Development of protein-based adhesives for wood composite materials

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Context and Objectives

Wood bonding has been practiced for many ages. The first adhesives used for the wood industry were made from bio-sources such as collagen, blood, casein, fish, starch, and other derivatives. However, the production of bioadhesives dropped dramatically due to the boom of products made from fossil sources, such as phenol-formaldehyde (PF), urea-formaldehyde (UF), melamine-formaldehyde (MF) and polymeric diphenylmethane diisocyanate (pMDI). These synthetic adhesives replaced renewable ones as a result of their superior strength and resistance to moisture. Formaldehyde has been subjected to strong regulations, which will eventually lead to banning wood-based panels from the European market due to its harmful emissions. In this perspective, concerns on environmental footprints and toxicity of these adhesive formulations made researchers investigate the utilization of bio-based materials to formulate wood adhesives. Protein- based adhesives have been used for many ages. They are a biodegradable alternative to synthetic adhesives due to their advantages, such as lower emissions of VOCs, renewable sourcing, and reduced environmental footprint. The present work is a summary of the recent development of bio-based adhesives and proteins for the formulation of new wood adhesives.

Current Bio-based Wood Adhesives

There are several reports of different biomass resources for the production of bio-based adhesives, such as lignin, starch, tannins, vegetable oils, and proteins. On the other hand, within bio-based adhesives, protein-based ones are the most abundant class of macromolecules, they function as the main organic building blocks in living organisms. For this reason, there has been an increasing interest in using proteins from both plant and animal sources for glues and adhesives.

Mechanics behind Bioadhesive Development

Mechanism of adhesion

Adhesion mechanisms have been investigated to be reliant on the surface characteristics of the materials. In general, it is approved that there are three primary mechanisms of adhesion: I) mechanical interlocking, II) physical bonding, and III) chemical bonding [1]. All these mechanisms are responsible for bonding, and normally, one of them plays a dominant role.

Wood bonding and Adhesion theories

The most recent state of the art allows to class the theories or mechanisms of adhesion into seven models or fields. These are mechanical interlocking, electronic or electrostatic theory, diffusion theory, adsorption (thermodynamic) or wetting theory, chemical (covalent) bonding theory, theory of weak boundary layers, and acid-base theory [2], [3]. The last four are based on adsorption/surface reaction. Usually, each phenomenon contributes to the whole strength of adhesion. In the case of wood bonding, the main adhesion mechanism includes interfacial secondary interactions such as Vander Waal's forces, dipole-dipole interactions, and H-bonding [4], [5]. To understand better the difference between theories and mechanisms of adhesion, the possible mechanisms underlying each of these theories is schematically represented in Table *1*.

Table 1: Adhesion theories and possible mechanisms.

Theory	Mechanism	Strength of interaction
Mechanical interlock	Wetting	Variable
Electrostatic	Ion-dipole interactions	Strong
Diffusion	Inter-diffusion	Variable
Adsorption/wettability	Vander waals, dipole-dipole interactions	Weak, moderate to strong
Chemical bonding	Covalent bond	Very strong
Weak boundary layer	Defects at interface	Variable
Acid-base	H-bonding, dipole-dipole or ionic interactions	Moderate to strong; very strong

Wood adhesion considerations

The adhesion process involves numerous factors that determine how successfully an adhesive bond will perform in service. The physical and chemical conditions of the adherend's surface are crucial to adequate joint performance. Wood surfaces should be flat, smooth, and free of machine's marks and other surface irregularities, including burnishes, oils, dirt, planer skips, torn and chipped grain. Moreover, a liquid based adhesive should be spread readily to join two wood adherents with maximum power ensuring full contact between the two surfaces. In addition to this, the bond ability of wood is influenced not only by the properties of the adherent's surface but also by wood's physical properties, including density, moisture content, porosity, and dimensional movement.

Protein-based adhesives for wood composites

Table 2 presents an overview of the most protein bio-based adhesives that can be used in the wood industry and the different advantages and disadvantages regarding their performance as wood adhesives.

Table 2: Advantages and disadvantages of various protein-based wood adhesives

Proteins	Advantages	Disadvantages
Wheat Gluten	• High amount of hydrophobic amino-acids • Abundant	• Water-insoluble • Highly viscous due to swelling of starch by water absorption and release of amylose chains
Soy meal	• Good strength under drying conditions • Good thermal resistance	• Limited water resistance • Poor wettability
Zein	• Hydrophobic protein • Water-resistant • A lot of chemical modifications is unneeded	• Yellow color due to xanthophylls, carotenoids, and other color pigments present in corn • Relatively high cost of extraction due to organic solvents needed
Casein	• Relatively safe to work with • Moderate resistance to water	• Eight gallons of skim milk are required to make one pound of dry casein
Keratin	• Is the most abundant among animal sources • Hydrophobic • Fungal decay protection	• Non-homogeneous composition • Poor solubility • Disinfecting process is needed to apply them
Blood	• Very rapid setting with heat • Moderate resistance to microorganisms	• Produce dark glue lines • Blood drying is an energy-intensive process
Collagen	• Globular in nature • Highly non-polar	• Needs processing to separate the collagen from other materials

Conclusion

Protein based-adhesives offer a sustainable solution to indoor air quality and formaldehyde concerns. All adhesive raw materials discussed above are renewable, available, and can substantially reduce emissions (formaldehyde and VOCs) when substituting synthetic adhesives currently used in the wood industry. On the contrary, protein-based adhesives have certain drawbacks that hinder their usage industrially, mainly poor water resistance for hydroxyl group-rich materials and viscosity for long molecule chain polymers. Developing an environmentally friendly wood adhesive system that is competitive with urea-formaldehyde and phenol-formaldehyde resins is feasible to achieve by a combination of technologies, such as protein denaturation, followed by chemical modification of denatured protein and chemical crosslinking. However, challenges are yet to be addressed regarding the costly chemical modifications, which hopefully can be regulated by incorporating hydrophobic proteins for better water resistance performance.

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