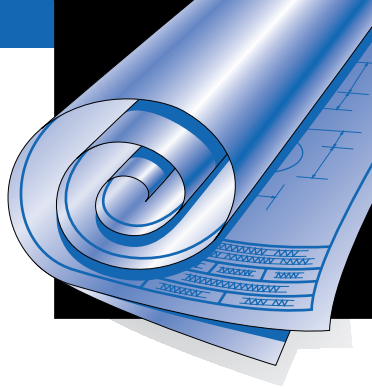

Structural Adhesives for Plywood-Lumber Assemblies

Number Y391C

May 1998

The fabrication of plywood and lumber into a structural component often requires the use of adhesives. The words "structural adhesive" can be somewhat ambiguous and should be defined. A structural adhesive is expected to produce a rigid joint and therefore must supply both stiffness and strength to the structure. The strength requirement is generally such that the adhesive must be as strong or stronger than the wood it bonds. Other adhesive types may be used in construction to provide other types of performance. A semi-structural adhesive, for example, may be assumed to supply stiffness only. Some glues used in the manufactured home industry are intended for the short term to improve over-the-road resistance. The purpose of this note is to discuss both structural adhesives, which provide both stiffness and strength to the joint, and some of the semi-structural adhesives which are assumed to provide stiffness only.

Structural adhesives for wood fabrication can be categorized in two end-use groups. Those that provide full waterproof glue strength are used for exterior exposure. Those that provide less than complete moisture resistance are restricted to interior application. Generally, interior conditions are defined as involving an equilibrium moisture content in the wood of 18% or less. Exterior exposure is then defined as involving a moisture content exceeding 18%, *or* direct exposure to the weather. As an approximate rule, small samples of wood require about a week at a constant 85% relative humidity to reach 18% equilibrium moisture content.

There are many adhesive types on the market with characteristics that lend themselves to different types of fabrication. Structural adhesives usually require the mixing of two components. The mixing procedure *must* be followed according to the manufacturer's recommendations if the glue is to perform adequately. Adhesives are characterized by assembly times and temperature required to cure them. Room-temperature-setting adhesives often have short open and closed assembly times. Open assembly time is the maximum recommended time period that the glue may be exposed to the air after being spread on the joint surface for gluing. Closed assembly time is that time during which the mating surfaces of the joint may touch before pressure and heat, if required, are applied for curing. Hot-setting resins require heat and pressure to cure, and most often have longer open and closed assembly periods than room-temperature-setting adhesives.

The choice of adhesive depends upon the needs of the production. For assembly-line-type production, a hot-setting resin should be considered because of its long assembly time and short curing time. Room-temperature-setting glues are used for smaller production, but often require quicker assembly and long curing times.

Adhesive Specifications

To insure that the adhesive is adequate for the job at hand the fabricator is encouraged to specify a glue which meets a standard fitting the end use.

A. Interior exposure structural adhesive
Structural adhesives which meet interior exposure requirements should conform to ASTM D4689 *Standard Specification for Adhesive, Casein-Type.* Adhesives meeting this standard would meet or exceed the older Federal Specification MMM-A-125, Type II, still found in some specification requirements.

B. Exterior exposure structural adhesive
Glues which may be subjected to exterior conditions should meet the conditions set forth in ASTM D2559, *Standard Specification for Adhesives for Structural Laminated Wood Products for Use Under Exterior (Wet Use) Exposure Conditions.* This standard will meet or exceed the older requirements set forth in Military Specification MIL-A-5534A and Federal Specification MMM-A-181a. These older specifications are sometimes still referenced.

C. Semi-structural adhesive
Mastic construction adhesives which are used in conjunction with the APA Glued Floor System should conform to ASTM Standard D3498, *Standard Specification for Adhesives for Field-Gluing Plywood to Lumber Framing for Floor Systems* (based on APA Specification AFG-01).

D. Manufactured home use
The state of California has established a standard (CA 25-4) for evaluation of

adhesives for structural use in manufactured homes and commercial coaches. This standard allows some of the modified-polyvinyl resins, which have heretofore been excluded from the group of structural adhesives. Note that this classification does not include the common polyvinyl acetates, or white glues. ASTM has also developed Standard D3930, *Standard Specification for Adhesives for Wood-Based Materials for Construction of Manufactured Homes,* which includes a similar glue and others.

Adhesive Types

Interior Structural Adhesives

Interior adhesives are generally manufactured from casein or casein and protein blends. These glue types usually have relatively low moisture resistance, and unless protected are subject to attack by microorganisms. Mold resistance is a requirement of ASTM D4689 Class A adhesives and is usually met by the addition of a biocide to inhibit mold growth.

Casein glue is the most common type. The chemical casein is the chief protein constituent of milk, and is derived from soured milk. The adhesive is prepared by the addition of sodium hydroxide and hydrated lime (calcium hydroxide). Casein glue has fairly good gap-filling capabilities and cures through the loss of water. Follow manufacturer's instructions for mixing; casein must usually be mixed, allowed to stand for about 20 minutes, and mixed again before using.

The glue may be spread by machine or hand and usually has an open assembly time of 15 to 20 minutes. A glue spread of 60 to 65 lb of wet glue per 1000 square feet is common. It cures at room temperature under 100-150 psi for four hours. A minimum of eight hours is required for a fully cured glue line.

Exterior Structural Adhesives

The majority of adhesives manufactured for exterior application are synthetic-resin glues. Specifically, they are thermosetting resins that undergo an irreversible chemical reaction due to the presence of heat or a catalyst. The nature of the synthetic resin is such that some may be modified to cure at room temperature under pressure. They are generally supplied in powder, solution or film form. The following terms are often used in conjunction with synthetic-resin glues and are worth review.

Hardener – This includes catalysts or reactants that produce the final chemical curing reaction. Generally added at the place of fabrication.

Filler – A relatively nonadhesive substance added to an adhesive to improve its working properties, permanence, strength, or other qualities.

Extender – A substance, generally having some adhesive action, added to an adhesive to reduce the amount of the primary binder required per unit area.

Solvents – Generally liquids which transform the resin to a usable liquid form and act as the vehicle for spreading. Solvents are often water, alcohol or a mixture of the two.

Fortifiers – A fortifier is added to increase the boil resistance of the glue.

Some general statements may be made about gluing with synthetic resins. With any gluing it is desirable to surface the material prior to applying the glue because synthetic resins lack gap-filling capabilities. The mating surfaces, then, should be smooth, clean and in close contact. This point may be emphasized by the fact that an efficient synthetic thermosetting glueline is usually in the neighborhood of 0.005" thick.

The adhesive spread depends upon the formulation of the glue. A spread of as little as 30 to 35 lb/1000 ft^2 may be sufficient for unextended resins, while 60 lb/1000 ft^2 may be required for lower-resin-content room-temperature-setting glues. The allowable open assembly time will run from 20 to 30 minutes for room-temperature-setting resins to several hours for hot-press glues.

Some synthetic resins will cure at room temperature under pressure, but require a long clamp time. The hot-press resins may require up to 220°F in the glueline to cure, but a clamp time of around ten minutes is usually sufficient. The pressure required will depend upon the species of wood, but a range of from 100 to 200 psi will generally be sufficient for most wood joints.

There are six basic structural synthetic-resin types. A brief description of each follows; for additional information see the referenced works in the bibliography.

1) *Phenol resins.* Hot-press or intermediate-temperature-setting glues, usually dark reddish-brown in color. The hot-press adhesive usually requires around 210°F, while the intermediate-temperature-setting formulations require 80°F to 210°F in the glueline to cure. These glues possess excellent durability. Generally the least expensive of the resin glues.

2) *Resorcinol resins.* Resins intended to cure at room temperature (not less than 70°F), usually dark red in color. The resins are reported to have excellent durability, storage life and assembly time. Most popular (with the phenol-resorcinols) of the resin glues, because of room-temperature curing.

3) *Phenol-resorcinol resin.* A combination of two basic resin types which is room-temperature-setting and dark red in color. This combined resin is often grouped with straight resorcinol due to their similar properties.

4) *Melamine resin.* A hot-press adhesive (140°F to 160°F glueline temperature) which is light in color. This glue has excellent durability. Generally the most expensive of the resin glues.

5) *Melamine-urea resin.* A hot-setting combination which is colorless. Only certain formulations of this resin type will pass the exterior glue standard (ASTM-D2559). Generally the melamine resin must compose at least 60% of the glue solids content to meet the standard.

6) *Emulsion polymer/isocynate.* A two-component system consisting of a base emulsion polymer and a crosslinking agent containing polymeric isocynate. The crosslinker is mixed with the base emulsion to provide an adhesive with a working life of several hours. This light, wood-colored adhesive cures at room

temperature (40°F to 100+°F) and is water-based, simplifying cleanup. Can be used to bond wood up to 16% moisture content.

A seventh synthetic type is urea resin. It is a light colored resin available in hot-press and room-temperature-setting formulations. *This synthetic resin, used alone, is not considered to be a structural adhesive due to its poor performance under high temperatures, and does not generally meet D2559.*

Epoxy adhesives are another type that have been used structurally in boat construction, and for repair and restoration of wood structural components. This type of adhesive is generally a thermo-setting, chemical-curing adhesive consisting of a two-component mix of resin and catalyst or hardener. The adhesives have high shear strength and moisture resistance. Upon heating, they tend to soften, however. They can be formulated with fillers to achieve gap-filling characteristics. An ASTM standard is under development (1998) to establish performance requirements for epoxy adhesives in structural applications. No epoxy adhesives have been recognized yet by model building code evaluation services for structural uses, although their use for structural repair has been researched and documented by wood scientists and engineers.

Semi-Structural Adhesives

In the discussion of the definition of structural adhesives, it was noted that both strength and stiffness are required for the resulting joint to be considered rigid. A class of semi-structural adhesives has found large-scale use in the housing industry. These are the mastic construction adhesives (sometimes called elastomeric) which are recommended for the APA Glued Floor System. The design procedure used for the glued floor system assumes that the adhesive adds some stiffness to the floor, but no strength. This limited composite action has, in some cases, allowed longer spans for the same joist size. The glued floor has further advantage in that the adhesive practically eliminates floor squeaks. Construction adhesives generally require no mixing and may be applied in a variety of weather conditions with good results. The principal ingredient is reclaimed rubber or synthetic rubber, which produces a non-rigid, flexible glueline. The adhesives have the capability of filling gaps. Most adhesives are available with an organic solvent vehicle, and range from 50 to 100 percent total solids. Open assembly time is generally 10 to 20 minutes, but they may not set for some hours. To insure that the adhesive is adequate for applications such as the glued floor, it should be specified to conform with ASTM D3498 (based on APA Specification AFG-01). Listings of adhesives meeting this standard are available from administrator organizations approved by the U.S. Department of Housing and Urban Development (HUD).

Another type of adhesive that is relatively new on the market is a one-part moisture-curing polyurethane adhesive, now produced by several manufacturers. These adhesives cure by reacting with moisture in the mating materials, or humidity in the air; very dry materials may need to be dampened to facilitate the curing process. The adhesive tends to foam and expand as curing progresses, thus the adhesive is able to fill gaps but with resultant lower shear strength when gluelines are thicker. The adhesive has high shear strength and good moisture resistance. However, its use in structural applications has not yet been fully studied. Although its shear strength is high, research indicates that the amount of wood fiber failure, evaluated by shear tests after wet exposure cycles to study adhesive durability, is less than with other recognized structural adhesives such as phenol-resorcinol resin. Some model building code evaluation services have recognized certain proprietary polyurethane adhesives for fabricating sandwich panels (structural insulated panels) for structural applications, when used to glue foam plastic cores to faces of wood structural panels.

Modified Polyvinyl Acetate Adhesives

The state of California has written a special standard entitled California Specification CA25-4, *Standard for the Evaluation of Adhesives for Structural Use in the Manufacture of Mobile Homes and Commercial Coaches.* As the title implies, adhesives passing CA25-4 find use in industrialized housing. A group of modified polyvinyl acetates (PVA) glues are manufactured which pass this specification. The glues are much like the common white glues but have better moisture and creep resistance. Some are two-part adhesives requiring the addition of an acidic liquid catalyst prior to use. These modified PVA glues find use in the fabrication of ridge beams and similar structural components of manufactured homes.

Acceptable modified PVA glues are listed by the state of California. These glues are not to be confused with the standard white glues, which are thermoplastic and not suitable for construction use.

Hot-Melt Adhesives

Hot-melt adhesives are thermoplastic and lack high resistance to solvents and moisture, and are prone to creep. Hot-melt adhesives are sold in pelleted, chunk or stick form, which is melted and applied in a molten form at temperatures of 350-400°F. The adhesives cure by chilling. While they are *not* accepted as structural or semi-structural adhesives, future developments may offer a more durable glue bond suitable for construction.

Fabrication Tips

The adhesive manufacturer should be considered the best source of information for application, mixing, and storage of any particular resin. The storage life of synthetic glues is quite variable, and may run from one month to several years depending upon the formulation of the resin. Often the storage life may be increased by refrigeration, but the manufacturer's recommendations should always be followed.

For fabrication of plywood-lumber components, the importance of proper pressure on the glueline is often not understood. Pressures of over 100 psi are usually required. Such pressures can be applied with presses, jackscrews, or similar devices. It is often assumed that weights placed on the just-glued component

would be effective to achieve pressure. The fallacy of this approach is exhibited by the fact that to achieve a 100-psi pressure on a glueline would require a depth of 230 feet of water, or 20 feet of solid lead.

Although nail-gluing has been used to achieve effective glue bonds, the procedure is difficult to control, and the results variable. It should be used only with properly mixed casein glue, due to the good gap-filling qualities of the adhesive. There are, of course, some shapes where nail-gluing is the only practical solution for achieving pressure on the glueline. For these applications APA fabrication specifications contain suggested nailing schedules. All such gluelines should be subjected to tests, as for any major component.

Moisture content of the lumber and plywood in the component is important. Proper gluelines can be attained when the lumber and plywood are at less than 19% moisture content (preferably less than 12% for hot pressing). Therefore, only kiln-dried lumber should be used. Plywood generally leaves the mill at less than 12% moisture content, and should not gain much more moisture unless left out in the weather for a long period of time. In addition, when using synthetic resin glues, the mating surfaces should have a maximum allowable variation of 1/32" on the surface to be glued.

Satisfactory glue bonds are best achieved when both surfaces are spread with adhesives. However, good glue bonds can be achieved with a single mating surface spread with adhesive if manufacturer's recommendations are followed closely.

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Form No. Y391C/Revised May 1998/0100