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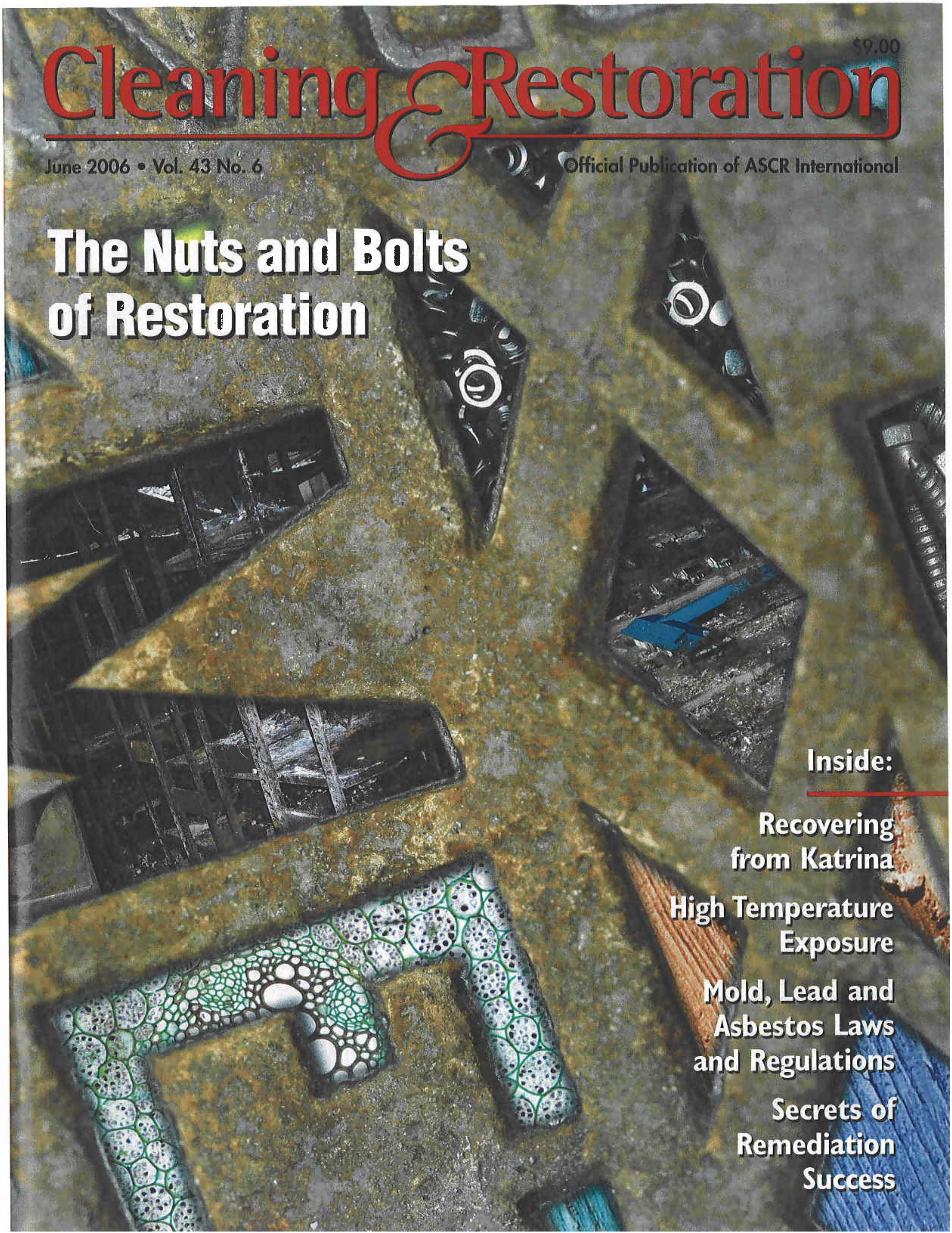


The Nuts and Bolts of Restoration

Inside:

Recovering from Katrina

High Temperature Exposure

Mold, Lead and Asbestos Laws and Regulations

Secrets of Remediation Success

HIGH TEMPERATU

WOOD AND ADHE

RE RESTORATION:
ESIVES – PART 2

By Ralph E. Moon, Ph.D. CHMM, CIAQP

Editor's Note: This is the second installment of a three-part series on Thermal Treatment, the use of High Temperature Restoration Techniques.

The restoration industry encounters a wide variety of wood products during drying following water losses. As the price of high quality lumber has outpaced the budget of most construction projects, composite wood products have replaced solid wood applications. In 2004, the production of particleboard (PB), medium density fiberboard (MDF) and hardboard (HB) totaled more than 10 billion square feet in the U.S. and Canada (Composite Panel Association, 2006). Increases in the residential housing market may increase the use of composite materials even more.

When high temperature heat is used, understanding the structural performance of wood and the release of volatile organic chemicals (VOCs) are important because they pose safety issues and possible claims of negligence. In the 1980s, concerns of formaldehyde emissions prompted research to improve adhesives because the bond used for particleboard and plywood emitted formaldehyde. Though improvements in adhesive technology and manufacturing techniques have diminished concerns about formaldehyde, owners and designers require that building materials and furnishings meet indoor air quality criteria. Research conducted to evaluate VOC emissions from particleboard and MDF helps us understand how composite wood responds to the early stages of high temperature heating.

Emissions from Composite Wood Products

The VOCs released from wood composites provide insight into the types of chemicals released during the early stages of high temperature heating. Research was conducted at the Forest Products Laboratory to identify the compounds emitted from wood products during manufacture and use (Bauman *et al.*, 1990). The research was conducted at room temperature. Wood specimens were placed in stainless steel chambers and clean air was passed through for a four-day period.

The primary compounds emitted were a-pinene and b-pinene (terpentine) and wood degradation products such as alcohols and aldehydes. The types of compounds emitted depended on the wood species or whether the wood panel was PB or MDF. Particleboard had the highest emission rates with the largest contribution from terpenoids. MDF had the lowest emission rates. Some volatiles, including pentanal, hexanal and nonanal, were also emitted even though they are not components of either the wood or the adhesives, but are a result of the oxidation of fats and fatty acids in wood (Svedberg *et al.*, 2004). The most predominant VOC emitted from soft woods was terpenes; however, when compared to all products, alcohols and aldehydes were present at elevated concentrations (Table 1).

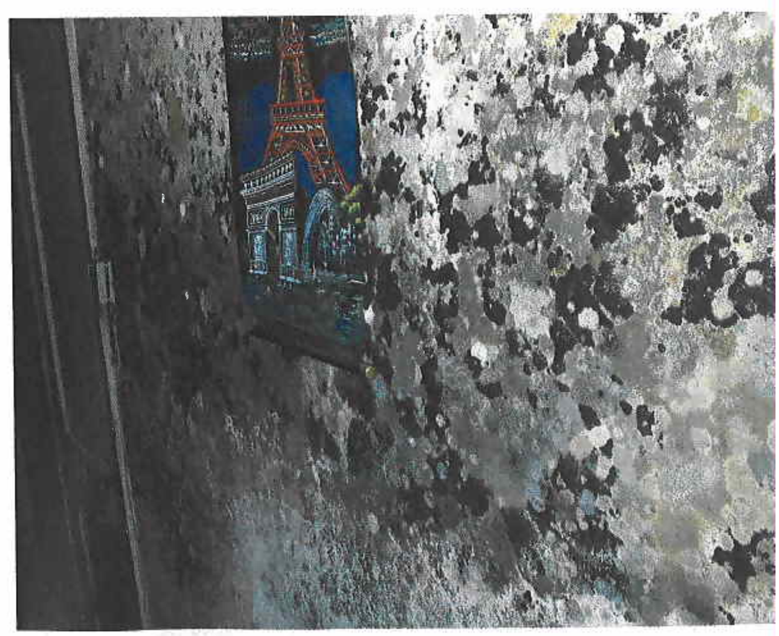
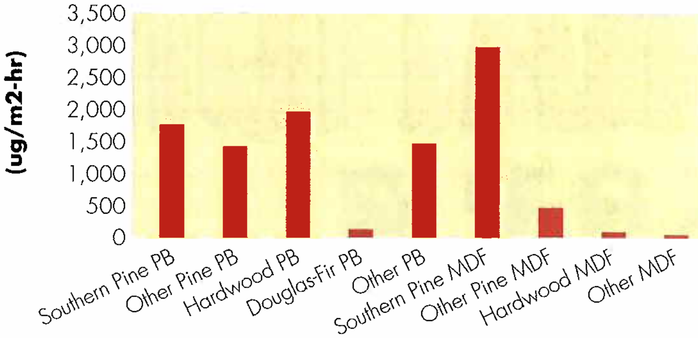


Table 1
Total Aldehyde Emissions in 24 hours



Recognizing that emissions occur during the early stages of high temperature heating is important because many VOCs pose potential risks via inhalation. Pinene, for example, is a strong oxidizing agent that attacks rubber and has been cited as reasonably anticipated to be carcinogenic (Young, 2001)

High Temperature Effects on Building Materials

Wood

The behavior of drying wood in commercial kiln operations underscores the importance of slow and consistent drying efforts at high temperatures. Structural wood, exposed to elevated temperatures, experiences the same potential damage as wood in a kiln (Simpson, 1983).

Water is present in three forms in wood cells: 1) liquid or free water, 2) water vapor, and 3) chemically bound or hygroscopic water. When wood dries, free (cellular) water is the first to leave the cell. When the cell is dry, the cell walls still contain chemically bound (hydroscopic) water. This stage of drying is termed the fiber saturation point

(fsp). Wood cells will not shrink (distort) until bound water is extracted from the cell wall. The fsp is a critical milestone in the drying process because wood strength and shape will not change until the moisture content falls below the fsp.

When lumber is dried too quickly, drying stresses and damage can affect the strength of structural members in the home (USDA, 1957). Damage is caused by two kinds of stress, hydrostatic tension and differential shrinkage. Hydrostatic tension is created where high drying temperatures build up the hydrostatic tension in a cell. As a result, the interior cells collapse and there is an appearance of excessive shrinkage and a washboard effect in lumber.

Differential shrinkage occurs between the shell and center of the lumber when the outer wood fibers dry and shrink before the inner wood cells have begun to dry and shrink. This condition is termed, "case hardening." When this occurs, the core moisture cannot pass through to the surface. This prevents proper "wicking" to the surface of the board and evaporating. Lumber that is dried too quickly will degrade during the initial stages and will slow the overall drying process.

Wood dries the fastest at the beginning because the moisture differential is at its highest. This is when wood and a home are most susceptible to damage. During the early stages of drying, low temperatures and high humidity are necessary for many species of wood. As drying progresses, the temperature is slowly raised and the humidity lowered to maintain a steady drying rate

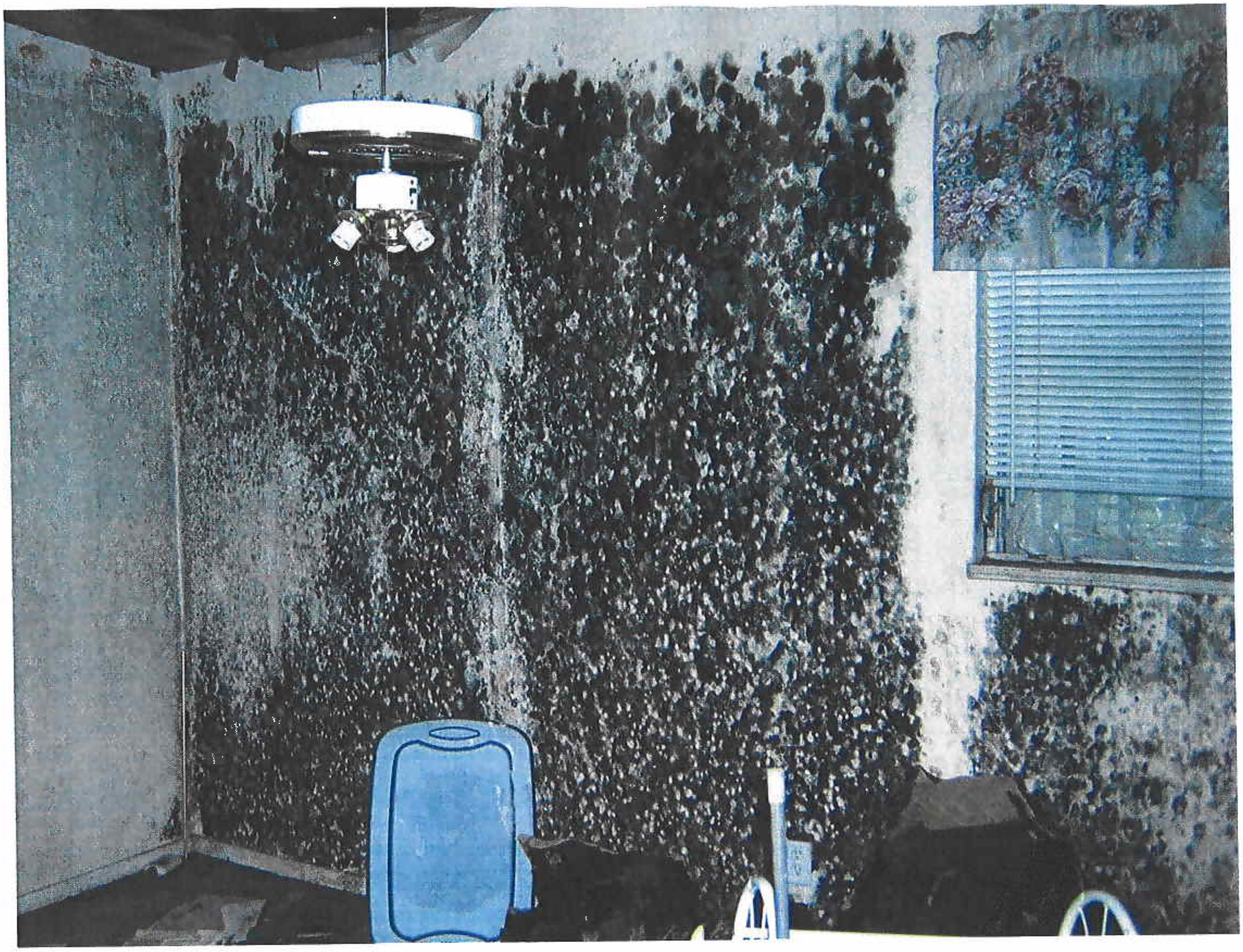
Wood: High Temperature Research

Research revealed that wood roofing systems (beams and sheathing) performed well when exposed to temperatures up to 150 F. Roof systems experience elevated temperatures *via* solar radiation [American Forest and Paper Association (AFPA), Inc., 1999].

Temperature measurements of roof systems vary depending on the orientation, hour of the day, season, color, ventilation rate and insulation thickness. Seasonal measurements showed that roof systems reached 150°F for short durations; the hottest members were limited to roof sheathing.

Under the severest conditions, the temperature of the structural beams, rafters and truss members in wood roofs generally do not reach 140°F. However, when these conditions do occur, the loss of strength associated with increased temperature is compensated by the increase in strength associated with lower moisture content.

Research results conducted during short-term, high temperature exposures has shown an increase in wood



strength properties when cooled below normal temperatures and a decrease in properties when heated above 150 F (AWC, 2005). When the wood returned to a normal temperature, it recovered its original properties.

Researchers who examined wood exposure at temperatures above 150 F showed a permanent loss in strength when cooled and tested at normal temperatures. These permanent effects were additive to those that occurred at the exposure temperature. Permanent strength losses occurred following exposure to temperatures >212 F; the damage was greater when wood was heated in water rather than in dry air.

Based on this research, temperatures of 150 F represent a threshold for the beginning of permanent loss of strength. This interpretation was substantiated by test data that showed an approximate 10 percent loss in bending strength for materials exposed for 300 days in water at 150 F and then tested at room temperature. The use of lumber or glued-laminated timber members that experience long-term exposure to temperatures over 150 F, should be avoided as shown in Table 2.

Table 2

Heating Duration	AWC Design Specifications
Short term heating up to 150°F	No design strength reduction required
Sustained temperatures 100°F	No design strength reduction required
Sustained temperatures 100°F to 125°F	10% to 30% design strength reduction, depending on the moisture content.
Sustained temperatures 125°F to 150°F	10% to 50% design strength reduction, depending on the moisture content and specific property.

Source: AWC, 2005

Wood: Adhesives

The vulnerability of adhesives to elevated temperature regimes (130-160 F) depends on the chemical structure of the adhesive used (Conner, 2001). Wood adhesives are generally classified as either synthetic or natural (Table 3). Synthetic adhesives are derived from petroleum products and are

Table 3. Wood Adhesives Comparison

Class	Nature	Resin Type	Adhesion System	Form and Color	Strength Properties	Uses	Vulnerability (1)
Synthetic	Thermosetting	Amino	Urea-Formaldehyde (UF)	Powder and liquid forms. White to tan with colorless borderline	Durable under damp conditions, low resistance above 122°F	Hardwood plywood furniture, fiberboard Underlayment, flush doors	HIGH
			Melamine-formaldehyde (MF) Melamine-Urea-formaldehyde (MUF)	Powder with blended catalyst; up to 40% urea. White to tan	High dry and wet strength. Resists water and dampness	Hardwood plywood end jointing, edge-gluing	LOW LOW
		Phenolic	Phenol-Formaldehyde (PF) Resorcinol-formaldehyde (RF) Phenol-resourcinaol-formaldehyde (PRF)	Liquid, powder, and dry film, dark red bondline Cured hot (>120°F)	High dry and wet strength. Resists water and dampness	Primary adhesive for exterior softwood plywood	LOW
		Isocyanate	Diphenylmethane- 4,4'-discocyanate (MDI)	Liquid emulsion and separate isocyante White with hardener colorless borderline	High dry and wet strength. Resists water and damp atmospheres.	Laminated beams laminated plywood to steel and plastics	LOW to MOD
		Epoxy	Bisphenol A-based eposy resins	Liquid resin and hardener	High dry and wet strength. Resists water and damp atmospheres	Laminated veneer and wood boat hulls aircraft components wood beams and railings	LOW
		Elastomeric	Styrene butadiene rubber (SBR)	Putty-like in consistency Tan, yellow or gray	Strength develops slowly. Resistent to waer and moist atmosphere	Decorative kitchen countertops wood and paper lamination	LOW to MOD
	Thermoplastic	Vinyl	Polyvinyl acetate (PVAc) Polyvinyl Alcohol (PVA)	Liquid applied ready to use. Dries off white.	High dry strength. low resistance to moisture and elevated temperatures	Interior and exterior doors and moldings Architectural woodwork Furniture	HIGH HIGH
		Hot Melts	Ethylene vinyl acetate (EVA) Polyurethane	Solid blocks, pellets ribbons, rods, or films White to tan; near colorless bondline	Strength develops quickly on cooling. Moderate resistance to moisture	Edge-banding of plastics plastic lamination paper overlays furniture assembly	LOW LOW
Natural		Protein	Casein	Powder with added chemicals, white to tan borderline	High dry strength Moderate resistance to water and dampness	Interior doors laminated lumber	MODERATE
			Soybean	Powder with added chemicals. White to tan. Same borderline	Moderate to low dry strength. Low resistance to water and dampness. Moderate resistance to intermediate temps.	softwood plywood fingerjoints for lumber	MODERATE
			Blood	Solid and partially dried whole blood. Dark red to black bondline	High dry strength: Moderate resistance to water and dampness and organisms.	Interior doors discontinued use in laminated lumber	MODERATE

References: Forest Product Laboratory, Wood Adhesives, Science and Technology FS-FPL-4703 A.H. Conner, 2001
(1) The range of vulnerablity is generally considered between temperatures of 120 and 160°F.

usually applied as a water-soluble liquid to the wood surface. Adhesive prepolymers cure by reacting further to form polymers at the contact point. Heat and cross-linking chemicals are often added to strengthen the curing reactions.

Synthetic adhesives are classified further as either thermoplastic or thermosetting resins. Thermoplastic resins such as Polyvinyl acetate (PVAc) ($CH_3COOCH=CH_2$) and Polyvinyl alcohol (PVA) (-CH_2-CH(OH)-(n) soften when exposed to heat and solidify when cooled to room temperature.

Thermoplastics are more vulnerable to elevated heat. PVAc is most widely used as an emulsion that is white to off-white in color and is used in many household applications. Commercial uses include laminating adhesives, floor tiling and paper coatings. When exposed to elevated temperatures (100 F), PVAc will soften and become less resistant to high moisture and humidity than thermosetting resins.

Thermosetting adhesives (*i.e.*, amino resins, phenolic resins, epoxy resins and isocyanates) are the principal type of adhesive used to bond wood and are less vulnerable to heat. The principal difference between thermoplastics and thermosetting adhesives is that thermosetting adhesives form polymers that cross-link when they cure. When cross linkage occurs, the cured adhesive is insoluble and does not soften when heated.

Natural adhesives are derived from starch, soybean, animal waste and meat processing and tanning by-products and casein from skim milk. Protein-based adhesives (*i.e.*, soy, blood and casein) are the most common; however, these adhesives are most often used for interior applications. Natural adhesives are used as a water-soluble application and cure when the solvent (water) is removed. Some formulations add chemicals to aid in cross-linking to enhance strength. These additives lessen the vulnerability of natural adhesives to high temperatures (130 to 160°F). The primary disadvantage of natural (proteinaceous) as compared to synthetic adhesives is their vulnerability to microbial degradation and lower resistance to moisture. ■

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