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Wetting and film formation of wheat gluten dispersions applied to wood substrates as particle board adhesives

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ABSTRACT

The wetting, penetration, and film formation of wheat gluten dispersions on porous wood substrates have been studied using different microscopy techniques. The effect variation of wheat gluten concentration, processing temperatures, dispersion composition, and the application scheme has been studied. The results have been correlated to previously obtained results on the function of wheat gluten dispersions as adhesive binders for particle boards. The results show that the dispersions readily penetrate the porous wood substrate and that the key parameters for a successful gluing are the dispersion viscosity, concentration, and the application scheme.

1. Introduction

The interest for materials from renewable resources has increased during the last years and one group which has been subjected to a significant amount of research is proteins. Proteins have a long tradition as adhesives for wood applications, as an example casein has been used for more than a century [1]. Another protein that has obtained significant interest in this context is wheat gluten [2–5]. Wheat gluten (WG) is a by-product from starch production and is at present mainly used in the bakery industry and as animal feed. Wheat gluten is an elastomeric protein which possesses unique visco-elastic and cohesive properties, making it suitable for material applications, such as films for food packaging, foams and wood adhesives [2–4, 6–14]. Wheat gluten is further readily available in large volumes since it is a by-product from the bio-ethanol production based on wheat.

The molar mass of wheat gluten (WG) is high and WG is not dispersible in water since its isoelectric point is about 7.3. On the other hand, this means that it is dispersible in alkali or acids. Commercially available wheat gluten consists of approximately 80% wheat storage protein, while the rest is polysaccharides, lipids and minerals. The wheat storage protein can be divided into two fractions, glutenins and gliadin. Glutenins are dispersible in acids or bases, while gliadins are soluble in alcohol. Both of these fractions are rich in proline and glutamine. Gliadins constitute the viscous components of gluten, while glutenin contributes to elasticity and strength [5,6].

Wheat gluten undergoes polymerization/crosslinking when subjected to heat under alkaline or acid conditions. Glutenin crosslinking starts at temperatures above 55 °C, while for gliadins a higher temperature (above 70 °C) is necessary in order to initiate crosslinking. Furthermore,

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gliadins link to glutenins at temperatures above 90 °C [15–18]. It has also been demonstrated that the mechanical properties of wheat gluten based materials can be adjusted by addition of external crosslinkers or plasticizers [9,15].

An important aspect for the performance of adhesives is the adhesion to the substrate. In the case of particleboards, this is the adhesion of the glue to the wood particles as well as the formation of the particle–particle linkage. Some parameters that influence the bonding performance of the adhesive are penetration of the adhesive into the wood and the wetting and the flow of the adhesive on wood. It is important to have a good flow of the adhesive on the surface; if a larger area is covered it is possible to have stronger bonds. The penetration into the wood is also a very important factor; poor results will be obtained both from over- or under-penetration. If the adhesive over-penetrates into the wood structure, there will not be a sufficient amount of adhesive left on the surface to get a strong bond between the particles. On the other hand, in the case of under-penetration the adhesive is not able to form a strong wood-adhesive interaction. The rheological behaviour of the adhesive has a great influence on penetration, wetting and flow. However, these do not only depend on the formulation of the adhesive but also on the wood material and the processing conditions. A driving force for wetting and flow is changes in the surface tension, while the viscosity restricts the flow. The situation becomes very complex in the case of film formation of WG dispersions on wood since viscosity and thus also the flow and film formation depend on shear rate, water evaporation rate, particle fusion, temperature ramping, and the possibility of chemical crosslinking. This, in combination with the porous and heterogeneous character of the wood substrate, makes it difficult to predict the effects of different processing conditions.

Previous research on wheat gluten as a wood adhesive has demonstrated that WG has a strong potential for wood application. The results show that WG-dispersions are film forming and already in these early developed adhesives fulfil the demands and durability in several niche applications i.e. furnitures for in-door use [19]. However, the wetting and flow of WG needs further investigation.

The present study aims to investigate details on how the film is formed during the gluing conditions resembling the first step of particleboard gluing, i.e. film formation of dispersions on rough heterogeneous and porous wood substrates subjected to low shear forces and rates. Model tests on veneers have been used to allow for a microscopy evaluation of the formed adhesive layers. The glued veneers have been studied using different microscopy techniques to determine the film morphology as well as penetration of the adhesive into the wood tissue.

2. Experimental

2.1. Material

Wheat gluten (WG) Reppe Vital (supplied from Lantmännen Reppe AB, Sweden) was employed in this study. The WG contains approximately 80% protein, the remaining part consist of polysaccharides, lipids, minerals and fibre residues. According to the supplier, 83% of this sample has a particle size equal or larger than 50 µm.

Table 1
Size of used veneers.

Veneer ID	Type of veneer	Veneer size
P1	Pine	15.0 cm × 16.6 cm × 0.8 mm
P2	Pine	15.1 cm × 16.8 cm × 0.8 mm
P3	Pine	15.2 cm × 17.2 cm × 0.8 mm
P4	Pine	17.8 cm × 15.2 cm × 0.8 mm
B	Beech	15.1 cm × 15.5 cm × 0.6 mm

Polyamidoamine epichlorohydrin Eka WS XO (PAAE; 15% in water) was supplied by Eka Ch,emicals Ltd. (CAS No 25212-19-5). Sodium hydroxide solution 40 wt% was supplied by Fischer Scientific. Citric acid (CA) monohydrate was supplied by Merck AB. Safranine-O (Basic Red 2), was supplied by ICN Biomedicals Inc.

Pine veneer (flat sliced) was supplied by Fanérkompaniet AB. For size of the veneers, see Table 1.

Beech veneer (flat sliced) was supplied by Holm Trävaror AB. For size of the veneers, see Table 1.

2.2. Equipment

A Leica DMRM optical microscope (Leica Microsystems AB, Stockholm, Sweden), equipped with a fluorescence filter (Leica filter cube H3) and a CCD camera (Leica DFC 280), was used for the optical microscopy studies.

An X-ray micro computed tomograph (Skyscan 1172, Bruker, Kontich, Belgium) was used to evaluate the penetration of the adhesives into the wood tissue.

Viscosity was determined using a Brookfield rheometer with spindle number 3.

2.3. Procedures

2.3.1. Preparation of the dispersions

A sodium hydroxide solution (0.1 M, pH 13) or a citric acid solution (0.05 M, pH 2.2) was employed as the dispersing agent. Wheat gluten (WG) dispersions with a concentration of 12%, 16%, 20% and 24% (wt%) were prepared at room temperature during 1 h. The wheat gluten was added portion-wise to a beaker containing the dispersing agent, while stirring with a mechanical agitator. The wheat gluten dispersions were prepared the day before they were used. The viscosity of the dispersion were determined the day after preparation and as expected the viscosity increased with higher WG concentration. The viscosity was 19 mPa s (WG 12%), 107 mPa s (WG 16%) and 875 mPa s (WG 20%).

2.3.2. Gluing of the veneers

The dispersions (12%, 16% and 20%) were brushed onto the veneers, while in case of the 24% dispersion a spatula was used.

Approximately 44 g WG/m^2 was added on all veneers. If not otherwise indicated sodium hydroxide was used as the dispersing agent and pine veneers were employed.