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Brief Survey of Wood Adhesives

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Introduction

Adhesives may be defined as any substance capable of attaching materials together by means of surface attachment. This property is not necessarily an intrinsic characteristic of the substance itself since the adhesive may be much weaker than the materials joined together, but it is developed as the adhesive interacts with the adherends under certain conditions of temperature and pressure.

Knowledge and use of adhesives is not new. The ancient Egyptians knew well the art of veneering and used adhesives to attach decorations to wood some 3500 years before Christ. Mud, dung, and clay, along with mixtures of these substances, must also be regarded as adhesives and have been used for centuries to build huts in many parts of the world. Thatched huts plastered with a mixture of camel's dung and mud are still regularly used in southwestern Saudi Arabia, for example.

Many types of glue have been used to bond wood together, but until the time of the Second World War, essentially all of the glues were of natural origin. Adhesives based on synthetic polymers were introduced just before WWII and now surpass most of the older natural glues in importance for wood bonding. These synthetic adhesives are used in situations which are far too demanding for adhesives of natural origin and satisfy moisture, durability, and strength requirements that were unthinkable a few years ago. At one time, adhesives belonged exclusively in the realm of the craftsmen; today, they have become indispensable to the engineer as well.

Classification and Description

For the most part, adhesives used to bond wood together may be separated into two distinct groups--those adhesives such as animal, vegetable, casein, and blood glues which are formulated from materials of natural origin, and those adhesives which are based on synthetic resins derived from petroleum, natural gas, and coal, i.e., products of the petrochemical and related industries. The properties of various adhesives are discussed below separated according to these two categories.Natural Adhesives

Animal Glues

Animal glue was usually made from the hides and bones of such animals as cattle, horses, and sheep and was usually classified as either hide or bone glue. Additional tissues such as sinews may also be used and substantial amounts of adhesive are made from fish. Animal glues may be purchased as a powder, as beads, or as a jelly. The solid forms must be soaked in water before they can be used. A good quality animal glue should be able to soak up several times its weight in water and still remain a gelatinous mass. They are heated in glue pots to about 60° C (144° F) to reduce their viscosity to a level where they can be applied. Some animal glues are sold in convenient liquid form, particularly the fish glues. Hot animal glues develop an initial or tack strength on cooling but develop their full strength only on drying. Animal glues have several shortcomings which have lead to their replacement by other adhesives in a large part of the woodworking industry. Specifically, they have low moisture resistance, are attacked by molds and fungi, are somewhat inconvenient to use and must be applied at the proper temperature, and are relatively expensive. More importantly, there is strong competition for animal remains today, and as a result animal glues are in short supply.

Capsule Summary

- Form: Many grades sold in dry form; liquid glues available.
- Properties: High dry strength; low resistance to moisture and damp conditions.
- Preparation and application: Dry form mixed with water, soaked, and melted; solution kept warm during application; liquid forms applied as received; both pressed at room temperatures; adjustments in gluing procedures must be made for even minor changes in temperature.
- Typical uses: Once widely used for furniture construction. Has largely been displaced as an assembly glue by PVA's.

Starch Based Vegetable Glues

Although starch glues still are used in the United States, they are used little in the wood industry. Of particular importance, they have been replaced by urea-resin adhesives in gluing interior-type hardwood plywood and furniture. They are included here largely as a matter of historical interest.

As the name implies, the principal component of these adhesives is starch which may be obtained from a variety of plants including corn, potatoes, rice and cassava. The root of the cassava plant is the source of tapioca. Prior to World War II, extensive cassava plantations were maintained by major glue companies in what is now Indonesia. During the war, these plantations were lost, substitutes were found, and production of glues which relied on this plant decreased accordingly. Vegetable glues are ordinarily sold in powdered form and must be mixed with water. Other chemicals such as alum may be added to improve their properties. These mixtures are heated to prepare them for use--heating flour paste, for example, renders the flour soluble. Vegetable glues are relatively inexpensive and have a relatively long pot life. They set through loss of

water, which may be quite slow, so that glued assemblies must often remain clamped overnight. Vegetable glues were widely used during World War I in such applications as veneering. They lack moisture resistance, however, stain certain veneer species, and are attacked by micro-organisms.

Capsule Summary

•Form: Mainly sold in dry form as flour.
•Properties: Produces tough dry bond; little resistance to moisture and damp conditions.
•Preparation and application: Flour, water, and caustic are mixed and stirred with a brief cooking period. Mixture life relatively long.
•Typical uses: Primarily of historic interest. Formerly used in production of plywood. Little used today.

Protein Based Adhesives

Soybean Glue

The principal protein-based vegetable glue is manufactured from either soybean meal or the vegetable protein isolated from it. Soybean glue has properties and characteristics which are similar to those of casein glue, but lacks its water resistance. Soybean glue may be hot-pressed, and in the past was widely used for interior grade Douglas-fir plywood. Soybean protein is also used in a blend, consisting primarily of blood and soybean proteins. These are mixed and used like the hot-press blood glues.

Capsule Summary

•Form: Protein sold in dry powder form (generally with small amounts of dry chemical added) to be prepared for use by user.
•Properties: Moderate to low dry strength; moderate to low resistance to water and damp atmospheres; moderate resistance to intermediate temperatures; white to tan in color.
•Preparation and application: Mixed with cold water, lime, caustic soda, and other chemicals; applied and pressed at room temperatures, but more frequently hot-pressed, especially when blended with blood protein.
•Typical uses: Bonding softwood plywood for interior use. Now largely displaced by phenolic resin in the softwood plywood industry.

Casein Glue

Casein glue is prepared from casein curd which is precipitated from skim milk or buttermilk either by allowing the milk to sour naturally, or by adding acid to it. About eight gallons of skim milk are required to make one pound of dry casein. To prepare the glue, the curds are dissolved in an aqueous alkaline solvent such as lime water to which other chemicals such as formaldehyde or copper chloride are added. Most casein glue is sold as a dry powder and must be mixed with water before it can be used. Once mixed with water, casein glue has a relatively short pot life. Pot life can be

increased but only at the expense of moisture resistance. Until the introduction of adhesives based on synthetic resins, casein glues were important because of their superior moisture resistance. They are markedly superior to animal and soybean glues in this respect. Casein glues have several characteristics which limit their usefulness. They tend to stain those species of wood which are rich in tannic acid such as the oaks, so that casein glue is largely excluded from the furniture industry. They also dull woodworking tools rapidly and are attacked by molds and fungi. In recent years, casein glues have become expensive because of the increasing needs for milk to feed the hungry of the world.

Capsule Summary

- Form: Several brands sold in dry powder form; may also be prepared from raw materials by the user.
- Properties: Moderately high dry strength; moderate resistance to water, damp atmospheres, and intermediate temperatures; not suitable for exterior uses; white to tan in color.
- Preparation and application: Mixed with water; applied and generally pressed at room temperature.
- Typical uses: Laminated timbers and doors for interior use.

Blood Glue

Blood-albumin glue is manufactured from whole blood which is a by-product of slaughterhouse operations. Dried soluble blood powder is produced by evaporating the serum from fresh whole blood. Blood-albumin glue is then made by mixing the dried blood powder with water and other chemicals such as lime and caustic soda.

Blood-albumin glues were, in a sense, forerunners of the synthetic resins in that they required hot pressing in order to obtain proper setting and curing of glue lines. In the dry state, blood-albumin glues have somewhat less strength than the casein glues, but they are much superior in moisture resistance. Until synthetic resins became generally available, blood-albumin glues were the most important water resistant glues available for plywood manufacture. They also showed moderate resistance to intermediate temperatures and to micro-organisms. As a result, these glues were widely used in the manufacture of plywood and still find some use in that industry today. Older glues, referred to as "blood albumin glues," which were dispersed in ammoniacal water solutions for use as hot-pressed plywood glues, are apparently used little in the United States.

Capsule Summary

- Form: Primarily, dry soluble or partially insolubilized whole blood. Commonly handled and used like soybean adhesives.
- Properties: Moderate resistance to water and damp atmospheres; moderate resistance to intermediate temperature and to micro-organisms; dark red or black in color.
- Preparation and application: Mixed with cold water, lime, caustic soda, and other chemicals; applied at room temperature and pressed either at room temperature or in hot presses at 240° F or higher.

•Typical uses: Primarily for interior-type softwood plywood. Sometimes in combination with soybean protein. Now largely displaced by phenolic resin.

Synthetic Resin Adhesives

Synthetic resins are man-made polymers which resemble natural resins in physical characteristics but which can be tailored to meet specific woodworking requirements. These resins impart to glue lines and joints the highest water resistance attained to date. In contrast to the natural adhesives which at best can resist only a moderate amount of moisture, properly formulated synthetic adhesives appear able to withstand repeated direct wetting indefinitely. Synthetic resins were introduced as woodworking adhesives during the early 1930's, but their greatest development and use occurred during World War II, and their use is still increasing today.

Synthetic resin adhesives may be separated into two distinct categories - thermosetting adhesives and thermoplastic adhesives. Thermosetting adhesives depend upon a condensation type of polymerization reaction in which water is eliminated. During this cross linking reaction, the adhesive undergoes an irreversible chemical and physical change which renders it insoluble. The reaction itself may be initiated by means of chemicals or heat or a combination of both. Urea-formaldehyde, melamine formaldehyde, phenol-formaldehyde, and resorcinol-formaldehyde along with phenol-resorcinol formaldehyde are included in this group of adhesives. All of these resins utilize formaldehyde as a common raw material.

Thermoplastic resins are prepolymerized and set by loss of dispersing solvent. They do not undergo a chemical cross linking reaction while curing, therefore, but remain in a reversible state and can readily be softened by heating. Polyvinyl acetate emulsions (white glue) and hot melt glues belong to this group of adhesives.

Thermosetting Resins

Phenol-formaldehyde, the first of the synthetic resins to be developed, was discovered by Dr. Leo Bakeland in 1909. Urea-formaldehyde, resorcinol-formaldehyde, and melamine-formaldehyde were discovered shortly thereafter. These products were already being considered for adhesive applications by 1920. Adhesives based on phenol-formaldehyde and resorcinol-formaldehyde resins were well established by 1940 and as previously noted, were widely used during World War II.

Urea-Formaldehyde

Urea-formaldehyde resins are probably the most widely used thermosetting resin for wood. They are widely used for the manufacture of interior grade plywood and also for the manufacture of particleboard. In particular, they are extensively used in producing hardwood plywood for furniture and interior paneling and for furniture assembly. They are available in both liquid and powder forms and may be mixed with

hardeners, fillers, and extenders to obtain formulations which cure at temperatures ranging from room temperature to nearly 400° F. Fillers and extenders are added to the resin to control flow, viscosity, resin penetration into the wood, and to lower glue line costs. Unmodified urea-formaldehyde resins are light colored and form joints which have high moisture resistance. Extension of these resins with various flours significantly reduces their moisture resistance. Urea-formaldehyde resins may also be fortified with melamine resins to improve both their moisture and temperature resistance.

Capsule Summary

- Form: Many brands sold as dry powders; others as liquids; may be blended with melamine or other resins.
- Properties: High in wet and dry strength moderately durable under damp conditions; moderate to low resistance to temperatures in excess of 120° F; white or tan in color.
- Preparation and application: Dry form mixed with water; hardeners, fillers, and extenders may be added by user to either dry or liquid form; applied at room temperatures; some formulas cure at room temperatures; other require hot pressing at 210° to 250° F.
- Typical uses: Hardwood plywood for interior use and furniture; interior particleboard; underlayment, flush doors, furniture core stock.

Melamine-Formaldehyde

Melamine resins are used primarily to improve the moisture resistance of urea-resin adhesives. In this respect, they are substantially more resistant than urea-resins but not as resistant as phenol and resorcinol resins. Melamine resins must be cured at temperatures of at least 240° F for most applications. They are also quite expensive relative to the urea-resins. These two factors have limited the use of straight melamine-resins to a few special applications such as marine plywood where the need for a light-colored water-resistant adhesive justifies their cost.

Capsule Summary

- Form: Comparatively few brands available; usually marketed as a powder with or without catalyst.
- Properties: High in both wet and dry strength; very resistant to moisture and damp conditions depending on type and amount of catalyst; white to tan in color.
- Preparation and application: Mixed with water and applied at room temperature; temperatures of 250° to 300° F. required to cure.
- Typical uses: Primarily a fortifier for urea resins for hardwood plywood, end-jointing and edge-gluing of lumber, and scarf joining softwood plywood. High-frequency cure compatible.

Phenol-Formaldehyde

Phenol-formaldehyde resins are widely used to produce softwood plywood for severe service conditions. These resins are dark reddish in

color and are available as liquids and powders or in film form. They may be manufactured to cure at a variety of temperatures ranging from room temperature to over 275° F. When compounded with fillers and accelerators, they still produce joints which exhibit high bond strength even under severe conditions of exposure. Their use is almost mandatory in plywood to be used in severe service conditions. Most types used in the United States are alkaline-catalyzed. Acid-catalyzed systems are also available, primarily for use at curing temperatures of 70° to 140° F, but are used little in the United States. Principal limitation is the possible damage to wood by the acid catalyst.

Capsule Summary

- Form: Many brands available, some dry powders, others as liquids, and at least one as dry film. Most commonly sold as aqueous, alkaline dispersions for plywood, and as powder or liquid for waferboard and OSB manufacture.
- Properties: High in both wet and dry strength; very resistant to moisture and damp conditions, more resistant than wood to high temperature; often combined with neoprene, polyvinyl butyral, nitrile rubber, or epoxy resins for bonding metals. More resistant than wood to chemical aging; dark red in color.
- Preparation and application: Film form used as received; powder form mixed with solvent, often alcohol and water, at room temperature; with liquid forms, modifiers and fillers are added by users; most common types require hot-pressing at about 260° to 300° F. Temperatures as high as 400° F may be used for structural composites.
- Typical uses: Primary adhesive for exterior softwood plywood and flakeboard.

Resorcinol and Phenol-Resorcinol Formaldehyde

These glues are more expensive than the straight phenol-formaldehyde resins and are used primarily as special purpose adhesives. They are dark reddish in color and are generally supplied in liquid form. A filled liquid or powdered hardener is added to the liquid prior to use. Curing temperatures range from 70° to 150° F. Because of their cost, resorcinol based adhesives are not widely used for plywood manufacture; rather, they are used as assembly glues in solid wood products which must resist exposure to the weather and to water such as glued laminated wood beams and I-joists. They have been of particular value in a few unique exacting applications such as the manufacture of wood aircraft.

Capsule Summary

- Form: Several brands available in liquid form; hardeners supplied separately; some brands are combinations of phenol and resorcinol resins.
- Properties: High in both wet and dry strength; very resistant to moisture and damp conditions; more resistant than wood to high temperature and chemical aging; dark red in color.
- Preparation and application: Mixed with hardener and applied at room temperatures; resorcinol adhesives cure at room temperatures on most

species; phenol-resorcinols cure at temperatures form 70° to 150° F, depending on curing period and species.
•Typical uses: Primary adhesives for laminated timbers and assembly joints that must withstand severe service conditions.

Isocyanates

Isocyanate based adhesives were first used in the 1940's, but their high cost, along with technical difficulties and associated health hazards, largely prevented their commercial application. Technical improvements, along with the demand for board products which are totally free of formaldehyde emissions, subsequently lead to the use of isocyanate binders for particleboard manufacture. Isocyanate particleboard has been manufactured in Germany since 1975 and is being used increasingly in the U.S. today. It has excellent resistance to moisture and hence is well-suited for exterior applications. In addition to wood, isocyanates may also be used to bond agricultural cellulosic wastes such as straw and bagasse. Isocyanates may also be used as assembly glues, but the cost of the adhesive limits their use at the present time.

The basic bonding mechanism consists of forming urethane bridges with the hydroxyl groups of the cellulose. This results in an extremely strong wood to adhesive bond which is resistant to moisture as well as dilute acids (Pizzi, 1963).

Capsule Summary

•Form: Liquid resins or water emulsions or with other resins to form polyurethane adhesives. Great versatility in formulating wide variety of adhesives; some forms may give toxic vapors.
•Properties: Excellent adhesion to wood and many other materials. Resistance to moisture and elevated temperature varies widely; excellent chemical aging resistance.
•Preparation and application: One-part adhesives cure on application of heat or in presence of moisture; two-part resins cure upon mixing at either room temperature or elevated temperature; very rapid cures are possible.
•Typical uses: Limited use in structural flakeboard , film laminating, and as an assembly adhesive; use has been limited by high relative cost and in some instances by sensitivity to heat and moisture.

Thermoplastic Resin Adhesives

Polyvinyl Acetates

Polyvinyl acetate adhesives--the common white glues seen in both drug stores and furniture factories--have become one of the most important assembly glues in the woodworking industry. They are ordinarily sold as a ready-to-use aqueous emulsion in which the amount of resin present is specified in percent. These resins set rapidly at room temperatures and have high dry strength, but their moisture resistance is inferior to that of the urea-formaldehyde resins; furthermore, joints with thick glue lines tend to creep under sustained loads. They also have poor

resistance to heat. Modified vinyl-resin emulsions are available, however, which involve addition of a curing agent at time of use, resulting in greatly improved resistance to heat and moisture.

Because of their ease of application, their high dry strength, the fact that they can be used with low clamping pressures (although joints of questionable quality may result) and their competitive cost, polyvinyl acetate adhesives are widely used for furniture assembly and have nearly displaced all other glues for this purpose.

Capsule Summary

- Form: Several brands are available , varying to some extent in properties; often copolymerized with other polymers; marketed in liquid form ready to use.
- Properties: Generally high in dry strength; low resistance to moisture and elevated temperature; joints tend to yield under continued stress; white or yellow in color.
- Preparation and application: Ready to use liquid; applied and pressed at room temperature.
- Typical uses: Furniture assembly, flush doors, bonding plastic laminates. Assembly of manufactured homes for transportation shock resistance.

Hot Melt Adhesives

Hot melt adhesives are resins which are normally solid but melt upon heating so that they may be applied as a drop or a bead of glue. Upon cooling, they immediately regain their adhesive properties. Ordinarily, hot melts are not used in structural applications where high strength is required but rather, are commonly used to attach decorative materials such as edge banding to panels and table tops. The adhesives themselves are based on various polymers including the polyolefins, the vinyl acetateolefin copolymers, polyamides, and the polyurethanes.

Capsule Summary

- Form: Solid chunks, pellets, ribbons, rods, or films; solvent-free.
- Properties: Rapid bonding; gap-filling; lower strength than conventional wood adhesives; minimal penetration; moisture resistant; white to tan in color.
- Preparation and application: Melted for spreading; bond formulation by cooling and solidification; requires special equipment for controlling bonding conditions.
- Typical uses: edge banding of panels; plastic lamination; patching; films and paper overlays; furniture assembly.

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