New Technologies and Materials For Bonding Wood Products

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The health of the wood products industry in the United States is controlled to a great extent by the rate of housing construction, which is in turn controlled by the health of the economy and by demographics. Within the wood products industry, the greatest use of wood adhesives by far is for manufacturing composite panels, for example softwood plywood, particleboard, waferboard, oriented strandboard (OSB), medium density fiberboard (MDF), hardboard and hardwood plywood.

Softwood plywood is made from Douglas fir veneer in the Northwest or from southern pine veneer in the southeastern states. Its major use is in construction, where it is employed for structural sheathing in flooring, roofing and walls, as well as for concrete forms. Virtually all softwood plywood in the United States is bonded with phenol-formaldehyde (PF) adhesives. On a volume basis, softwood plywood is the predominant wood panel product in the United States.

Particleboard is made from small particles (about 1-10 × 0.1-1 × 0.1-1 mm), whereas MDF is made from wood fibers and has a more uniform structure. Almost all U.S. particleboard is bonded with urea-formaldehyde (UF) adhesive, while MDF is made with both UF and PF adhesive. Particleboard is used as subflooring and as the core for furniture and cabinets. UF-bonded MDF is also used as the core for furniture and cabinets, while PF-bonded MDF is used for exterior siding for houses.

Hardboard is a relatively high density fiberboard made either without adhesive or with PF adhesive. Its applications include furniture, cabinets and exterior siding; in the last case, the product is similar to PF-bonded MDF.

Waferboard particles are approximately square (about 25-75 × 25-75 × 0.5-1 mm). Flakeboard particles are a little thinner than wafers and somewhat longer than they are wide (about 10-75 × 10-75 × 0.25-0.5 mm); strands have an even larger length-to-width ratio (about 10-75 × 5-75 × 0.25-0.5 mm). Oriented strandboard is usually made in three layers, alternating 90° in orientation. These products are becoming more widely used as substitutes for softwood plywood in construction because of their lower cost. They are mostly bonded with PF adhesive, although the use of isocyanate adhesive may grow here. The PF adhesive for waferboard is a solid powder, whereas for OSB it is liquid.

Hardwood plywood is used mostly as an interior wall paneling and is bonded with UF adhesive.

Figure 1 (1-8) summarizes the production levels for these various panel products in the United States for the past few years and in some cases provides an extrapolation to 1995. In conformance with U.S. practice, the data are given in panel surface area for thicknesses that differ somewhat for different products. Several interesting points emerge from this figure:

- Waferboard and OSB use is growing rapidly and at an accelerating rate.
- Softwood plywood is certainly the predominant product and will remain so for the near future, despite the fact that the supply of large logs for making veneer has been decreasing for some time and despite the growing use of waferboard and OSB. This strength of the softwood plywood industry is due in great part to the vigor with which it has developed and implemented new bonding and production methods, two of which will be discussed later.
- Both particleboard and MDF production continue to grow. On a percentage basis, the MDF growth is especially strong. To what extent such growth will continue if formaldehyde regulations are tightened greatly is not clear at this point.

1 Hardboard and hardwood plywood panel production are both falling.

Adhesive Use and Prices

The reason I have emphasized wood panel production is that those products use the largest quantities of wood ad-
Adhesives, which happen to be predominantly UF and PF. This predominance is clearly shown in Figure 2, which plots adhesive usage for wood bonding in 1986 versus adhesive type. Sales are given in metric kilotons for adhesives as sold, i.e., for resin solids plus solvent as appropriate. Sales ranged from nearly 800 kilotons for both UF and PF down to just over 1 kiloton for polyvinyl acetates (PVAs).

Table I provides more detailed information about 1986 sales, including total sales value, unit prices and the major wood bonding applications of each adhesive type. Points to be noted here are:

- UF adhesives are clearly the least expensive, followed by PFs; as noted earlier, these two are by far the major types used.
- Next in order of use are the mastics — the elastomeric, gap-filling adhesives that are widely used in construction applications such as bonding panel skins to wood frames. These are made with a variety of polymers, but the major one is probably styrene-butyadiene rubber.
- Resorcinol-formaldehyde adhesives are quite expensive and are used in structural applications where durability may be important and where elevated cure temperatures are not necessary. They are often used as phenol-resorcinol-formaldehyde systems. Their primary application is in making laminated lumber and beams.
- Melamines are relatively expensive in the United States compared to UFs and PFs, and their use is relatively low. Their application is in laminating and in finger jointing, and they are often cured by radio frequency (RF).
- Isocyanates are also somewhat expensive and are used to a limited extent in waferboard, usually in the core layers.
- PVA adhesives are moderately costly and are used primarily in the furniture industry for assembly of components and in mobile homes for bonding panels to wood frames.

**New Adhesives**

What can be said about wood adhesives in the future? New technologies and new products are continually being introduced. In addition, there is the possibility of using low quality forest-derived materials more efficiently and cost effectively.

**Research is under way to develop new wood adhesives from renewable resources.**

Except for two major uncertainties, there is every reason to expect that UF and PF systems will continue to be the dominant wood adhesives in the United States. The two uncertainties are the possibility of much more stringent regulations of formaldehyde-containing products and the possibility of limitations or interruptions in the supply of petrochemicals. One result of these two uncertainties is that considerable research has been conducted in the area of developing new wood adhesive systems from renewable resources.

Adhesives From Renewable Resources. After the second world war, the U.S. wood products industry began a shift from the so-called “natural” adhesives based on animal and vegetable proteins and on casein to synthetic adhesives. In recent years, however, industry has been strongly supportive of research aimed at developing adhesives from renewable resources for the reasons outlined previously.

U.S. industry now uses synthetics almost entirely and has, therefore, become highly dependent on a continuous oil supply at reasonable prices. But, as the 1973 oil embargo clearly emphasized, the possibility of supply interruptions exists, and the certainty of an eventual supply depletion must be faced. Additionally, of course, the formaldehyde emission problem exists.

Three general areas of research are being followed in the renewable resource area (9). First is the effort to derive the current resin synthesis precursors from renewable sources, for example, the extraction or pyrolysis of pulping liquors to produce phenols and resorcinols or the oxidation of naturally produced methane to formaldehyde.

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**Table I — 1986 U.S. Adhesive Sales and Price***

<table>
<thead>
<tr>
<th>Adhesive</th>
<th>Major application</th>
<th>Sales (metric kton)</th>
<th>Sales value (Million $)</th>
<th>Price ($/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea-formaldehyde</td>
<td>Particleboard</td>
<td>700</td>
<td>142</td>
<td>0.09</td>
</tr>
<tr>
<td>Urea-formaldehyde</td>
<td>Hardwood plywood</td>
<td>45.4</td>
<td>11</td>
<td>0.11</td>
</tr>
<tr>
<td>Phenol-formaldehyde</td>
<td>Softwood plywood</td>
<td>681</td>
<td>195</td>
<td>0.13</td>
</tr>
<tr>
<td>Phenol-formaldehyde</td>
<td>OSB</td>
<td>82</td>
<td>33</td>
<td>0.18</td>
</tr>
<tr>
<td>Phenol-formaldehyde (powder)</td>
<td>Waterboard</td>
<td>30</td>
<td>33</td>
<td>0.50</td>
</tr>
<tr>
<td>Resorcinol-formaldehyde, phenol-resorcinol formaldehyde</td>
<td>Laminated lumber</td>
<td>3.6</td>
<td>17</td>
<td>2.10</td>
</tr>
<tr>
<td>Melamine-formaldehyde</td>
<td>Laminated lumber and finger joints</td>
<td>1.4</td>
<td>3</td>
<td>1.00</td>
</tr>
<tr>
<td>Isocyanate</td>
<td>Waferboard</td>
<td>1.4</td>
<td>2</td>
<td>0.67</td>
</tr>
<tr>
<td>Polyvinyl acetate</td>
<td>Furniture, doors, mobile homes</td>
<td>1.1</td>
<td>2</td>
<td>0.80</td>
</tr>
<tr>
<td>Mastic</td>
<td>Construction</td>
<td>12</td>
<td>14</td>
<td>0.54</td>
</tr>
</tbody>
</table>

*Includes resin solids and solvents.

Second is the attempt to replace synthetic precursors partially or totally with functional compounds derived from renewable sources. Obvious examples of those functional compounds include lignins, tannins, modified carbohydrates and furans. The third area of research is the effort to develop durable adhesives from the old “natural” systems — blood, soybean and casein.

Although research results have indicated that a number of new systems have promise, their commercial use is very limited as yet. Research and development continues, however, because of the importance of establishing “backup” systems to be placed in use if needed. “Natural” adhesive systems still have specialized applications; for example, casein-soybean adhesives are used in assembling some types of doors, and casein adhesives are used in certain lumber laminating operations.

Isocyanates. These materials are hardly new and have been investigated as wood-bonding adhesives for several years in numerous countries. However, their commercial adoption has been quite slow in the United States, so it seems reasonable to include them within the category of new systems. Their slow adoption is, of course, due to their high cost and their toxicity. They do possess some definite advantages, however, including rapid cure at a moderate temperature, insensitivity of cure to moderately high moisture, good durability of bonded products and absence of formaldehyde emission. To my knowledge, at the present time isocyanates are being used consistently in only one plant in the United States - to make waferboard for siding, concrete forms and flooring. I am also told that isocyanates are used at times in several OSB plants.

New Technologies

I want to describe briefly a few of the more exciting adhesive bonding technologies that are coming into use in the U.S. wood products industry.

Composition Panels: Waferboard and OSB. I mentioned earlier that waferboard and OSB production was growing rapidly and that these panels were finding increasing use as substitutes for plywood, primarily in construction as sheathing. Although this development has been in process for several years, it is sufficiently important to examine it a little further.

What are the reasons for the growth of waferboard and OSB? One large factor is the wood raw material - its cost and availability. The relative costs of softwood plywood and OSB are compared in Figure 3 (10), where the much lower wood cost for OSB is obvious. This cost difference is due to two factors: the decreased supply and increased cost of quality logs for veneer and the availability of large stands of under-utilized lower quality aspen, spruce and mixed hardwoods for use as furnish in waferboard and OSB. Many of these large stands are located near urban areas, thus reducing shipping costs of the finished panels and further lowering their final cost.

Another important factor underlying the acceptance of waferboard and OSB is the development of a system of product standards based not on specific products but on performance requirements (11). Where the new, less expensive panel materials could be shown to meet those performance requirements, builders have been willing to substitute them for softwood plywood. Table II (11) presents some representative bending properties of the three panel types. Parallel to the strand alignment, the OSB properties clearly equal those of plywood. The lack of alignment in waferboard decreases its bending properties, but it still meets many performance standards.

High Moisture Content Veneer Bonding. I mentioned earlier that the U.S. softwood plywood industry has shown considerable vigor in recent years in developing new bonding and production methods; this is due at least partly to the increasing competition from other structural panel products. I want to describe two examples of new veneer bonding procedures, the first of which is high moisture veneer bonding.

Historically, softwood plywood production has proceeded by peeling veneer from wet logs and then drying the veneer to about 3-4% moisture content (MC). Drying the veneer to such low MC creates the potential for several problems, however (12):

• In many plants the drying step has limited overall production.
• Excessive penetration of adhesive and water can lead to poor bonding.
• Excessive drying can cause surface deactivation and poor bonding.
• Veneer becomes brittle, causing veneer breakage and loss.

Plywood out of the press only contains about 4% moisture; it subsequently absorbs moisture and can warp and buckle.

On the other hand, making plywood with high MC veneer also has problems. New PF resins had to be developed because high moisture alters resin flow and penetration behavior and inhibits cure. Such resins have been found to be more costly. With high veneer moisture contents, the range of moisture contents encountered is broader, and the resin and process must be more tolerant to that spread. Finally, existing instruments for monitoring veneer MC were found to be inadequate for the higher MC ranges, and new instruments are needed.

Several approaches have been followed to develop PF adhesives that would allow the use of high MC veneer.

![Figure 3. Relative cost of softwood plywood and OSB.](image)

![Table II - Panel Bending Properties (MPa)*](table)

<table>
<thead>
<tr>
<th>Product</th>
<th>Modulus of elasticity</th>
<th>Modulus of rupture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waferboard</td>
<td>8,600</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>8,600</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>3,400</td>
<td>21</td>
</tr>
</tbody>
</table>

* Parallel to face grain for plywood and to face strand for OSB.
including dropping the adhesive water content to compensate for the higher veneer MC, optimizing the extenders or fillers to gain further control of flow and penetration, and altering the adhesive system to increase cure rate. One of the most effective methods found to increase cure rate is the use of an external catalyst, i.e., a two-part adhesive. Using such systems, a large number of plywood plants are now operating with veneers at 12%-13% MC and higher instead of the previous 3%-4%.

Foamed Adhesive for Plywood. The second relatively new plywood bonding technology is the growing use of foamed PF adhesive in the last few years. Figure 4 (13) is a schematic of a foamed adhesive extrusion system. The PF adhesive is pumped into a foamer where it is mixed with about five times its volume of air to form the foam. From there the foam is pumped to the extrusion head where it is divided into separate strands — up to 160 — which are laid onto the veneer passing under the extrusion head. After the other veneer layers are in place, the assembly passes between rolls, where the foam strands are mashed into a continuous film that makes intimate contact with both the upper and lower veneers. Figure 5 shows an extrusion head and the separate strands of foamed PF adhesive being laid on a passing panel.

The foamed adhesive contains less conventional extender, but has foaming aids such as animal protein. Better control can be maintained of the amounts of adhesive being applied, leading to 20%-30% savings in adhesive use. Because the strands have only small contact with the wood, water and adhesive penetration are minimized prior to the mashing step. Consequently, under the pressure of the mashing rolls, a thin uniform adhesive film results during passage between the rolls.

Laminated Lumber and Beams. Laminated lumber and beams are, of course, not new products; they have been around for several decades, and they continue to be used. However, there is one general class of laminated lumber whose use is expanding rapidly — parallel laminated veneer (PLV). It is made by a continuous process, and the grain of all the laminated veneers runs parallel to the beam length. These are made by bonding the veneer with PF adhesive in a continuous hot-pressing operation. Beams are made at high production rates and are up to 76 cm wide, 6 cm thick and 24 m long. Because high quality softwood veneer is used, and defects are small and randomized, mechanical properties and reliability are excellent. Relative to conventional lumber, the cost of such beams is high, but the cost of an installed system is competitive because of decreased installation labor and low rejection rates.

PLV beams are used in housing construction as headers over windows and as main roof beams. An increasingly important application of PLV is in composite I-beams. In some applications, the flanges are made from PLV, and the I-beam web is softwood plywood that is pressure-fitted into the flanges and bonded with phenol-resorcinol-formaldehyde adhesive at about 50°C. In other I-beam installations, OSB is used as the web material. Still another application of PLV is as flanges on trusses where the webs consist of tubular steel. Both the I-beams and the tubular trusses can be designed to provide the desired strength for a particular application, and they possess the advantage of light weight.

Steam Injection Pressing. Steam injection pressing is an emerging technology in the United States and some other countries for very rapid pressing of composition panels. In this process saturated steam is injected from perforated platens into a particle mat during and after press closure. If the steam is
injected before the mat density becomes too high, it creates permanent paths around the particles and penetrates to the center and edges of the mat, resulting in very rapid heating of all portions of the mat. Figure 6 (14) shows the observed changes in board thickness, pressure and core temperature when steam is injected shortly after initiating press closure but before the mat is fully compressed. In this particular case, core temperature rises very rapidly and reaches a maximum of about 280°F in about 10 sec. Thereafter, the steam can be cycled on and off, and the temperature and pressure respond appropriately.

In addition to the rapid heating, and consequently short press times, with steam injection pressing, another advantage is the production of a relatively flat density profile through most of the cured board (Figure 7) (14). It also seems likely that particle damage is lessened by the plasticizing action of the high temperature steam. Thus, boards with good internal bond strength can be produced at high rates. Boards that are 12 mm thick bonded with PF adhesive reportedly can be made using total press times less than 2 min. Press times for UF or isocyanate boards could obviously be much shorter. Moreover, quite thick boards can be pressed by steam injection in relatively short times. It is my understanding that several steam injection pressing plants are now planned or in construction in various countries; two of these are in the United States - one for making UF-bonded particleboard and the other for making a PF-bonded MDF.

**Conclusion**

Composite panels as a class represent the major use of wood adhesives in the United States; softwood plywood is the predominate type. Other panel products are growing, however, most notably
MDF and OSB/waferboard. UF and PF are by far the dominant wood adhesives by virtue of their properties and costs. Because of the formaldehyde problem and potential petroleum supply problems, new adhesive systems based on renewable resources are actively being pursued as backup systems if needed. Meanwhile, new technologies and products based on current adhesives are continually being developed and implemented.

References