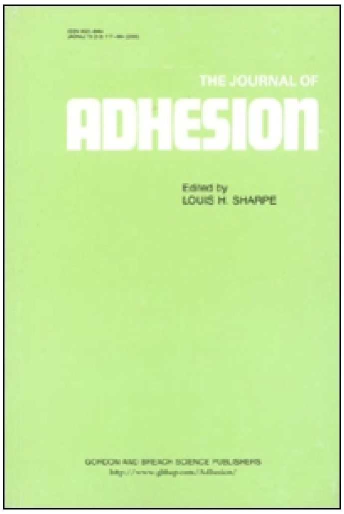

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Bonded Wood Products—A Review

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The bonding of wood uses a significant amount of the adhesives consumed annually in the United States to manufacture a wide variety of consumer products. Bonded wood products serve as primary building materials for house construction and furniture manufacture and provide mankind with other necessities of existence, comfort, and convenience. The role adhesives play in this conversion of a basic raw material into useful products is reviewed with a consideration for the ever-changing nature of the raw material, for an increasing population, and for the need to apply multiple-use management of our Nation's timber resources.

INTRODUCTION

The bonding of wood dates at least to the Egyptian pharaohs and probably much further back in antiquity. Subsequent developments in the science and technology of adhesives and their use for bonding wood products demonstrated time and again that wood bonding conserves our Nation's timber resources.

As early as a half century ago, wood bonding was considered a conservation measure. T. R. Truax in his bulletin on "The Gluing of Wood" in 1929 stated, "The use of glue in the fabrication of wood products brings about more complete utilization of timber through the use of lower grades, inferior species, and small sizes of material; it conserves supplies of clear material and of scarcer and more valuable woods; and it makes possible a saving of material in the production of articles of unusual form, dimensions, and properties. Nearly every article of glued-wood construction represents an economy in the use of timber resources."[1] The opportunities to achieve even more economy of use are greater today than ever before.

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ADHESIVE CONSUMPTION BY THE WOOD-USING INDUSTRY

Today the manufacture of bonded wood products consumes over 37% of the thermoset resins produced annually in the United States and over 5% of the thermoplastic resins. Total adhesives consumption in the United States in 1980 was 9 billion dry pounds, of which 21% of the total, or 1.91 billion dry pounds, was used in wood product manufacture. Additional amounts were used in subsequent assembly operations where wood products are combined with each other or with other materials in the many different applications where wood is used today.

The amounts of synthetic resins used in adhesives for wood products manufacture in 1980 are shown in Table I.[2]

SELECTION AND USE OF ADHESIVES FOR BONDED WOOD PRODUCTS

Proper selection and use of adhesives for various types of wood products and their assembly depends on a variety of factors. These include service conditions (interior or exterior use), construction of the products, wood species, surface protection or finish, plant facilities available, and cost. The question is, "Will the adhesive in this application perform satisfactorily for the intended use?"

The adhesives used for these bonding processes are many and varied. The adhesives from natural materials in the past (animal glues, casein, soybeans, and blood) have been largely supplanted by those from synthetic resins. Those from synthetic resins include the formaldehyde condensation products from urea, melamine, phenol, resorcinol, and mixtures of these resins; polyvinyl

TABLE I

Thermosetting resin consumption

Thermosets	Consumed for wood products 1980, billions of dry pounds
Urea-formaldehyde	1.200
Melamine-formaldehyde	0.070
Phenol-formaldehyde	0.520
Polyester	0.120
	1.910

acetate emulsion or white glues, thermoplastic and thermosetting types; rubber-based contact and mastic types; diisocyanates; polyurethanes; epoxies; and hot melts.

OUR TIMBER RESOURCE

A discussion of adhesive use in the wood industry must take into consideration the renewable nature of timber resources, the quality of harvested timber, and the types of products required by an ever-increasing population. We are growing more fiber in our forests today than we are harvesting, but the quality and size of harvested trees is declining and there is an accumulation of unused species and low-quality hardwoods that have potential for use. Adhesives can play a dominant role in making big pieces out of small ones, in producing useful products from mill and forest residues, and in upgrading the value of wood fiber now wasted or burned for fuel.

BONDING PROCESSES IN THE WOOD INDUSTRY

Three orders of bonding in the wood and related industries can be identified and regarded as basic:

I. Primary—The bonding together of the initial wood elements that are made directly from trees to form products for the commodity market—essentially lumber and panel producing processes.
II. Secondary—The bonding of primary bonded products to form components—essentially sub-assembly processes.
III. Tertiary—The assembly of primary or secondary bonded products into structures—essentially shape-producing processes.

WOOD ELEMENTS FOR BONDING

Tree harvesting yields sawlogs from which heavy timbers, beams, and dimension lumber are obtained; peeler logs for veneer production; and pulpwood for chipping. In the process, considerable residue is generated at the logging site. Also, timber stands often contain large volumes of materials that are uneconomic to process into lumber and plywood. These forest residues, and mill residues left after wood processing, constitute an enormous resource from which bonded wood products can be manufactured. The individual wood elements are available from this resource in many different sizes and shapes which may be described as lumber, veneer, flakes, wafers, chips, strands, splinters, particles, fiber bundles, separated fibers, etc. This wide diversity of wood elements may be combined with themselves or in combination with one another, and even with different nonwood materials to produce an almost endless array of useful bonded products.

PRIMARY BONDING

Panel products

The amount of panel products manufactured in the United States in 1980 is shown in Table II.[3]

Of these panel types, softwood plywood manufacture accounted for a large proportion of the phenol-formaldehyde consumption. For softwood plywood, exterior-type performance is usually required; with particleboard and hardwood plywood, interior applications predominate. Particleboard and hardwood plywood consumed a large proportion of the urea-formaldehyde resins.

Panel products are manufactured from fibers, particles, strands, flakes, wafers, and veneers in many different combinations. Softwood plywood is used for construction and hardwood plywood for decorative paneling in interior applications. Fiber furnishes are used for insulation boards, hardboards, and medium-density fiberboards; particles for underlayment and industrial grades of particleboard; wafers or flakes for structural grades of flakeboards, usually as three-layer combinations of different flake sizes and types. Oriented strands with veneer faces make up composite panels suitable for construction. These panel products are all examples of a primary bonding process. Most panel products are manufactured in flatbed presses under controlled conditions of time, temperature, and pressure.

Lumber and timber products

The lamination of dimension lumber can produce heavy timbers and beams in sizes no longer available. Lamination can also produce beams and arches in

TABLE II

Wood panel products

Panel type	Million square feet
Softwood plywood	16,950 on $\frac{3}{8}$-in. thickness basis
Particleboard	2,850 on $\frac{3}{4}$-in. thickness basis
Hardboard	7,100 on $\frac{1}{8}$-in. thickness basis
Hardwood plywood	1,360 surface measurement
Medium-density fiberboard	485 on $\frac{3}{4}$-in. thickness basis

sizes and shapes never grown in a living tree. The laminations may vary as to species, number, size, shape, and thickness. Straight beams may have horizontal laminations or vertical laminations with horizontally laminated timbers being most widely used. Curved members are horizontally laminated to permit bending of laminations during bonding. Because of the size of most laminated timbers, pieces of wood must be joined end-to-end to provide laminations of sufficient length. The highest strength end joints are obtained with well-made scarf joints, but finger joints, essentially folded scarfs, are more widely used. Preservatively treated laminations bonded with phenol-resorcinol-resin adhesive are used in exterior applications such as highway and railroad bridges. Today, industrial flooring and decking are produced by laminating 1-inch boards in a tongue and groove configuration rather than milling from solid timbers. Laminated bowling pins replaced solid pins long ago.

SECONDARY BONDING

Many examples exist of secondary bonding or sub-assembly processes, such as overlays bonded to various panel products to provide special surface characteristics. Paper impregnated with phenolic resin is often applied to plywood or particleboard to provide a paintable surface for highway signs and other exterior uses, or to provide a durable surface for such applications as concrete forms. Vinyl films, back-printed with a wood-grain pattern and embossed to simulate pore structure, are applied to particleboard for subsequent conversion into finished speaker cabinets. Decorative laminates are bonded to particleboard or plywood for kitchen countertops. Flush doors consist of thin 3-ply plywood door "skins" bonded to rails and styles and also to the packing in the hollow spaces. Lumber, previously edge-glued into panel form, is provided with faces by bonding veneer crossbands and veneer faces to yield lumber core panels useful for kitchen cabinets. Edge banding is often applied to these panel sub-assemblies to complete the decorative finish desired on all external surfaces.

Highly efficient structural members can be produced by bonding plywood to lumber, producing such components as box-beams, I-beams, stressed-skin panels, and folded plate roofs. In beam application, lumber flanges resist bending moment while the plywood webs provide primary shear resistance. Stressed-skin panels consist of plywood skins bonded to lumber framing members where the plywood resists bending and the wood stringers resist shear. Sandwich panels are also examples of highly efficient components with exceptional strength and stiffness. They involve thin, stiff skins bonded to thick cores of lower-strength materials such as resin-impregnated paper honeycomb or polymer foams.

Many kinds of joints are bonded during sub-assembly operations, particularly in the furniture industry. End-to-end grain joints may be made as a simple butt-joint, as a scarf, or as a variety of finger joint configurations. End-to-side grain joints are made in a number of variations including miter, dowel, mortise and tenon, dado tongue and rabbet, slip or lock corner, dovetail, blocked, and tongued and grooved. These joints have been designed for specific applications to overcome the problems associated with bonding directly to the end-grain surface of wood.

Another secondary bonding operation is the development of diaphragm floor systems where plywood or particleboard sheets have the edges tongued and grooved and bonded together edge to edge with mastic type adhesives; the diaphragm is then nail-glued to the joists. Increased strength and stiffness is obtained without using additional primary building material. In mobile homes the particleboard underlayment is customarily bonded to the floor joists. In addition, panel material is often bonded to studs in wall sections, particularly in shear walls, to provide increased resistance to racking forces during transportation.

TERTIARY BONDING

Tertiary bonding normally produces a finished structure and is a shape-producing process. There are many examples. Furniture manufacture often consists of bonding for final assembly. Mobile homes, panelized or modular homes, and portable military shelters are all examples of sub-assemblies being bonded together in final form. Very large wood structures can result. For example, the indoor stadium and convention center being constructed at Tacoma, Wash. in 1982, is claimed to be the world's largest wood dome. It is 530 feet in diameter, rising to 15 stories above ground level. The dome is supported by 1,602 laminated beams covered with 2 × 8-inch tongue-and-groove decking. While many of these building construction operations traditionally use mechanical fasteners rather than adhesive bonding in the shape-forming process, adhesive bonding is beginning to play an important role.[6]

COMBINATION BONDING

All bonding processes do not fit neatly into this classification of primary, secondary, and tertiary. For example, wood particles with phenolic resin are being bonded in a single operation to produce a molded pallet. This can be considered a combination primary and tertiary process because a primary building material is being formed and shaped at the same time. All assembly joints in furniture manufacture are possibly examples of tertiary bonding because they start the shape-forming process. The manufacture of box beams and I-beams from lumber and plywood constitute a combination of primary and secondary bonding, as is the bonding of furniture parts from veneers, flakes, or fibers. Panels that are formed and overlayed in a one-shot press operation combine primary and secondary bonding.

FUTURE DEVELOPMENTS

Wood utilization research today focuses on the development of new products to meet consumer demand while considering the changing nature of our timber resource. Also, the harvesting, collection, transportation, and processing of the raw material must be done in such a way that the multiple-use concept of managing our Nation's forests is encouraged and fostered. Wood utilization research continues to seek ways to convert into useful products more and more of the wood substance that has grown in our Nation's forests. This can include unused species, low-quality trees, trees killed by insects and disease, or those damaged in storms. How much of this material should be removed for production into wood products or used as fuel, and how much should be left in the forest to control erosion, shelter wildlife, protect new seedlings, or to decay and return minerals, nutrients, and organic matter back to the forest floor? Answers to such questions will assist forest managers in deciding the best course of action in harvesting trees, in disposing of slash, in clearing unproductive areas for reforestation, in timber stand improvement, and in cutting and thinning. These management decisions determine the kind, amount, and form of wood substance that can be made available for conversion into bonded-wood products.

The thrust of wood utilization research concentrates on developing bonded wood products from veneers, flakes, strands, particles, or other small elements. Sawmills today use very thin saws to minimize sawdust formation. Veneer slicing and rotary cutting is being advocated to eliminate sawdust formation entirely. Veneer as thick as $\frac{3}{8}$ to $\frac{1}{2}$ inch can be produced. These veneers can then be laminated in a parallel grain configuration to produce laminated veneer lumber (LVL). The commercial possibilities for such products have already been demonstrated. Dimension lumber of any size, shape, or length can be produced with greater uniformity and stiffness than solid lumber. Laminated veneer lumber will prove useful in all applications where solid lumber has been used heretofore for as diverse uses as roof and floor decking or frames for upholstered furniture. LVL is currently being produced commercially for use as roof truss members.

Another replacement for dimension lumber, particularly for joists, rafters, and possibly wall studs, consists of a thick particleboard core with two or more thick veneers bonded to the surfaces normally being nailed during construction. With joists and beams, the veneers would be reinforcing the top and bottom faces that are in tension or compression. Such composite lumber has reached the stage of practical demonstration and awaits commercialization.

An entirely new industry has been developing during the past 10 years—structural waferboards or flakeboards. Plants built to date convert aspen into panel products by flatbed pressing, using a phenol resin adhesive. A thick panel with red oak flakes in a three-layer construction has developed through the laboratory stage as a potentially useful roof decking for industrial buildings.

Composite panels are now a commercial reality. The central core consists of particles or oriented strands with veneer faces. These are usually bonded with phenol-resin adhesives, while one version is being bonded with a diisocyanate.

These products are only a sampling of what is to come. With innumerable combinations of ways to bond wood elements together, in combination with one another, or combined with nonwood materials, our needs for wood products in the future should be fulfilled. Adhesives have played an important role in the past when converting wood elements into useful products and they will play an even more dominant role in the future.

The adhesives used for these many wood bonding applications are described by various authors in Skeist's Handbook,[4] the basic principles of wood bonding in USDA Technical Bulletin No. 1512,[5] the use of adhesives in building construction in USDA Agricultural Handbook No. 516,[6] and the properties of the primary building materials in the USDA Wood Handbook.[7]

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