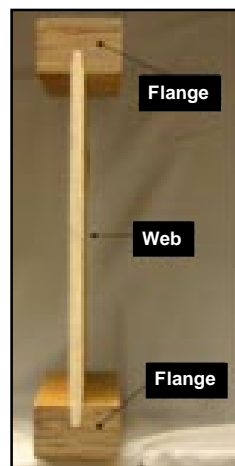
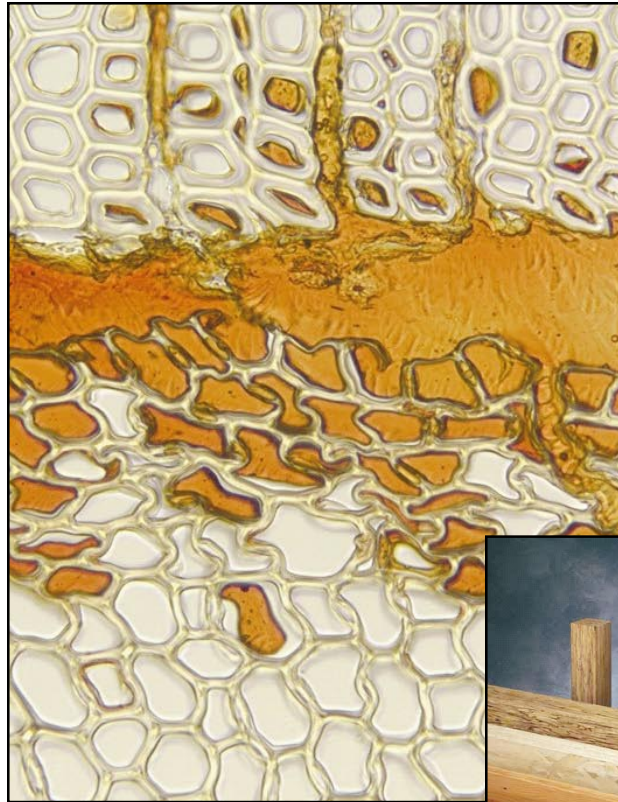
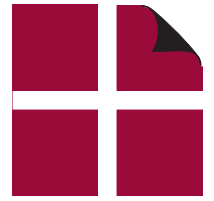


ADHESIVES AWARENESS GUIDE



**American
Wood
Council**

ADHESIVES AWARENESS GUIDE

The American Wood Council (AWC) is the voice of North American traditional and engineered wood products, representing over 75% of the industry. From a renewable resource that absorbs and sequesters carbon, the wood products industry makes products that are essential to everyday life and employs over one-third of a million men and women in well-paying jobs. AWC's engineers, technologists, scientists, and building code experts develop state-of-the-art engineering data, technology, and standards on structural wood products for use by design professionals, building officials, and wood products manufacturers to assure the safe and efficient design and use of wood structural components. For more wood awareness information, see www.woodaware.info.

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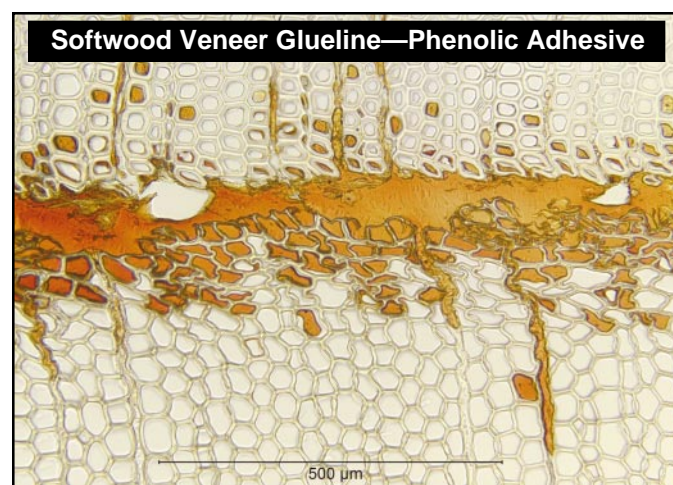
The purpose of this informational guide is to provide awareness to the fire service on the types of adhesives used in modern wood products in the construction of residential buildings. This publication is one in a series of eight Awareness Guides developed under a cooperative agreement between the [Department of Homeland Security's United States Fire Administration](#) and the [American Wood Council](#).

Adhesives Used in Modern Engineered Wood Products

PURPOSE OF THIS GUIDE

The purpose of this Awareness Guide is to provide the fire service with information on the types and properties of adhesives used in modern engineered wood products (EWP) and structural wood panels (Figure 1). The guide also tells how these materials are used in residential construction.

Figure 1 Softwood Veneer Glue Line—Microscopic View



ADHESIVES AND A NEW GENERATION OF PRODUCTS

Getting the Most from Our Forest Resource

Wood adhesives have been important in helping use timber resources efficiently. As large trees become less available, the wood industry has developed new and innovative wood products as alternatives. Wood adhesives have made that possible. These new products use small logs, less desirable species of wood, and even wood that would otherwise be burned or land-filled. Modern engineered wood products are manufactured from wood and as such they have structural characteristics similar to that of solid-sawn lumber. Because the natural defects of solid wood are removed in the manufacturing process, the structural properties of these modern products are more uniform. The type of adhesive used to join the individual pieces could, however, affect their fire resistance characteristics.

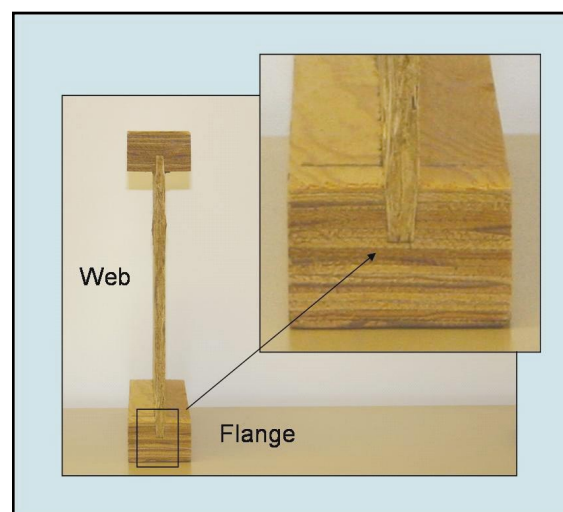
Examples of Modern Engineered Wood Products Using Adhesives

Building products manufactured with adhesives include:

- I-joists (Figure 2)
- End-jointed lumber
- Glued laminated timber (glulam)
- Structural Composite Lumber (e.g. LVL, PSL, LSL, and OSL)
- Oriented Strand Board (OSB)
- Plywood
- Particleboard
- Medium Density Fiberboard (MDF)
- Hardboard
- Architectural doors, windows, and frames
- Factory-laminated wood products

Other products using adhesives in the construction industry include panelized floor and wall systems and non-structural applications such as floor coverings, countertops, cabinets, furniture, ceiling and wall tile, trim, and decorative accessories.

Figure 2 Glued Components of I-joists



The Laminated Veneer Lumber used for the I-joist flanges (horizontal components) and the Oriented Strand Board used for the web (vertical component) are glued products. The products are bonded together to create an I-joist.

What Adhesives Do

An adhesive is used to bond wood components such as veneer, strands, particles, and fibers, etc. The adhesive must provide the required strength immediately after manufacture as well as after long-term use. Some of the adhesives available for use in the manufacture of modern wood products are suitable for exterior exposures.

Adhesives Used in Wood Products

Natural Adhesives

Before synthetic adhesives were introduced in the 1930s, adhesives made from natural polymers found in plants and animals were used for bonding wood. These adhesives were made from animal blood, hide, casein, starch, soybean, dextrin, and cellulose. While natural adhesives are still being used in some non-structural products, they do not provide the necessary strength and durability required for today's engineered wood products.

Synthetic Adhesives

To meet the needs of modern engineered wood products, polymer scientists have developed synthetic adhesives. These adhesives are designed to perform a variety of functions in product applications. As such, there are many types of wood adhesives used in the manufacture of wood products. The choice of an adhesive is based on many factors, such as cost, structural performance, fire performance, moisture resistance, adhesive curing needs, etc. Some of the early synthetic adhesives were similar in chemical structure to lignin, the natural adhesive in solid-sawn lumber that bonds wood fibers.

Two Adhesives Groups

Adhesives used in the North American wood products industry today fall into two primary groups:

Group 1: Adhesives for Structural Products

- This group of adhesives includes Phenolic (also called phenol formaldehyde or PF), resorcinol, phenol resorcinol, polymeric diphenylmethane diisocyanate (polymeric MDI), emulsion polymer isocyanate, polyurethane/emulsion polymer, polyurethane polymer, polyvinyl acetates (PVA), and melamine. These adhesives are generally used in wood products that require structural strength immediately after manufacture and after exposure to moisture (see Table 1).
- Examples of structural products: OSB, plywood, glued laminated timber (glulam), I-joists, end-jointed lumber, and structural composite lumber (Figure 3).

Group 2: Adhesives for Interior, Non-Structural Products

- This group of adhesives includes urea formaldehyde (also called urea or UF), hot melt, casein, blood, starch, and animal glues. Because of their low resistance to heat and moisture, these adhesives are generally used for indoor, non-structural wood products, such as particleboard, decorative wall paneling, medium density fiberboard (MDF) for furniture, and cabinets, interior doors, and architectural millwork.

Thermoplastic vs. Thermosetting Adhesives

Synthetic polymer adhesives can also be further classified as *thermosetting* and *thermoplastic*. In general, modern wood products made for structural applications use thermosetting adhesives. Thermosetting adhesives undergo a chemical change during application and curing. The bonds formed by thermosetting adhesives are generally moisture resistant, and support loads under normal use.

Thermoplastic adhesives do not undergo a chemical change during the application or the curing process. Such adhesives may soften when exposed to heat and therefore have a limited application where structural fire performance is desired. There are also adhesives that have both thermosetting and thermoplastic characteristics.

Thermosetting Polymers

Thermosetting polymers undergo irreversible chemical change when cured. While the method of curing depends on the specific adhesive, a typical method of curing involves the use of heat and pressure. During curing they form cross-linked polymers with high strength and resistance to moisture and other chemicals.

The degree of moisture resistance depends on the type of thermosetting adhesive used. Phenolic, resorcinol, phenol-resorcinol, polymeric MDI, emulsion polymer isocyanate, polyurethane/emulsion polymer, polyurethane polymer, and melamine adhesives have excellent moisture resistance. They are used in structural panels and structural wood products, since they are able to support long-term static loads without deforming. Urea, although a thermosetting resin, offers high strength when dry, but has poor moisture resistance and is used primarily in interior applications (floor underlayment, furniture, and cabinets, etc.) that are not generally exposed to moisture.

Bond Integrity:**Does the Glue Hold When Exposed to Fire?**

A study conducted at the U.S. Department of Agriculture Forest Products Laboratory evaluated bond integrity of Douglas-fir and Southern Pine blocks after exposure to fire. For the test, the blocks were glued together with phenol resorcinol, polyvinyl acetate (PVA), urea, melamine, 60/40 blend of melamine and urea, and casein adhesives (Schaffer). The integrity of both the pyrolysis and normal wood zones were examined. (Pyrolysis is the decomposition of wood into simpler components when subjected to heat.) The author concluded that with both wood species:

- Phenol resorcinol and melamine adhesives maintained bond integrity throughout the pyrolysis and normal wood zones.
- Urea, a 60/40 melamine and urea blend, and casein adhesives had bond separation in the pyrolysis zone, but maintained bond integrity throughout the normal wood zone.
- Polyvinyl acetate adhesives had bond separation in both the pyrolysis and normal wood zones.

Thermoplastic Polymers

Thermoplastics are long-chain polymers that soften and flow on heating, and then re-harden upon cooling. They generally have less resistance to heat, moisture, and long-term static loading than do thermosetting polymers. Common wood adhesives based on thermoplastic polymers include: polyvinyl acetate emulsions, elastomers, contacts, and hot-melts.

The fact that thermoplastic adhesives soften and flow when exposed to heat limits their use in modern wood products where fire resistance ratings are required. However, they are widely available for use in the manufacture of furniture, counter tops, laminating, and other applications not requiring a fire rating.

Many Adhesives, One I-joint

The efficient manufacture of some structural engineered wood products may require that different types of adhesives be used during the manufacturing process. Wood I-joists, for example, are typically fabricated with more than one type of adhesive. A phenolic or polymeric MDI adhesive (or both) may be used to manufacture the hot-press oriented strand board (OSB) or softwood ply-

wood panels used for the web. The web might then be joined to the flange with resorcinol or polymeric isocyanate adhesives designed to cure in a warm room, or at ambient temperature. The flange could be laminated veneer lumber (LVL) or end-jointed lumber. LVL is typically bonded with phenolic adhesives in a hot press. I-joist end-jointed lumber flanges are assembled by bonding machined finger-shaped pieces end-to-end, typically with phenol resorcinol formaldehyde (PRF), polyurethane or melamine adhesives. PRF adhesive is usually cured by radio frequency (RF) process somewhat similar to heating food in a microwave oven), while end pressure is applied to obtain good contact between the fingers.

Figure 3 Examples of Engineered Wood Products Today

From left to right: I-joist, Oriented Strand Lumber (OSL), Laminated Veneer Lumber (LVL), Laminated Strand Lumber (LSL), and Parallel Strand Lumber (PSL).

Adhesive Performance During a Fire

Fire containment, fire growth, smoke density, and smoke toxicity are important issues to firefighters. It is important that firefighters know how modern wood products may perform in a fire.

Phenolic and resorcinol adhesives have been used to manufacture structural wood products since the 1950s. As such, most of the historical performance information is based on experiences with these adhesives.

Fire Performance of End-jointed Lumber

Recent fire resistance tests by Forintek Canada and American Wood Council (AWC) have shown that the type of adhesive used can affect the fire resistance rating of end-jointed lumber (Figure 4) used in stud wall assemblies.

The following table summarizes the full-scale fire-resistance test results.¹ All fire tests were conducted on the 1-hour rated wall assembly design specified in *2003 International Building Code* Table 720.1(2), Item Number 15-1.14 (identical to *2006 International Building Code* Table 720.1(2), Item Number 15-1.15).

End-jointed Lumber Adhesive	Fire Resistance Rating
Phenol Resorcinol Formaldehyde	1 hour
Polyurethane	51 minutes
Polyvinyl Acetate	49 minutes

To address this adhesive performance issue, a method has been developed to qualify adhesives for use in end-jointed lumber used in fire-rated assemblies.²

The American Lumber Standard Committee, the committee that develops rules for lumber grading, now requires that end-jointed lumber made with qualifying adhesives be marked "HRA" and others be marked "Non-HRA." End-jointed lumber, marked "HRA," is interchangeable with solid-sawn lumber in 1-hour fire-rated assemblies, while those marked "Non-HRA" are not.

A Misconception

It is sometimes assumed that adhesives ignite more easily, and cause faster flame spread and more toxic smoke than wood alone. Available fire test data does not support this assumption and hence it is a misconception.

Figure 4 Example of 2x4 End-jointed Lumber

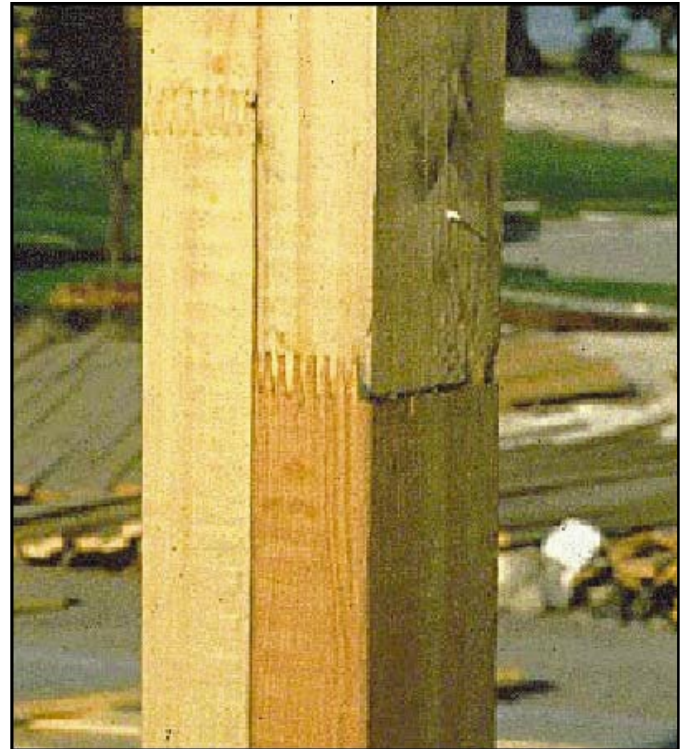


Table 1: Types of Adhesives Used in Modern Wood Products

Engineered Wood Products	Type of Thermosetting Adhesive Used
Wood Structural Panels	
Oriented Strand Board (OSB)	Phenolic, Polymeric MDI
Softwood Plywood	Phenolic
Wood I-joists	
Web (OSB or Softwood Plywood)	Phenolic, Polymeric MDI
Flange (Finger-Jointed Lumber)	Melamine, Phenol resorcinol, Resorcinol, Polyurethane polymer adhesive, Emulsion polymer isocyanate adhesive, Polyurethane/Emulsion polymer adhesive
Flange (Structural Composite Lumber)	Phenolic, Polymeric MDI
Web/Flange Joint	Phenol resorcinol, Polyurethane polymer adhesive, Polyurethane/ Emulsion polymer adhesive, Emulsion polymer isocyanate adhesive
Web/Web Joint	Phenol resorcinol, Polyurethane polymer adhesive, Polyurethane/ Emulsion polymer adhesive, Emulsion polymer isocyanate adhesive
Glued Laminated Timber (Glulam)	
Laminating	Melamine, Phenol resorcinol, Polyurethane polymer adhesive, Emulsion polymer isocyanate adhesive
Finger Joint	Melamine, Phenol resorcinol, Resorcinol, Polyurethane polymer adhesive, Emulsion polymer isocyanate adhesive, Polyurethane/Emulsion polymer adhesive
Structural Composite Lumber	
Laminated Veneer Lumber (LVL)	Phenolic, Polyurethane polymer adhesive, Emulsion polymer isocyanate adhesive, Polyurethane/Emulsion polymer adhesive
Laminated Strand Lumber (LSL)	Phenolic, Polymeric MDI
Parallel Strand Lumber (PSL)	Phenolic
Oriented Strand Lumber (OSL)	Phenolic, Polymeric MDI
End-jointed Lumber	Polyvinyl acetate, Polyurethane, Phenol Resorcinol, Melamine

Note: The information above refers only to examples. Modern wood product manufacturers may use other types of adhesives or a combination of adhesives.

Combustibility

All organic materials will burn when subjected to sufficient heat in the presence of oxygen. Adhesives are no exception.

Charring

When wood is exposed to elevated temperatures, the surface of the wood undergoes thermal degradation resulting in the formation of a residual char layer.

A study conducted by the USDA Forest Products Laboratory evaluated the performance of several adhesive bonds in OSB, softwood plywood, Com-Ply, and LVL when exposed to the fire exposure specified in ASTM E119. Results showed that the linear charring rate ranged from 1.45 to 1.52 mm/min, which is similar to the 1.6 mm/min charring rate for some species of solid-sawn wood. The tested glued-wood products contained phenolic and/or polymeric MDI (White, 2003).

The rigid three-dimensional, cross-linked structure of a phenolic adhesive resists thermal stress without softening or melting. As the phenolic material is heated to ignition temperature, it is transformed into a char-forming material (Knop).

Smoke Obscuration and Toxicity

The amount of smoke released from wood burning has been measured for most wood products. Like flamespread, this index has a value of 100 for red oak. Most of the solid and engineered wood products tested did not exceed a smoke developed index of 450, a limiting value used in building codes.

The major chemical elements found in wood products are carbon, hydrogen, and oxygen. When burned, these elements primarily produce carbon monoxide, carbon dioxide, and water. Where nitrogen or halogens are present, the potential for production of hydrogen cyanide, nitrogen oxides, and hydrogen halide during the burning process exists.

Solid wood, as well as some of the adhesives used to manufacture modern engineered wood products, contain small amounts of nitrogen and thus have the potential to form and give off some quantity of hydrogen cyanide and nitrogen oxides when they burn.

Combustion toxicity research has shown there is no significant difference in the toxicity of the smoke from solid wood and modern engineered wood products. Because the adhesive is a minor component (usually 2-5%) of an engineered wood product and is mostly contained within the product, the effect on toxic combustion products is small, if any.

Studies on Toxicity

Phenolics

In *Phenolic Resins: Chemistry, Applications and Performance—Future Directions* (Knop), the following is reported:

- Phenolics are fire resistant materials with low smoke emission and low toxicity; hence, they exhibit favorable flame retardant characteristics under fire conditions.
- Since phenolics are mainly composed of carbon, hydrogen, and oxygen, their combustion products are water vapor, carbon dioxide, carbon char, and moderate amounts of carbon monoxide, depending on combustion conditions. The toxicity of the corresponding combustion products is, therefore, relatively low.

Other Adhesives

Morikawa reports that polymeric MDI (pMDI), polyurethane based adhesives, and melamine adhesives contain nitrogen, and thus when burned can give off some quantity of hydrogen cyanide and nitrogen oxides, as well as carbon monoxide and carbon dioxide.

A study conducted for Huntsman Polyurethanes by Warrington Fire Research in the United Kingdom (using the Tubular Furnace method,⁴ compared the gaseous combustion products (carbon monoxide, carbon dioxide, hydrogen cyanide, and nitrogen oxide) from untreated wood to those from wood glued with 3% pMDI, 6% phenolic, and 8% UF⁵ (urea formaldehyde). Results showed the following (ranked from lowest quantity to highest quantity):

- Carbon monoxide off-gassing
 - 3% pMDI (lowest)
 - 8% UF
 - Untreated wood
 - 6% PF (highest)
- Carbon dioxide off-gassing
 - 3% pMDI
 - Untreated wood
 - 8% UF
 - 6% PF
- Hydrogen cyanide
 - 6% PF
 - Untreated wood
 - 3% pMDI,
 - 8% UF
- Nitrogen oxide
 - 6% PF
 - 3% pMDI
 - Untreated wood
 - 8% UF

Ashland, a specialty chemical company, reports (Ashland, 2001) that there was no difference in thermal decomposition of products during the burning of samples of black spruce with and without finger joints bonded with a polyurethane polymer.

Fire Resistance of Structural Composite Lumber

Structural Composite Lumber (SCL) is a modern alternative to large-section solid-sawn and glulam timbers. In general, SCL and solid-sawn wood products burn similarly in a fire. As with solid-sawn wood, the size and mass of SCL has an effect on fire resistance. A study conducted at the USDA Forest Products Laboratory involving several types of SCL (laminated veneer lumber, parallel strand lumber, and laminated strand lumber), showed that charring of SCL products was comparable to solid-sawn wood and glulam.⁶ These results support the use of fire resistance calculation design procedures developed for solid-sawn wood and glulam for SCL as well. (White, 2000). The adhesives used in the SCL products tested in this study were polymeric MDI and phenolics.

General Thermal Degradation Information

Phenolic adhesives are temperature-resistant polymers and yield high amounts of char during pyrolysis (Knop).

The thermal degradation of phenolic adhesives can be divided into three stages (Knop):

- In the first stage, up to 300° C (572° F), the polymer remains virtually intact. The quantity of gaseous components released during this stage is relatively small (1-2%) and consists mainly of water and unreacted monomers (phenol and formaldehyde) that were entrapped during curing.
- During the second stage, from 300° C to 600° C (572° F to 1112° F), decomposition commences and gaseous components (mainly water, carbon monoxide, carbon dioxide, methane, phenol, cresols, and xylenols) are emitted. Random chain breakage begins to occur in both the adhesive and wood.
- In the third stage, above 600° C (1112° F), carbon dioxide, methane, water, benzene, toluene, phenol, cresols, and xylenols are liberated.

END NOTES

¹ ASTM E119, "Standard Test Methods for Fire Tests of Building Construction and Materials," American Society for Testing and Materials, 2005, <http://www.astm.org>

² <http://www.awc.org/Technical/Elevated-TemperatureAdhesiveQualificationProcedure.pdf>

³ http://www.alsc.org/untreated_gluedlbr_mod.htm

⁴ DIN 43436, 500° C, air flow rate 5 lpm.

⁵ It is noted that UF resins are designed for use in interior, non-structural applications and are not used in structural engineered wood products.

⁶ Several of these products are used in the top and bottom flanges of wood I-joists.

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