Chapter 11

Wood Adhesives and Bonding Theory

Onur Ülker

Additional information is available at the end of the chapter

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Abstract

In this last century, world had grown faster than before; now people need more furniture than in the past century. More furniture means, more particleboards and more adhesives. Wood adhesives are used in every step of furniture manufacturing. Wood adhesives aim to bond wooden materials with each other or with different materials. Today, production with a faster pace is more important. Furniture production lines could be more productive with fast curing glues. Wood adhesives are used in more than 70% of wood products today in the world. The main reason is their use in gluing furniture joints and wood composite materials. In this chapter, readers can find four different topics: (1) technical properties of wood adhesives, (2) environment friendly adhesives, (3) semisynthetic adhesives, and (4) synthetic adhesives.

Keywords: wood adhesives, bonding theory, penetration of adhesives, measures of wetting, organic adhesives

1. Introduction

Wood is an anisotropic and porous material with many inherited anatomical features. Major features are longitudinal tracheids in softwood species, and vessel elements and longitudinal fibers in hardwood species. The lumens of their cells are large enough to provide a good pathway for flow of liquid resin. Interconnecting pits are often adequate to permit resin flow. However, high-molecular weight resins or occlusions in the pits or lumens may inhibit flow. This conglomeration of resin and wood substance is called the "interphase region." Two substrates, each with its own interphase, and the interface between the substrates, comprise the "bond line." The geometry of the interphase region varies as a result of many factors, such

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as wood anatomy, permeability, porosity, resin viscosity, surface energy, consolidation pressure, and others [1].

A cursory glance through the literature shows the creation of a new or existing wood adhesives, which are seen as research and development activities to improve. Glue in all industrial sectors is a modern need; it is also important in the furniture industry. Now in the new world “green living, green thinking” is the order. It needed a lot of research on environmental and human friendly adhesives for the new chorus. For example, there are a lot of research works done for the elimination of formaldehyde emissions from particleboard adhesive. Wood glue is a major area of importance for industrial and commercial activities. This particular study was made to explain the importance to improve the adhesion strength.

2. Technical properties of wood adhesives

It is more important to know the use of wood adhesives and their technical properties. These properties are given below.

2.1. What is bonding? (Science of adhesion)

In furniture and forest product industry, “wood adhesives” have played an important role in the development and efficient use of wood. In wood products, the most commonly used material is glue. If we check different wood products (plywood, MDF, particleboard, OSB, structural frame and wooden architectural doors, windows, and frames), adhesives are more important to retain their structure. Significant amounts of adhesives are used in floor coverings, kitchen counters and for ceiling and wall tiles. They are also used in nonstructural applications, within car upholstery and accessories. Adhesives increase the resistant strength and stiffness of the composite sheet. The adhesion of the glue depends on the wood-adhesive bonding chain.

Adhesive bonding performance between wood elements is presumed to be significantly influenced by the degree of penetration of the adhesive into the porous network of interconnected cells. Research on the bonding performance has been conducted through microscopic examination and associated techniques, in an effort to establish relationships with the bond performance. Variation between wood species, the wide variety of adhesive application and curing processes, and many types of adhesive chemistries and formulations make sweeping generalities difficult. However, troubleshooting bonding problems and designing new adhesive systems and processes may be facilitated by understanding the fundamentals of adhesive penetration [1].

The interphase region is an uneven layer, as illustrated in **Figure 1**. The geometry of the interphase is assumed to affect bond performance. Adhesive joints under load must transfer stress from component to component through the interphase region. The structural makeup of the interphase, its volume and shape, will dictate the magnitude of stress concentrations and ultimately have a significant impact on the performance of the bond [1].

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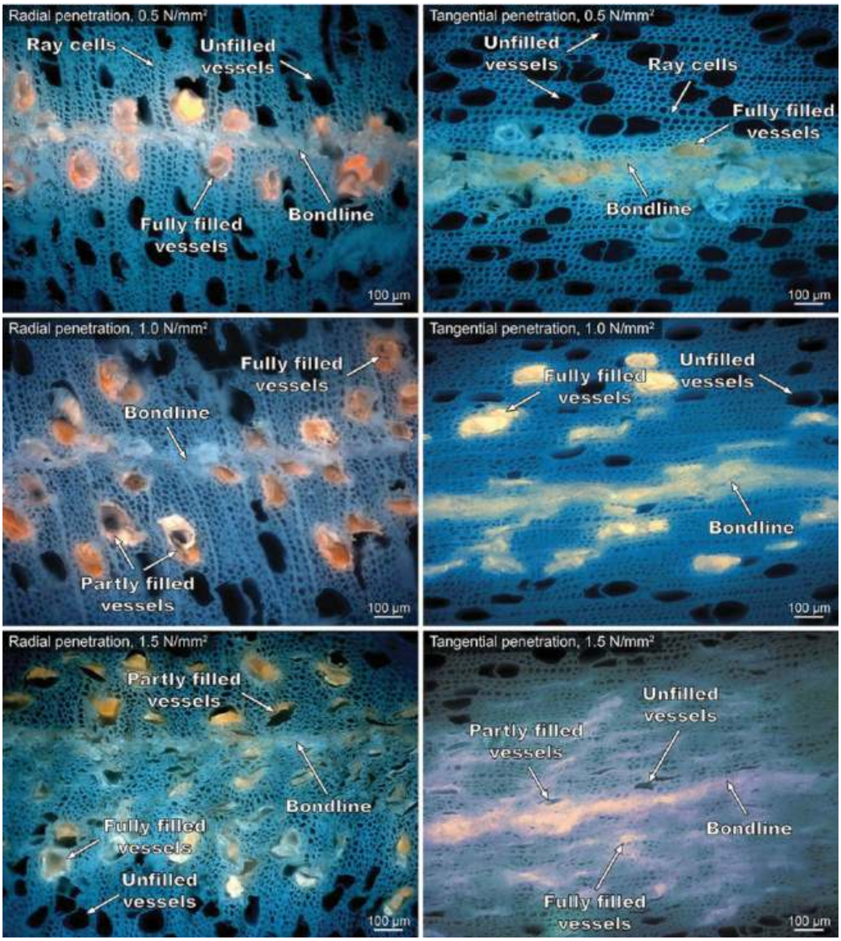

Figure 1. Example of epi-fluorescence microphotograph with the penetration of UF resin into poplar at three different pressures applied during the press cycle: 0.5 N/mm^2, 1 N/mm^2, and 1.5 N/mm^2 for radial and tangential penetration [2].

2.2. Penetration of wood adhesives

There were many researches made on penetration of wood adhesives. The penetration of adhesive into wood can be categorized into two groups:

- Gross penetration
- Cell wall penetration.

Gross penetration results from the flow of liquid resin into the porous structure of wood, mostly filling cell lumens. Hydrodynamic flow and capillary action could be explained as gross penetration. Cell-wall penetration occurs when resin diffuses into the cell wall or flows into microfissures.

In wood, the least resistance to hydrodynamic flow is in the longitudinal direction, following the lumens in the long and slender tracheid of softwood, or through the vessels of hardwoods. Since vessels are connected end-to-end with perforation plates and there is no pit membrane, this cell type dominates the penetration of adhesives in hardwoods. Using optical microscopy, the author has observed resin in pit chambers of both hardwood and softwood species and in cell lumens in which the only entry pathway for the resin was through the pit.

Adhesive penetration influences link 4 through 7 in reference [3]. All of the potential adhesion mechanisms are influenced by penetration. The concept of mechanical interlocking is obviously dependent on penetration of the adhesive phase beyond the external wood surface. In addition, the combined adhesion force due to covalent bonding and formation of secondary chemical bonds is directly related to the area of surface in contact between the adhesive and the cell wall.

In reference [3], a chain-link analogy for an adhesive bond is proposed as shown in **Figure 2** and inferred that the bond is only as good as the weakest link in the chain. Adhesive penetration plays a vital role in this analogy. Link 1 is the pure adhesive phase, unaffected by the substrates. Links 2 and 3 represent the adhesive boundary layer that may have cured under the influence of the substrates and is no longer homogeneous. Links 4 and 5 represent the interface between the boundary layer and the substrate and constitute the "adhesion" mechanism. That mechanism may be mechanical interlocking, covalent bonding, or secondary chemical bonds due to electrostatic forces. Links 6 and 7 represent wood cells that have been modified by the process of preparing the wood surface or the bonding process itself.

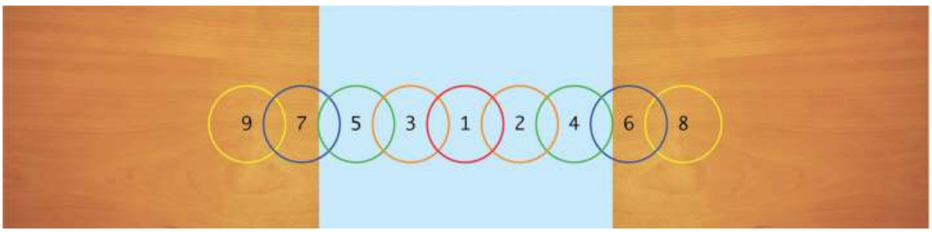

Figure 2. Chain link analogy for an adhesive bond in wood.

For example, rotary peeling of veneer causes fractures that initiate in the radial-longitudinal plane. The cells in the region may have been weakened, and thus increase the potential for failure of the bond. Planning, flaking, sanding, and other mechanical surface preparation techniques will also cause minute fractures in the wood cells. Finally, links 8 and 9 represent the unadulterated wood. A properly designed adhesive bond would have the lower limit of structural integrity located at links 8 and 9. In other words, the wood should be the weakest link [1].

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2.3. Overview of adhesion and cohesion

Adhesion is the tendency of dissimilar particles or surfaces to bond to one another. The internal forces between molecules that are responsible for adhesion are chemical bonding, dispersive bonding, and diffusive bonding. These intermolecular forces can make cumulative bonding and bring certain emergent mechanical effects.

Cohesion word (cohaerere in Latin language) means "stick or stay together." Cohesive force is the tendency of similar molecules to stick together. They attract mutually. Cohesive force caused by the shape and structure of molecules, which makes the distribution of orbiting electrons irregular when molecules get close to one another, creating electrical attraction that can maintain a microscopic structure such as a water drop.

Chain link analogy for adhesion and cohesion is shown in **Figure 3**. The adhesive and cohesive definition refers to the forces that keep together the adhesive with the substrate (adhesion) and the adhesive to itself (cohesion). These forces correspond to:

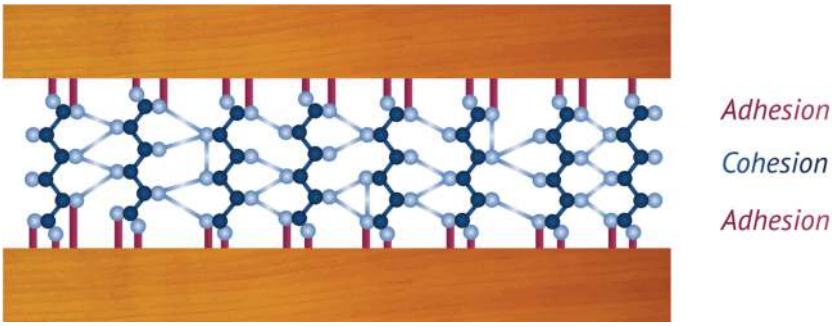

Figure 3. Chain link for adhesion and cohesion.

a. chemical bonds

b. intermolecular forces

2.4. Explaining the wetting

The meaning of "wetting" is always misunderstood because there are many explanations for wetting in the literature. Some examples are given below:

a. *"The liquids which spread over a solid surface, the adhesion of these liquids to the solid could explain the wetting properties of the solid* [4]."

b. *"Good wetting will assist spreading and penetration, but it is not identical with them, good wetting is a zero contact angle* [5]."

c. *"Wetting is that phenomena of a liquid spreading out over and intimately contacting a solid surface* [6]."

d. *"If the molecules at the interfaces of the liquid and the solid are attracted more strongly by the solid than by the liquid, the liquid wets the surfaces and tends to creep outward along them, on a non-wetted surface the liquid molecules are still influenced by their own attraction for one another* [7]."

"In reference [8], *wetting is the term that has come into common usage to describe what happens when a liquid comes in contact with a solid surface."*

Because several phenomena occur when this contact is made, it seems logical to assume that the term wetting is best used in a generic sense. Putting this concept in perspective, the term wetting is used to cover the processes of adhesion, penetration, and spreading. All these cases

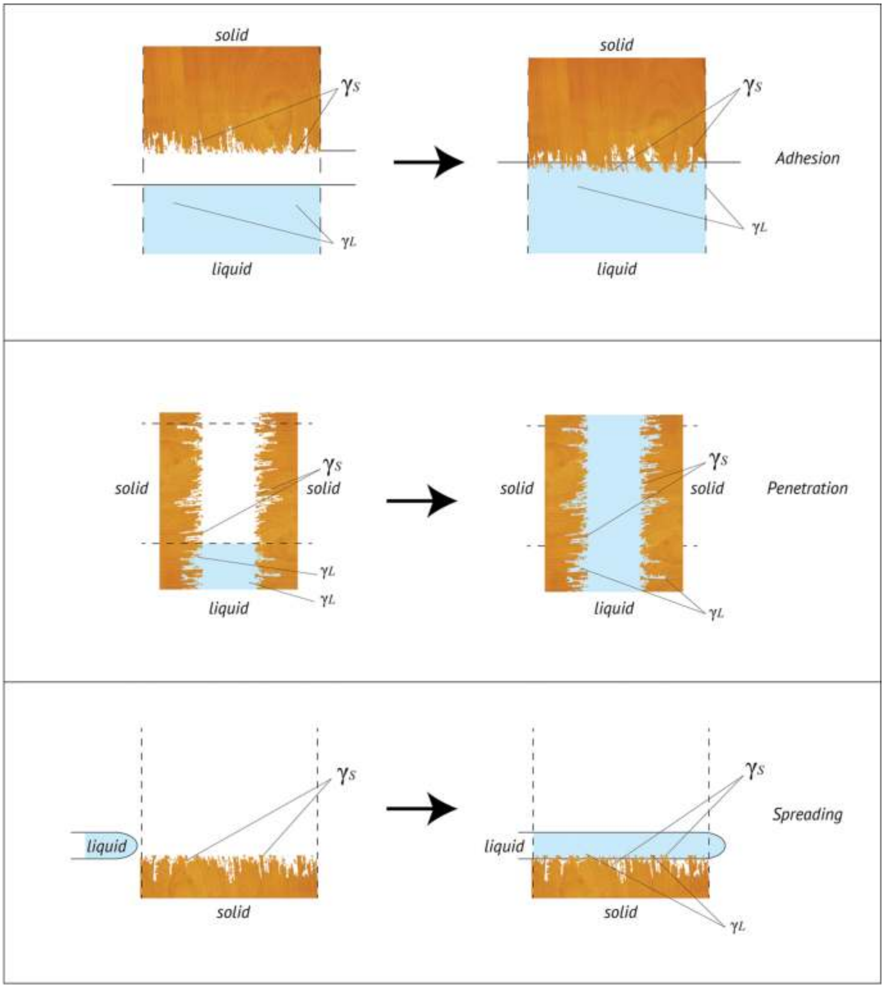

Figure 4. Explaining the wetting.

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explain definitely different types of wetting. Setting adhesion as a subgroup of the wetting is a result of its surface energetics. It is identified simply as the wetting conditions that apply during “face to face contact” [9].

We can clarify this by stating that using the surface energetics approach. The word adhesion implies strictly an interracial phenomenon, while in practical, two materials bond together. Wetting phenomenon is shown in **Figure 4**.

“Penetration” refers to wetting conditions when a liquid works its way up along the walls of a solid material, and “spreading” refers to wetting conditions involved when a liquid flow out over a surface. In **Figure 4**, this theory is explained. In reference [10], wetting is explained as a process that takes place when a liquid contacts a solid surface. Usually the process of adhesion takes place in air; thus, three phases are involved: liquid, solid, and vapor.

2.5. Measures of wetting

The contact angle of a liquid with a solid surface is a convenient measure of wettability; it is an indicator of the affinity of a liquid for a solid. In reference [11], contact angle measurements are made in various ways, the balance of a liquid drop which is lean on a plane solid surface is under the movement of three surface tensions. In **Figure 5**, basic conditions are explained.

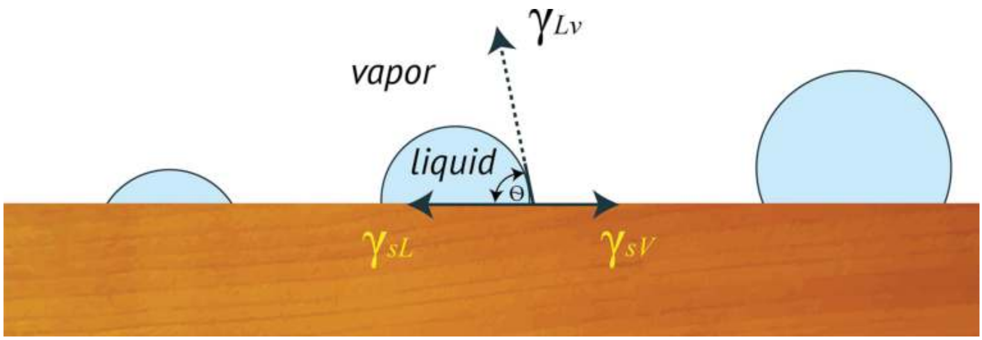

Figure 5. Finite contact angle with liquid resting on solid surface.

The three types of surface stress are explained below:

a. at the interface of the liquid and vapor phase, γ_{Lv};

b. at the interface of the solid and the liquid phase, γ_{sL};

c. at the interface of the solid and vapor phase, γ_{sv}.

Using of contact angle in wettability reduces the fact that the tendency for a given mass of liquid to spread and adhere to a solid surface increases as the angle “θ” decreases.

If the contact angle is “θ", it will be inverse measure of wettability, while the cosine of “θ” is an apparent direct measure. In Young's equation for the classical case of the three phase line, get in touch with between a smooth, rigid, and solid phase "S", a liquid "L", and vapor "V', expresses the relationship between the equilibrium contact angle "θ ", and the three-surface tensions γ_{Lv}, γ_{sL}, and γ_{sv} .

As mentioned in reference [12], "Young equation" is given below,

$$\gamma_{sv} = \gamma_{sL} - \gamma_{Lv} \cdot \cos\theta \tag{1}$$

This equation contains two solid-surface tensions, which are extremely difficult, if possible at all, to measure, it is usually combined with in reference [12], and this relationship relates the work of adhesion, W_{sL}, between solid and liquid:

As mentioned in reference [13], ''Dupre equation" is given below,

$$W_{sL} = \gamma_{sv} + \gamma_{Lv} - \gamma_{sL} \tag{2}$$

The combination of Eqs. (1) and (2) yields the original Young-Dupre equation, which has been one of the most useful tools in the experimental approach to study surface behavior:

As mentioned in reference [10], ''Young and Dupre's equation" is given below,

$$\mathrm{W}_{SL} = \gamma_{Lv}(1 + \cos\theta) \tag{3}$$

In reference [14], many of the main derivations and arguments concerning the validity of these equations are described. Their conclusion, after detailing the results of the various thrusts to this end, seems worthy of particular note: '' *The present reviewers lack sympathy with much of this work, finding it difficult to understand why it should have been thought necessary to raise so many objections to, or to devise so many derivations of, what is, in their opinion, a set of self-evident equations." We lay ourselves open to the charge of enjoying the advantages of hindsight, and perhaps also to that of being naive in outlook, but we do not see why it should have taken so long for workers to appreciate, for example, that we must be the work required to separate the liquid from the solid to give both solid and liquid phases in equilibrium with the vapor phase. If the three-phase system is truly in equilibrium, both before and after separation, then (these) equations necessarily follow* [14]."

Although in reference [14], the results of various derivations of Young's and Dupre's equations have been discussed, it is important here to note briefly the major results because of their relationship and bearing on other methods of measuring wettability. W_{SL}, the reversible work of adhesion per unit area, is not the same value when measured in a vacuum on the one hand and in the saturated vapor of the wetting liquid on the other [15, 16]. The two are distinguished, as $W_{SL}{}^{0}$ or $W_A{}^{0}$ or the work under vacuum, and W_{sL} or W_A as the work in the saturated vapor of the wetting liquid [10].

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$W_{SL}{}^0$ has been shown to always be greater than W_{sL} [11]. In essence, what this means is that on adsorption of a gas or vapor the surface free energy (surface tension) of the solid is reduced. This phenomenon is expressed by the following equation:

As mentioned in reference [11], ''Boyd and Livingston equation'' is given below,

$$\pi_{sv} = \gamma_s - \gamma_{sv} \tag{4}$$

where :

π_{sv}: the change in the surface free energy upon adsorption of the vapor of the contacting liquid.

γ_s: the solid surface free energy in a vacuum.

γ_{sv}: the solid surface free energy in saturated vapor.

In reference [10], Eq. (3) includes the factor π_{sv} in cases other than vacuum, and more correctly assumes the following form:

$$W_{SL} = \pi_{sv} + \gamma_{Lv}(1 + \cos\theta) \tag{5}$$

3. Environmental friendly adhesives (organic adhesives)

Glue is the most important raw material coming after wood in furniture industries. Especially after World War II, glue ameliorated its time and bonding techniques and developments occurring in plywood block board and in the production of chipboard. It has led to developments in a positive direction. Results of the physical and mechanical properties of these materials have been borne and assessed in a wide variety of places where there are opportunities for its usage. In past, plant and animal glues are used, later they left the place for the synthetic resin. Animal glue has to fight against instability and resistance to hot water and microorganisms and the lack of block board limit their usage, though the use and application of synthetic resin in plywood production eliminate these drawbacks. Thus, these materials are now in different atmospheric conditions, letting in water, as well as in direct contact with the water on the concrete breakdown, in mold making, etc., as these are used widely in very different fields. Adhesives used in the furniture industry prior to 1930s were obtained from crop and animals, and those obtained from animals are classified as:

a. Animal glue or gelatin—obtained from skin, bone, and fish residues.

b. Blood—obtained from the raw with blood from slaughterhouses.

c. Casein—derived from an animal milk protein.

3.1. Environmentally friendly adhesives obtained from animals

Adhesives obtained from animals are gelatin-type adhesives. They are obtained from waste and by-products of the animal industries. Raw materials of animal adhesives are hides, sinews, and bones of cattle and other animals. The wastes of leather industry (from tanned hides) are also utilized. Adhesives that are made from hides are of higher grade than glue obtained from bones and tendons [17].

Adhesives obtained from animals are of gluten origin and are obtained by boiling collagens in water agent. To prepare such a solution, adhesive solution is left in cold water which induces swelling (15-30 minutes for the powder and 2 hours for beads), and then if necessary, heat at temperatures not exceeding 60°C in bain-marie. Animal glues can be wetted with water and pasted on any support material. During withdrawal, dry animal glue is proportional to the water used to prepare the solution. The viscosity of the binder solution varies with the change in pH. At low viscosities, pH is between 4.5 and 5.

Adhesives obtained from animals are treated one or three times with cold and clean water depending on the part of the animal, glue weight, and size keeping it for a while in this aqueous gel and by heating at 60°C temperature to bring it to the suitable condition. If the glue is not suitable for boiling, it will weaken its gluing property. In plywood and veneer industries, the glue is applied with a gluing machine. It is more important not to use excess glue unnecessarily. Because, in this case, the deterioration of the balance between the amount of water present in the glue and moisture content of the wood material will cause distortion, such as a crack up, swelling, and corrugated formation of drawbacks. In this regard, the inconveniences of glue application are much more than the minimum driving. These issues suggest that when applied, the amount of glue from animals should be held in 10 per 9.29 m^2.

Plywood unit is prepared by applying hot melted adhesive between the layers placed in the cold press, uses the fluid state glue, and is subsequently heated to 60°C in order to bring it by a press. Later heat up to 25°C for the purpose of heated press 60°C so. Subsequently, 25°C > a is cooled. Unfavorable side of animal glues are that they comes off when contacted with water or at 80°C temperature and due to higher relative humidity of animal glue bonding there is the loss of precision. Furthermore, animal glues, with the action of microorganisms can easily undergo deterioration.

3.2. Environmentally friendly adhesives obtained from botanical plants

Botanical adhesives are obtained mostly by processing starchier plants. As well as some of the resins of wood species fall into this group. Both in animal glue and vegetable glue, formaldehyde (an organic compound with the formula CH_2O) and so on are used to prevent microorganisms.

Plant-derived adhesives are divided into two groups as starch- and cellulose-derived. The first group is adhesives derived from starch, extracted from plants, such as corn, rice, potatoes, and wheat and is generally used in bookbinding, paper bags, and cardboard boxes.

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The second group of adhesives is made from cellulose, derived from trees, shrubs, or fruits such as bananas, which are used more in stickers affixed to glass.

4. Semisynthetic adhesives

Cellulosic derivatives are thermoplastic adhesives. Thermoplastics are in solid phase at normal temperature. On heating, they soften and melt; this property helps them to protect the floor when a chemical alteration occurs. They occur as an adhesive solution, dispersion, and in solid form. Once heated, they become solid ones. A liquefied thermoplastic material can provide adhesion when allowed to cool. In solution and dispersion they remain as a film by the evaporation of the liquid solvent. They are classified into two groups:

Cellulose nitrates are cellulose, which are obtained from cotton by reaction with nitric acid and sulfuric acid. The color of cellulose nitrate normally is opaque or transparent, but under the day light, it will be dark. It is resistant to water and oils, and it biodegrades at moderate temperature in weak acids, alkalis, and organic solvents. But it is a strong, flexible adhesive. There is even aged adhesive reversibility.

Cellulose ethers are prepared by reactions of suitable alcohol sulfate or chloride salts in an alkaline environment. They are sold in the market as organic solvents or by dissolving the gel powder in water and a vaporizable solvent. After the evaporation of the solvent, they remain as thermosetting polymers. Upon evaporation, there is a degree of shrinkage and decrease in volume. In these cases, the adhesive is not suitable to be used for structural strength.

5. Synthetic adhesives (inorganic adhesives)

In 1930s, synthetic resin adhesives were used in the woodworking industry. They have many advantages for use in the woodworking industry. In the outdoor furniture, synthetic resin adhesives can be used in joints that remain as strong as the wood even in unprotected exposure to the weather. Most of the “animal” adhesives can be used in furniture joints for interior use only [18].

Inorganic adhesives are based on typical compounds, such as sodium silicate, magnesium oxychloride, lead oxide (litharge), sulfur, and various metallic phosphates. These materials form strong resistant bonds for special applications, and are still widely used. The advent of synthetic organic polymer adhesives during the last two decades has led to a decline in the use of many of the older inorganic adhesives laboratory recipes [19].

The more important adhesives for wood are currently produced by chemical synthesis. Chemical synthesis, usually converts synthetic adhesives from liquid to solid by a hardener or a setting agent. These agents may be furnished separately for addition to the resin before use, or they may be present (particularly with spray-dried powdered resins) in the resin as supplied [18, 20].

The advantages and disadvantages of synthetic resin adhesives are given below.

Advantages

a. low cost materials,

b. easy to use and to scale-up for industrial use, and

c. high temperature resistant joints.

Disadvantages

a. cannot cope with large CTE mismatch,

b. are only good for low stress applications,

c. joints not leak-tight, and

d. surface preparation is critical.

5.1. PVA adhesives

Polyvinyl resin emulsions are thermoplastics, softening when the temperature is increased to a particular level and hardening again when cooled. PVA adhesives are copolymer based. PVA adhesive solidifies by evaporation or by absorption of water by the gluing material. Solidification time is relatively short, about 45 seconds. The best temperature for using PVA adhesive is around 20°C. PVA resins have long storage and working lives at normal room temperatures. Users must avoid in-storage evaporation or freezing. Packaging should be modified to keep them cool. They are diluted to last longer. PVA adhesives are milky-white fluids to be used at room temperature in the form supplied by the manufacturer. Emulsion films are resistant, waterproof, usually applied quickly, does not smell, and they do not change the taste. They are durable to machine use and are oil-resistant [17, 18, 20].

5.2. PVAC adhesives

PVAC (the term embraces both homopolymer and copolymers) was in the forefront of the transition of adhesives from natural to synthetic adhesives. While overall consumption of homopolymer plus copolymer doubled during the 1975–1987 period, the copolymer adhesives increased by a dramatic 250%. The preferred comonomers are ethylene acrylate esters. Three uses for PVAC in packaging, construction, and textiles account for 80% of the polymer and 95% of compound usage. PVAC adhesives are found to be used in a dozen construction applications; the largest is ready-mix joint cement for gypsum board. These are highly filled formulations with a polymer content of 3%. Concrete adhesives containing PVAC serve to bond new concrete to old. Vinyl acetate-ethylene is the material of choice for vinyl and paper lamination to hardboard gypsum board and other substrates [21].

As a furniture adhesive, PVAC is used for general assembly applications, film overlay and high-pressure lamination, edge gluing, wood veneer, and edge bonding. The demand has increased by 400% in the last 20 years. In furniture market ''white glue" continues to be a staple for both home and shop.

5.3. Hot-melt adhesives

To spread and for adhesion of substrates, adhesives should have the "soaking" feature. In most adhesives used in packaging, easily evaporating agent such as water flow (water as solvent) is used for dissolving the adhesive. It evaporates leaving behind a sticky substance and it easily glues. On the other hand, a solvent is used in Hot-melt before applying instead of dissolving it. The unifying feature can be caused by the solidification of hot melt adhesives. Heat dissipates more quickly in the case of a volatile liquid even for a waterproof layer. Fast heat dissipation provides quick bond formation. In the furniture industry, hot-melt adhesives are furnished in solid form.

Therefore, hot melt is ideal for applications, especially where high speed, early adhesion is important. The lack of a liquid solvent, frost, weathering, and decay do not affect the shipment and storage of hot-melt adhesives. The biggest disadvantage of hot-melt adhesives is their limited heat resistance. In furniture market, they usually are sold as chunks, granules and in cord form on reels.

Hot-melt adhesives are thermoplastic materials. Even at mildly elevated temperature, a major part of the glue is lost by melt at the end. The bond is formed very quickly depending upon the temperature difference between the glue and the parts being joined. The setting time as brief as a fraction of a second has been reported. The durability of hot melt used in the packaging decrease at 60°C and deteriorate at 70°C. The most common use of hot melt is in packaging material, joining a low molecular weight resin and a waxy ethylene-vinyl acetate copolymer (EVA). According to the attached, EVA additives integrate power, product durability, and resistance to hot seam and heat. (If the resin is useful in the hot seam accelerates adhesion largely determines the color and odor). Most crystallized substances as waxy material softening point, resistance to heat and set the time. Most frequent uses of hot melts in wood gluing have been for edge banding of panel boards [22–24].

5.4. Contact adhesives

Contact adhesives are generally based on synthetic rubber, which is obtained by dissolving in suitable liquids. Contact adhesives are sold under a variety of names in the market. As a result of evaporation of the flux contained in the glue, the glue dries. Bonding of large surfaces with contact adhesive is difficult.

Contact adhesives are usually used to bond:

a. plastic laminates to plywood or particleboard for counter-tops,

b. restaurant and kitchen tables,

c. edge of particle boards and MDF,

d. upholstering of sofas, and

e. PVC edge to boards.

Contact adhesives should be applied to both surfaces, and allowed to dry, depending on the ambient temperature and the chemical structure of glue. The wait and airtime (10 minutes, 15 minutes) varies. Contact adhesives are unique in that they develop considerable strength immediately upon contacting surfaces [16].

5.5. Urea formaldehyde resin adhesives

Urea formaldehyde resins are widely used in chipboard or plywood production. UF resin is produced by heating suitable urea and formaldehyde at 115°C for 5 hours. They are usually produced during the production of high quality glue E3 formaldehyde emissions. UF resins came into market in 1930s. UF resin can be formulated either for hot pressing or for room temperature curing by different types and amounts of catalyst. UF resins are compatible with various low cost extenders or fillers, thus permitting variation in both quality and cost. They are available with solid contents from about 40–70% percent. They are also marketed as dry powders, with or without incorporating the catalyst [18].

UF resins are used as adhesives provide a number of advantages to manufacturers in the wood industry. The use of UF resins adhesives make it superior to other chips and boards them, providing the reasons for the choice of MDF and plywood production as follows:

a. low cost,

b. a very different baking (curing) conditions,

c. easy to use,

d. low energy consumption during production with low firing temperature,

e. ability to easily dissolve in water,

f. microorganisms and abrasion resistance,

g. hardness,

h. great thermal properties, and

i. colorless.

UF resin has some disadvantages despite an outstanding advantage. UF resins have a high durability, especially in low humidity and high temperature. Hence UF resin produced from forest industry products are suitable for indoor use only. The combination of temperature with humidity reduces adhesive property of the urea formaldehyde and melamine urea formaldehyde adhesives in the product and leads to formaldehyde gas emission.

5.6. Melamine resin adhesives

Melamine-formaldehyde resin is obtained from polycondensation of melamine and formaldehyde. In the reaction between formaldehyde and melamine, the melamine (2, 4, 6 - triamino-1, 3, 5- triazine) gives derivatives containing different numbers of methyl groups participating amine group. The number of methyl groups may be up to six. The water-soluble methyl melamine cross-linking at elevated temperatures over a methylene or ether bridges are converted to the formaldehyde resin.

MF resins are usually used in the impregnated decor paper, barrier lining the balance and preservation, post-forming craft, and overlays. They are also used in production for hardwood Kraft paper impregnated overlay and coatings for the tray. MF resin adhesives are sold in furniture market as powders. MF resin adhesives are prepared by mixing with water or used with a MF hardener. The color of MF adhesive is almost white, but the addition of filler usually gives them a light tan color similar to the urea resins. MF resins are considerably more expensive than PF or UF resins. Uncatalyzed MF resin adhesives also have been investigated for gluing heavy laminated ship timbers at curing temperatures of 140–190°F [18, 20].

5.7. Silicone adhesives

Silicone adhesives are known as polysiloxanes. In the chemical structure of silicones, silicon (*Si*) and oxygen (*O*) atoms are sequentially arranged instead of carbon (*C*) contained polymer is the common name. The most methyl or phenyl groups are located bound to silicon atoms of the silicone molecules. Silicones are the most fluidic produced in the form of a resin. Silicone fluids are quite stable substances, and they are not affected by water or influenced by rising heat.

They are very good electric insulators as well as hydraulic fluids and emulsion-breaking agents, and they are also used to reduce water permeability of various materials, such as paper. Silicone rubbers are also electrically insulating and chemically resistant and maintain flexibility in a wide temperature range. These are the important features. It is most commonly used in protective sheath and insulating varnishes.

In furniture industry, silicone adhesives are usually used to:

a. finish material at counter-tops,

b. bond edges and finish points at parquets,

c. bond kitchen and bath cupboards, and

d. bond upholstering fabric of sofas.

Single component silicone adhesives require a humidity of 5–95% to cure. Besides the presence of humidity, a temperature between 5 and 40°C is required to cure the adhesive [25].

6. Conclusions

The aim of this chapter has been to present a selective review of the literature of wood adhesives. Different kinds of wood adhesives were explained. Today wood products and wood adhesive industry have many aspects in common. Furniture designers should know wood adhesives and their using tips. Bonding theory and wetting phenomenon were explained in this chapter. An effort was made to tie the status of research in wood adhesion with main adhesive types. The principal results of this section can be summarized as follows:

a. The positive relationships of glue-bond quality and adhesive penetration into the wood structure.

b. The positive relationships glue-bond quality and wettability of the wood structure.

c. Explaining bonding theory with samples.

d. Chain link analogy for adhesion and cohesion has a strong influence on optimum conditions for good bonding.

e. Organic (animal, plant), semisynthetic, and synthetic adhesives were explained with their usage.

On the forefront of adhesion research, types and using tips of adhesives are important. Wood adhesives and adhesion theory depends on wood surface, contact angles, and adhesive type.

Author details

Onur Ülker

Address all correspondence to: ulker79o@hotmail.com

Department of Interior Architecture and Environmental Design, Fine Arts Faculty, Kırıkkale University, Kırıkkale, Turkey

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