 1992). In a comparison study on plywood, OSB, particleboard, medium density fiberboard (MDF), and solid wood, both plywood and OSB showed drastic weight loss when exposed to white rot and brown rot fungi. In particular, plywood exhibited the largest weight loss (36%) after eight weeks with OSB following a similar trend (results summarized in Figure 2) (Chung *et al.* 1999). The loss of mass that occurs when these decay fungi metabolize wood substances may provoke a substantial strength loss of wooden components (Bayerbach *et al.* 2006).

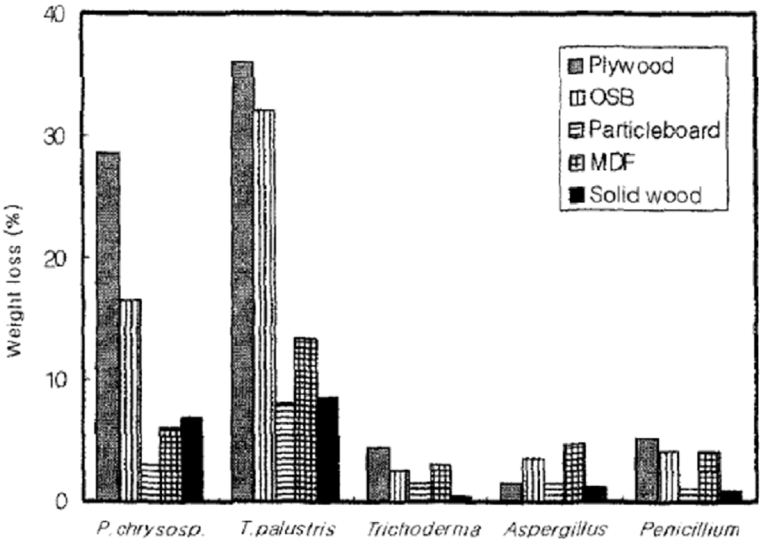

Figure 2 – Weight loss of wood composite boards exposed to various fungi (Chung *et al.* 1999)

In many countries, including those with tropical and sub-tropical climates, Formosan subterranean termites (*Coptotermes formosanus*) also pose a serious threat to wood-based materials, since wood comprises a majority of their diet. The hazard of termite infestation is greatest in an earth fill or any substructure wood component close to the ground (Forest Products Laboratory 1999). In the U.S., the greatest threat of termite infestation occurs in the southern states (see Figure 3).

Figure 3 – Range of Formosan subterranean termite (Louisiana-Pacific Corp.)

OVERVIEW OF MINERAL-BONDED WOOD COMPOSITES

As previously stated, there is much ongoing research to improve the durability and extend the service life of wood-based panels used for residential home construction. An outcome of such research is the development of new classes of mineral-bonded wood composites. These products vary greatly by the geometry of the wood particles, fibers, or strands used; processing steps; and end-use applications.

Brief History of Mineral-Bonded Wood Composites

The first mineral-bonded wood composite panels utilized a magnesite binder and were developed in Austria in the early 1900s. These products still exist today mainly for interior applications, and are currently manufactured in Europe and the U.S. by Heraklith (now Knauf Insulation) and Tectum, respectively. In Europe and the U.S., these low-density panels (approximately 400 kg/m^3) are often used as insulation boards because of their excellent thermal and acoustic properties. Soon after, cement-bonded wood composites became popular with the development of Wood-Wool Cement Board (WWCB). WWCBs are used for internal applications and for exposed decorative ceilings and roof decks, and because Portland cement-bonded WWCBs are fully moisture-resistant, they are also used successfully for permanent shuttering of concrete floors and walls, and most recently for thick and very Large Wall Elements in Scandinavia and Russia. The worldwide demand for these Large Wall Elements is expected to increase because of increasing heating and cooling costs and greater demand for personal comfort. Sophisticated and automated turn-key plants that are capable of producing several types of WWCB, Wood Strand Cement Board (WSCB), and Large Wall Elements on one combined manufacturing line are now available.

Cement-Bonded Particle Board (CBPB) is a high-density product that was developed in the 1970s to replace asbestos-cement board for structural applications. Common uses of CBPB in Europe are facades, electrically-heated and raised floors, permanent shuttering of concrete floors and walls, and fire- and moisture-resistant furniture. The applications of CBPB have been restricted by its high density (approximately 1,250-1,400 kg/m^3), reduced flexibility and strength, relatively high expansion and shrinkage when exposed to moisture, and the need to pre-drill pilot holes when attaching screws. Therefore, manufacturers, builders, and architects were interested in developing a product that could better meet structural requirements and overcome these hurdles – this was attained with the development of the new Wood Strand Cement Board (WSCB), which accepts screws without pre-drilling, and exhibits lighter weight, greater bending strength, more flexibility, and less expansion and shrinkage due to moisture than CBPB.

For a more detailed description of the history of mineral-bonded wood composites, the author refers the reader to Gerry van Elten's paper "History, Present, and Future of Wood Cement Products" presented at the 9th International Inorganic-Bonded Composite Materials Conference in Vancouver, BC, Canada. This paper can be viewed at www.eltomation.com under "Publications."

Advantages & Attributes of Mineral-Bonded Wood Composites

A unique feature of mineral-bonded wood composites is that their manufacture is adaptable to either end of the cost and technology spectrum. This means that manufacturing plants with varying levels of automation are available – from full automation to low levels of automation (which rely more on manual labor and hand-operated equipment). This is especially true with Portland cement-bonded composites because no heat is required to cure the cement binder. These composites also exhibit manufacturing versatility; with a small investment, the products can already be manufactured on a small scale using simple tools, and as the market has grown, automated equipment for their manufacture has been developed and is readily available for implementation.

In contrast to conventional urea- and phenol-formaldehyde resin-bonded wood composite panels, cement-bonded wood composites possess much higher fire, insect, and fungal resistance, in addition to good weatherability and acoustic absorption. Also, the increasing cost of resins and machinery necessary for the production of resin-bonded boards is another point in favor of mineral-bonded composites (Ahn and Moslemi 1980; Simatupang and Geimer 1990; Simatupang *et al*. 1991; Oyagade 1994; Badejo 1999; and Ajayi 2000).

In summary, the general attributes of mineral-bonded wood composites are:

- High fire resistance
- Wet and dry rot resistance
- Freeze-thaw resistance
- Termite and vermin resistance
- Excellent workability
- Exceptional insulation and acoustic performance (WWCB)
- Low cost and ease of manufacture

WOOD STRAND CEMENT BOARD (WSCB)

As previously stated, manufacturers, builders, and architects became interested in developing a product that better met structural requirements, had less of a weight penalty (such as with CBPB), more elasticity, and possessed the attributes of mineral-bonded wood composites. Now, research by Eltomation BV has led to the development of WSCB-EltoBoard – a commercially-available WSCB that has structural strength, medium density, adequate elasticity (see Figure 4), and high resistance to fire, rot, termites, and freeze-thaw damage. A further advantage of WSCB-EltoBoard over CBPB is its reduced expansion and shrinkage due to moisture.

Figure 4 – WSCB-EltoBoard elasticity

Wood Strand Cement Board Production

WSCB requires only a few common widely-available raw materials and minimal processing steps, and its manufacture is not energy-intensive. Fully-automated plants are able to produce up to 10,600 m^2 of 60 cm wide boards per day. A simplified WSCB-EltoBoard production flow chart is shown in Figure 5.

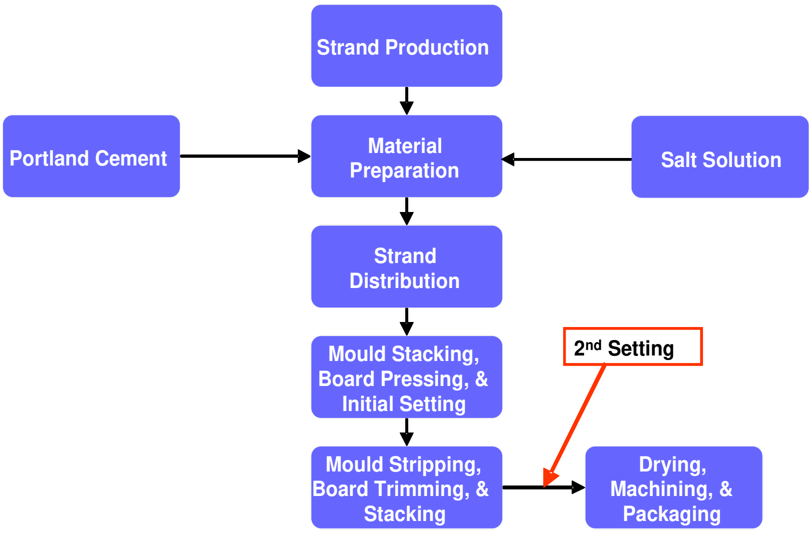

Figure 5 – Simplified WSCB-EltoBoard production flow chart

Raw Materials

The selection of cement-compatible wood species is critical for successful production of WSCB. Some species such as alder (*Alnus glutinosa*) and larch (*Larix decidua*), for example, have demonstrated limited compatibility with cement because they contain excessive amounts of tannins and/or sugars that retard the setting of cement. Therefore, it is critical to select proper species or to remove the tannins and sugars (as discussed below) before proceeding with board manufacture. Available scientific literature written by Professor W. Sandermann in the early 1960s identifies the compatibility of Portland cement with a variety of wood species. Alternately, as described by Elias *et al.* (2004) and Ferreira *et al.* (2004), one can conduct cement hydration studies to understand specific hydration characteristics such as hydration curves, maximum hydration temperatures, time to maximum hydration temperature, and decrease of heat release during the exothermic process of cement hydration; all of which give an indication of the compatibility of cement with the suspect wood species.

Generally, pine, spruce, and several hardwoods, when cut in the autumn and winter when the sap has retreated into the root system, work very well for WSCB production. Zhou and Kamdem (2002) reported that the addition of low-density wood appears to be an important factor that may influence the development of wood-cement composite panels by reducing their overall density. Further, it is known from practice that lower-density wood cuts easier and produces stronger and more flexible strands, which allows for production of WSCB with superior mechanical and physical properties.

Usually, logs with diameters of approximately 70-270 mm are cut from the forest, debarked, and seasoned outside for up to one year to remove remaining sugars and extractives that may inhibit the setting of the cement. Water-soaking of cut strands is another option for removal of sugars and extractives from certain tropical hardwoods. In this method, strands cut from green logs can be soaked in warm water for up to a few hours to remove the water-soluble cement-setting inhibitors.

Physical and Mechanical Properties of WSCB-EltoBoard

Tests completed by Moscow State Forestry University (MSFU) (2005) showed that WSCB-EltoBoard exhibits 3.94% thickness swell, 2.24% width swell, and only 1.22% length swell after a 24-hour water soak. MSFU also reports that WSCB-EltoBoard exhibits 0.5% and 0.4% thickness swell when going from 30% RH to 65% RH and 65% RH to 85% RH, respectively. Other tests conducted on WSCB-EltoBoard by MSFU are presented in Table 1. Similar testing completed by the Institute for Tests and Research of Building Materials (IKOB) (2002) shows 0.35% of swelling when WSCB-EltoBoard is submersed in water for 66 hours; only 0.12% shrinkage when boards go from fully-saturated condition to reconditioned in air at

20°C and 65% RH; and 0.20% shrinkage when the boards go from conditioned at 20°C and 65% RH to oven dry. Note that the test results presented by IKOB show WSCB-EltoBoard performs much better than CBPB; however, they also show much better (and different) values than those presented by MSFU. Because of the varied results, the author recommends that more testing be done to further define the swelling and shrinkage properties of WSCB-EltoBoard.

When compared to CBPB, WSCB-EltoBoard exhibits less expansion and shrinkage due to moisture. This is because a large portion of the strands are oriented in the longitudinal direction; they are much better aligned and situated fully parallel to the plane of the board. Because wood expands and shrinks less length-wise as opposed to across the fibers, WSCB-EltoBoard performs much better than CBPB (where the wood particles are mainly situated at random positions in the boards), especially in the longitudinal direction. This difference can be increased if the wood strands are oriented even more in the longitudinal direction of the board during distribution, which will accordingly increase bending strength, flexibility, and swelling and shrinkage properties in the longitudinal plane. Thus, length swell is much lower than thickness and width swell – this is especially advantageous when WSCB-EltoBoard is manufactured in long planks for exterior cladding.

According to German DIN 4102, WSCB-EltoBoard is non-combustible (Class B1).

Parameter	GOST Norm*	Average Values
Density	GOST 26816-86	1,130 kg/m^3
Moisture content	GOST 26816-86	6-10%
Modulus of rupture (MOR) (10mm thickness)	GOST 26816-86	20.3 N/mm^2
Hardness	GOST 11843-76	42.6 N/mm^2
Impact strength	GOST 11842-76	1720 Dzh/m^2
Screw pulling force	GOST 10637-78	76.8 N/mm
Thermal conductivity		0.21 W/(m*K)
Frost resistance	GOST 8747-88	<1.7% decrease in strength

Table 1 – Properties of WSCB-EltoBoard (*GOST Norm is a governmental Russian State quality norm similar to DIN or ISO) (Moscow State Forestry University)

Decay Resistance of WSCB

WSCB is especially desirable for use in warm and humid climates where termite and fungal decay are problematic. Both the alkaline pH of the cement/wood matrix and the physical encapsulation of wood fibers by the cement matrix prevent biological attack. Because of this quality, wood-cement composites have even been put into service in below-ground applications (such as permanent shuttering of concrete foundations, basements, and walls) where decay hazards are expected to be severe (Hodgson 1985 and Inoue 1987).

Wood-cement composites have high resistance to biodegradation, especially against fungi (Ferreira *et al.* 2004), and should continue to perform well in many exterior environments. It appears that fungi control the pH of their environment in the process of decaying wood, and brown rot fungi in particular, can lower the pH of the microenvironment to 2.0 or lower (Green *et al.* 1991 and Jellison *et al.* 1992). It is thought that this acidic environment is necessary to cause certain metabolic and extracellular chemical mechanisms associated with the breakdown of wood by the fungi (Goodell *et al.* 1997; Hyde and Wood 1995; and Shimada *et al.* 1994). As described by Goodell *et al.* (1997), the production of oxalate crystals by the fungi and packed into the wood cell lumens suggests that the fungi are trying to neutralize the high pH associated with the cement matrix, but they are unsuccessful in doing so.

The resistance to biological attack has been tested extensively in WWCB and CBPB but, only until recently, has it been examined in WSCB. Papadopoulos (2006) compared the resistance of WSCB and commercial

OSB to decay by brown and white rot fungi after 16 weeks of exposure. The results of his research are presented in Table 2. To summarize, he found that both fungi failed to attack the WSCB, and that higher cement:wood ratios provided greater resistance to fungal decay. *(Great care must be taken, however, to ensure that the cement:wood ratio is within the proper range. Research suggests that a cement:wood ratio of approximately 2.0 yields WSCB with optimal physical and mechanical properties).*

	Brown Rot Fungi	**White Rot Fungi**
Cement:Wood Ratio	**Weight Loss (%)**	**Weight Loss (%)**
1.5	5.25	7.33
2.0	0.72 (0.06)	3.24 (0.55)
3.0	-3.21 (0.59)	-2.22 (0.7)
Commercial OSB	11.22 (2.11)	28.25 (3.21)

Table 2 – Weight loss of experimental WSCB panels after 16-week exposure to decay fungi. (The standard deviations are in parentheses "( )." Each value is the mean of eight samples) (Papadopoulos 2006)

Applications of WSCB-EltoBoard

WSCB-EltoBoard offers durability, structural strength, and resistance against fire, moisture, termites, and fungi; thus, it is suitable for a wide range of internal and external applications. In Europe and Asia, WSCB-EltoBoard is used in the general construction industry as well as for refurbishment of residential, industrial, commercial, and agricultural buildings. It can be nailed, screwed, and stapled using standard tools, and can accept a wide range of finishes such as mortar, plaster, and paint. It can also be embossed with a fully-closed and textured surface to imitate wood grain, brick, or natural stone patterns.

Some applications for industrial and developed countries are:

- Flooring and underlayment
- External siding
- Permanent shuttering for concrete forming systems
- Prefabricated houses
- Sound barrier walls

Some special applications for developing countries are:

- Medium- and low-cost housing
- Corrugated roofing boards
- Roofing shingles

Handmade WSCB of relatively low density (900 kg/m^3) has been used successfully for medium- and low-cost housing and other applications in the Philippines as illustrated in Figures 6-9. Please see the author's accompanying PowerPoint presentation "Wood Strand Cement Board" for more pictures of WSCB utilized in medium- and low-cost housing applications in the Philippines.

Figure 6 – WSCB-EltoBoard siding and shingles

Figure 7 – All exterior and interior walls, floors, and facade cladded with WSCB-EltoBoard (painted)

Figure 8 – Two-story house entirely constructed with WSCB-EltoBoard. The exterior ground-floor walls have been stuccoed

Figure 9 – Interior of house shown in Figure 8 with WSCB-EltoBoard floor, ceiling, and walls (painted)

CONCLUSION

WSCB-EltoBoard has the potential to substitute for plywood and OSB sheathing in the construction and refurbishment of residential, industrial, commercial, and agricultural buildings – especially in environments with consistently warm temperatures, high humidity, and moderate to heavy rainfall. It is a versatile material that is suitable for both interior and exterior applications. It is durable; highly resistant to fire, water, rot, freeze/thaw damage, and biological decay; easily workable with standard wood-processing tools; and can be manufactured to meet structural strength requirements. However, further research and testing is needed to ensure that WSCB-EltoBoard panels meet proper end-use requirements and any applicable building codes.

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