Over 95 percent of the approximately 1.5 million homes constructed in the United States each year are framed with wood, the world’s most sustainable building material. Wood-based composites, including structural composite panels and engineered composite lumber, are being increasingly utilized in both interior and exterior applications and frequently are the principal structural elements in buildings. These applications include sheathing, floors, I-beams, door and window components, joists, and molded wall panels as both skin and structural elements.

The exterior application of structural wood composites has led to increased exposure of the materials to wetting, and consequently, to decay fungi and insects (primarily termites). For example, widespread infestations of the Formosan subterranean termite (Coptotermes formosanus Shiraki) in southern Louisiana have caused damage estimated in the hundreds of millions of dollars. Formosan subterranean termites pose a major threat to all cellulosic building materials because they consume wood much faster than native subterranean termites, and their colonies are more than 10 times larger than those of native termites. It is the most destructive insect in Louisiana. Other states recording infestations include Alabama, California, Florida, Georgia, Hawaii, Mississippi, North Carolina, South Carolina, Tennessee, and Texas. Mold, decay, and other moisture-related problems have also led to significant economic losses in the building industry. Wood composites are particularly vulnerable to these biological attacks, if unprotected.

Durability concerns have historically been addressed through the use of chemical treatments employing a variety of application methods, includ-
Structural wood composites are manufactured by heat and pressure consolidation of wood furnish (i.e., strands, particles, veneer, and fiber) coated with adhesive, and may incorporate wax. The modern manufacturing process represents a fine balance of raw material (i.e., wood, resin, wax, and other additives) and production variables (e.g., mat forming, pressing temperature, and time) in terms of costs and product performance. The addition of a preservative component or the use of chemically modified furnish may have a major effect on product properties and often requires changes in the manufacturing process. A number of factors need to be taken into account when developing such a system. These factors include the nature of the preservative (e.g., solid or liquid, heat stability, diffusivity during consolidation, solid or liquid), the nature of the wood furnish (e.g., species and dimension), the nature of the adhesive (e.g., phenol-formaldehyde [PF] versus polymeric diphenylmethane diisocyanate [MDI]), the influence on panel properties from interaction of preservative with adhesive and wood, and the methods of preservative incorporation.

Preservative treatment of wood has a long history in the United States and can be traced back to the early 1800s. Two comprehensive reviews were recently made by Evans (2003) and Freeman et al. (2003) on wood preservatives, treating processes, and emerging protection technologies for wood and wood composites. In general, the preservatives for wood and wood products are designed to consider health, safety, and environmental properties for manufacturers and consumers; product life cycle; compatibility and adaptability of manufacturing processes, resin, and additive systems; stability and consistency in the manufacturing process; final board properties; durability; and other related issues.
nish; 2) in-line or integral treatment during the manufacturing process; and 3) post treatment of finished products.

**Pretreatment of Wood Furnish**

Wood furnish can be pretreated with a preservative through either pressurized or non-pressurized (i.e., spraying or dipping) processes. The treated furnish is then dried and used for composite manufacturing. With an appropriate combination of preservative and adhesive, these processes can provide a product with a constant loading of preservative throughout its thickness. Development of such manufacturing processes can also help recycle treated wood (e.g., wood treated with chromated-copper-arsenate [CCA]) through a composite process.

There are some concerns when furnish is treated. Emissions from the driers and pressing operations can be an issue with respect to current clean air regulation compliance. Clean air regulations can be adhered to; however, additional equipment may be required when implementing a new treatment system. Treated wood furnish that is not used can be another concern. Waste materials such as trimmings and sawdust are treated and then disposed of, which means costly preservatives have been wasted. Another example is during “ramp up” and “ramp down,” which is when the product line is changed from non-treated to treated furnish and back again from treated to non-treated furnish. This transition period creates products that do not have the level of treatment required to carry the treatment label. Therefore they must be sold at a lower non-treated price or accounted for by other means, and both of those options increase the treating costs. Another concern is that the disposal of preservatives and treated waste products is getting more difficult and expensive.

Pretreatment processes are viable, however. Pressure treatment of chips or flakes with a combination of insecticide and fungicide is being used for treatment of OSB, plywood, laminated veneer lumber (LVL), medium density fiberboard (MDF), particleboard, and hardboard. This includes combinations of 3-iodo-2 propynyl butyl carbamate (IPBC) and various insecticides in a light hydrocarbon solvent for protection against termites, decay, and mold. This process provides a durable panel, but is not inexpensive.

Chemical modification of wood furnish with polymer systems also provides a way of producing composite products with improved decay, insect, and dimensional performance properties. Among the polymers, isocyanates have proven to be very effective modifying agents, reacting with the wood constituents to form cross-linkages. This crosslinking reduces the adsorptive nature of wood and makes it less susceptible to attack from biotic agents. The challenge is to produce modified wood with low weight gain and without losses in properties common to many of the current methods such as acetylation. Wood modification has the potential for lessening the environmental impact found with some conventional systems of wood protection.

Another chemical modification under consideration includes low molecular weight PF. Treatment levels of 10 to 23 percent by oven dry weight of furnish were found to help stabilize OSB, increase bending modulus of elasticity (MOE) and modulus of rupture (MOR) properties, and provide resistance to decay and Formosan subterranean termites. It was not found to provide adequate resistance to mold.

**In-line or Integral Treatment**

In-line treatment refers to the process whereby the active preservative ingredients are combined with dry wood furnish before mat forming and hotpressing. Organic and inorganic active ingredients are used. Included are fungicides, insecticides, and water repellents, either singly or in combination. The preservatives are applied to wood in two ways:

- Spraying the preservative directly to dry wood furnish in blenders. This is often done for strand-based structural composites such as OSB and parallel strand lumber (PSL) with powder-type preservatives (e.g., zinc borate).
- Premixing the preservative with resin and spraying the mixture to wood furnish. This process is often referred to as glueline treatment and is mainly applied in products made from veneers such as LVL and plywood.

In both methods, it is critical to assure good distribution throughout the treated composite. Active ingredients must be capable of withstanding the processing temperatures of up to 220°C associated with production, and they must be compatible with the resins used. Since they are distributed throughout the thickness of the substrate, the treatments
can offer long-term protection against decay, mold, insect attack, and water intrusion.

Organic waterborne water-repellent preservative systems similar to those used to protect solid lumber have also been developed and tested for structural composite products. The biocides (i.e., fungicides based on iodo-carbamates, triazoles, and isothiazalones, and insecticides based on synthetic pyrethroids and nicotinimides) can be introduced as furnish treatments during manufacturing to provide insect, water, and fungal resistance of structural composites.

Inorganic borates are being used as an additive during panel manufacturing to provide structural composite panels with required biological resistance. Among these products, disodium octaborate tetrahydrate (DOT) has the ability to diffuse into engineered wood products, making it useful as a component of penetrating barrier surface treatments during manufacturing to provide insect, water, and fungal resistance of structural composites.

Recent research on durability analysis of borate-treated structural panels has shown that calcium borate can also be used in this application. Calcium borate with an appropriate particle size can be successfully used to protect OSB bonded with PF resin with required mechanical strength and biological resistance. Leaching of zinc borate or calcium borate from OSB under direct water exposure is still a problem. The use of pMDI resin can help reduce the leaching problem, especially for OSB products treated with calcium borate. However, the process will increase the cost of manufacturing. Thus, it is desirable to develop non-leachable borate systems for exterior applications. Hydrated sodium calcium borate hydroxide (NaCaB5O6(OH)6·5H2O), often known as Ulexite, has also been studied for treating structural wood composites. Neither calcium borate nor Ulexite is yet registered as a wood preservative with the U.S. Environmental Protection Agency (EPA).

Long-term structural performance under sustained loading conditions is one of the major concerns with the use of borate-treated composites in structural applications. It has been shown that boards bonded with both phenolic and isocyanate adhesives can display a reduction in bending strength upon the incorporation of borate. Thus, durability issues of borate-treated structural composites will arise both in load-bearing (e.g., OSB shear walls, roofs, and I-beams) and non-load-bearing (e.g., OSB siding and sheathing) situations. When this occurs, adjustments in resin content or board density have to occur to comply with strength requirements, which may significantly increase manufacturing costs.

The influence of cyclic environmental exposure can also affect the extent of degrade. Because borate is an inorganic salt, it diffuses throughout the wood with moisture movement. In some situations, such as roofs, elevated temperatures and humidity changes cause shifts in the equilibrium moisture content of the wood. As the moisture moves, so do the inorganic salts. This cycling could cause migration of the salts within the wood. At each new site, the acidic salt can cause further degradation.

A study reported by Q. Wu and J.N. Lee in 2002 demonstrated creep performance of zinc and calcium borate-treated OSB under both constant and varying moisture conditions. In that study, the influence of initial borate content, wood species, and stress level on the creep deformation was studied. Under constant moisture condition, there was almost no difference in creep for boards at various borate levels for either type of borate. The creep data were fitted well with a spring-dashpot model. Predicted fractional creep validated the current adjustment factor up to a 30-year duration under a constant moisture content level. Under constant moisture condition, however, large creep deflection developed due to the mechano-sorptive effect. The effect of borate on wood deformation became significant for OSB treated with either zinc borate or cal-

Engineered wood products including I-beams and LSL treated with IPBC plus insecticide in Hawaii. The studs were treated with ammoniacal copper zinc arsenate (ACZA) in 2000, when ACZA was still allowed.
# Overview of Structural Wood Composites and Treatments

<table>
<thead>
<tr>
<th>Structural Composite Product</th>
<th>Treatment Methods*</th>
<th>Commercialized Treatments</th>
<th>Emerging Treatments</th>
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<td>Glulam timbers</td>
<td>Pretreat laminates (pressure)</td>
<td>Waterborne preservatives (CCA, CA-B, ACQ, etc.)</td>
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<td>Oilborne (penta, creosote, copper naphthenate, copper-8); Waterborne (CCA, copper azole, ACQ) Light organic solvent-based treatments (LOSP)</td>
<td>Penetrating barrier treatment with proprietary borate formulations and organics**</td>
</tr>
<tr>
<td>Plywood (softwood)</td>
<td>Preservative applied directly to green veneer</td>
<td>Low molecular weight phenol-formaldehyde</td>
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<tr>
<td></td>
<td>Preservative applied directly to dry veneer prior to application of adhesive</td>
<td>Fungicides (propiconazole, tebuconazole), insecticides (permethrin, deltamethrin, bifenthrin, imidacloprid)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preservatives mixed with adhesive, then applied</td>
<td>Fungicides (propiconazole, tebuconazole), insecticides (permethrin, deltamethrin, bifenthrin, imidacloprid), arsenic trioxide</td>
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</tr>
<tr>
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<td>Post manufacture penetrating surface treatments</td>
<td>Penetrating barrier treatment with proprietary borate formulations and organics**, glycol/borates</td>
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</tr>
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<td></td>
<td>Post manufacture pressure treatment</td>
<td>Waterborne (CCA, CA-B, ACQ, DOT); Light hydrocarbon solvent formulations of a fungicide (IPBC, propiconazole, tebuconazole) with or without an insecticide (chlorpyrifos, permethrin)</td>
<td></td>
</tr>
<tr>
<td>Laminated Veneer Lumber (LVL)</td>
<td>Preservative applied directly to green veneer prior to drying and application of adhesive</td>
<td>Low molecular weight phenol-formaldehyde</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preservative applied directly to dry veneer prior to application of adhesive</td>
<td>Fungicides (propiconazole, tebuconazole), insecticides (permethrin, deltamethrin, bifenthrin, imidacloprid)</td>
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</tr>
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<td></td>
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<tr>
<td></td>
<td>Post manufacture pressure treatment</td>
<td>Light hydrocarbon solvent formulations of a fungicide (IPBC, propiconazole, tebuconazole) with or without an insecticide (chlorpyrifos, permethrin); oilborne treatments (pentachlorophenol, copper-8)</td>
<td></td>
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</tr>
</thead>
<tbody>
<tr>
<td>Parallel Strand Lumber (PSL)</td>
<td>Preservative applied directly to green strands prior to drying and application of adhesive</td>
<td>Low molecular weight phenol-formaldehyde</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preservative applied directly to dry strands prior to application of adhesive</td>
<td>Fungicides (propiconazole, tebuconazole), insecticides (permethrin, deltamethrin, bifenthrin, imidacloprid)</td>
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<tr>
<td></td>
<td>Preservative mixed with adhesive, then applied</td>
<td>Fungicides (propiconazole, tebuconazole), insecticides (permethrin, deltamethrin, bifenthrin, imidacloprid)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post manufacture penetrating surface treatment</td>
<td>Penetrating barrier treatment with proprietary borate formulations and organics**, glycol/borates</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post manufacture pressure treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laminated Strand Lumber (LSL)</td>
<td>Blending with strands</td>
<td>Zinc borate</td>
<td>Low molecular weight phenol-formaldehyde, calcium borate and other boron compounds, copper complexes and organic fungicide/insecticide blends</td>
</tr>
<tr>
<td></td>
<td>Post manufacture penetrating surface treatment</td>
<td></td>
<td>Glycol/borates, penetrating barrier treatment with proprietary borate formulations and organics**</td>
</tr>
<tr>
<td></td>
<td>Post manufacture pressure treatment</td>
<td>Light hydrocarbon solvent formulations of fungicides and insecticides (IPBC plus chlorpyrifos or permethrin)</td>
<td></td>
</tr>
<tr>
<td>Oriented Strandboard (OSB)</td>
<td>Preservative applied directly to green strands prior to drying and application of adhesive</td>
<td>Copper</td>
<td>Low molecular weight phenol-formaldehyde</td>
</tr>
<tr>
<td></td>
<td>Blending with strands</td>
<td>Zinc borate, copper complex, cypermethrin or permethrin, low molecular weight phenol-formaldehyde</td>
<td>Calcium borate and other boron compounds, copper complexes and organic fungicide/insecticide blends</td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>I-joists / I-Beams</td>
<td>Assemble from pretreated components</td>
<td>See relevant descriptions above</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post manufacture pressure treatment</td>
<td>Light hydrocarbon solvent formulations of a fungicide (IPBC, propiconazole, tebuconazole) with or without an insecticide (chlorpyrifos, permethrin)</td>
<td>Additional organic insecticides such as deltamethrin, bifenthrin and imidacloprid</td>
</tr>
<tr>
<td>Particleboard</td>
<td>Blending with furnish</td>
<td>Organic insecticides (e.g. permethrin) and fungicides</td>
<td></td>
</tr>
<tr>
<td>Fiberboard products</td>
<td>Blowline blending with dry fibers</td>
<td>Zinc borate, boric acid</td>
<td></td>
</tr>
</tbody>
</table>

*Method of treatment and preservative actives used will depend on intended end-use (ref. AWPA Use Category System).
**Penetrating barrier systems include various combinations of synthetic pyrethroids, nicotinimides, and borates with proprietary chemistries to facilitate penetration.
cates the need for studying long-term duration of load properties of the modified OSB under combined mechanical and moisture loadings.

**Post Treatment of Finished Products**

Post manufacturing treatments are applied to structural wood composite products either through pressure impregnation, immersion, or spray applications. These provide an envelope of protection to the substrate and can be designed to provide either short-term or long-term resistance to insects, mold, decay, and/or water intrusion. Short-term treatments are surface applications that often are utilized to protect building materials through transportation, storage, and the construction process. Their major advantage is that they are relatively easy to apply and can be very cost effective. Long-term treatments include both pressure impregnation and surface treatments. These surface treatments involve newer chemistries that enhance penetration of the preservative.

Pressure treatment of laminated beams and plywood with both oilborne and waterborne preservatives is well known. In addition, most preservative types can be incorporated through pressure to LVL and PSL. Since CCA was voluntarily removed from the residential construction market in January 2004, the following preservatives have seen increased use: ammoniacal/alkaline/amine copper quat (ACQ-B, ACQ-C, ACQ-D), copper boron azole (CBA), and copper azole-type B (CA-B). LVL and PSL products can also be pressure treated with pentachlorophenol (PCP), copper naphthenate (CuN), and ammoniacal copper zinc arsenate (AZCA) but only in certain end-use categories as defined by the American Wood-Preservers’ Association and allowed by EPA regulations.

Other inorganics include the organophosphates, chlorinated aromatics, and benzimids. Hawaii building codes require treatment of all wood construction materials including all engineered wood products. To accommodate these codes, combinations of 3-iodo-2 propynyl butyl carbamate (IPBC) and an insecticide such as chlorpyrifos or permethrin in a light hydrocarbon solvent are used to pressure treat laminated beams, PSL, LVL, OSB, and I-joists to protect against termites and decay. They tend to be relatively expensive but have been shown to provide excellent performance during service.

The use of surface treatments combined with diffusible preservatives such as borates offers deeper protection by forming a “penetrating barrier” of protection. In these systems, the face components...
remain at the surface where they are most needed to form a protective barrier against mold, insects, and surface moisture. The diffusible components penetrate to provide deeper protection against decay and insects. This penetration is achieved through a variety of compounds including synthetic pyrethroids, nicotinimides, and borates. Treatments incorporating tri-alkyl nitrogen oxide compounds as adjuvants synergistically increase or facilitate penetration of the active ingredients through the wood furnish and gluelines. This combination of ingredients penetrates to the core of engineered wood products to provide protection against decay, termites, and mold. This process is being used in New Zealand and meets their H1.2 specification. Its use is currently being introduced in the United States. Penetrating barrier treatments are relatively easy to apply to most structural wood composites and can be cost effective since only finished material is being treated.

Vapor boron treatments have been examined as another way to post treat structural wood composites. This method involves exposing wood products to the volatile boron compound vapor trimethyl borate (TMB), which leads to hydrolysis of the ester and deposition of the active preservative ingredient boric acid in the wood. Most boron esters are hydrolytically unstable and the reaction proceeds very rapidly with any water present within the wood product. To date, however, vapor boron treatments have not been found to be commercially viable.

Glycol/borate applications can also be used for post treatment of finished products. They have been shown to be effective as in-situ treatments for protection against Formosan subterranean termites on solid wood studs and non-wood construction materials. The boron component in this mixture appears to be picked up by the termites when they build their tubing over the treated material. As termites ingest the boron through normal social insect activities (e.g., cleaning each other) mortality occurs. Since termites will then abandon this route, untreated wood located above the treated material will not be reached by the termites, thereby protecting it from damage. A major supplier of engineered wood products has also tested structural composite products sprayed with glycol/borate with a mold inhibitor. No adverse effects on bending shear properties were found.

Mold treatments are most commonly a post manufacturing application since mold is primarily a surface phenomenon. Mold inhibitors include treatments of iodo-organics, azoles, isothiazolones, and borates for protection of OSB, LVL, hardboard, and MDF. Various levels of treatment performance can be obtained, increasing in cost as greater mold resistance is achieved. This requires a decision by the manufacturer of the product as to the desired level the product label should carry. Low-level resistance may provide protection through product storage, medium resistance may provide protection through product delivery and construction, and high resistance may provide protection for a year after wall closure.

FUTURE RESEARCH DIRECTIONS

Structural wood composites, including engineered composite lumber, are the future. The durability of these products is increasing greatly but needs continual improvement. The successful incorporation of preservatives in structural wood composites, however, must consider the effect of the
chemical on the chemical interaction with the resin used, the physical properties of the composite, the distribution of biocide within the composite, the efficacy of the treated composite, and the effect of manufacture on composite properties. Suggested specific research needs are as follows.

**Successful commercialization of treated structural composite products depends on the development of a cost-effective manufacturing process and a solid market base.**

- Continued development of new generations of “environmentally friendly” preservatives applicable to structural wood composites. The emerging technology should include suitable replacements for CCA, including ground contact.
- Development of an information database on fungal flora and insects as related to wood species, resin type, and service situations. This information would permit more useful laboratory testing of products and preservatives.
- Better understanding of moisture relations in panel products in conjunction with finishes and overlays. This information would permit more understanding of moisture requirements for common rot fungi development in panel products.
- Better understanding of wood-adhesive/preservative interaction at the glueline under hygro-thermal treatments experienced during hot-pressing of composite products. A promising technique is based on micro-thermal analysis. The technique combines the high positioning accuracy and imaging capabilities of scanning probe microscopy (i.e., atomic force microscope) with methods of localized thermal analysis. The technology allows investigation of the spatial variations in thermal-mechanical properties within the composite interphase region to study complex interactions among wood, adhesive, and preservatives.
- Better understanding of micro-distribution of preservatives within treated panel products. For borate systems, the low molecular weight of boron makes it very difficult to determine its distribution within the glueline and wood using traditional methods (e.g., EDAX-SEM system).
- Assessment of structural performance of treated composites under combined mechanical and moisture loading for structural applications.
- Development of useful and reproducible test methods to assess decay, leaching, mold, and termite resistance properties of treated structural composite products. Existing American Wood-Preservers’ Association and American Society of Testing and Materials test methods were developed primarily for solid wood. The unique properties of composite materials (e.g., swelling) and new end-use requirements suggest that new test methods should be established and evaluated.

**CONCLUSIONS**

Treated structural engineered composite products have a strong future. As the type of timber available for use in forest products continues to change and the demand for exterior-use products continues to grow, there will be an increasing need for fungal- and insect-resistant structural composites. The development of these products is especially important since these materials are critical to almost all wood structures.

Successful commercialization of treated structural composite products depends on the development of a cost-effective manufacturing process and a solid market base. Even though the need for these products is great for protection against decay and insects, there is not yet a large consumer demand from either the building industry or homeowners. Incorporating treated product use in building codes is one way to encourage demand. Another approach, which can be done simultaneously, is educating builders on how these products can increase their revenues and home buyers on how the benefits of using treated structural composite products far outweigh any additional construction costs they may incur.

**SELECTED BIBLIOGRAPHY**


