INFLUENCE OF SOY TYPE ON WOOD BONDING PERFORMANCE

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Background

Proteins were the main wood bonding adhesives for centuries, but they were displaced by fossil fuel-based adhesives in the 20th century because synthetic adhesives offered better water resistance, ease of use, and lower cost. Recently, studies using a polyamidoamine–epichlorohydrin (PAE) curing agent have led to soybean-based adhesives that are being used commercially for interior plywood, engineered wood flooring, and particleboard (1). Commercial products typically use the less expensive soy flour, while the majority of the published research has been on the soy protein isolate and purified glycinin and conglycinin proteins (2). Although soy flour contains about equal proportions of carbohydrate and protein (Figure 1), the common assumption is that the protein provides most of the adhesive strength. Thus, to make better products, it is important to understand protein structure and how other components in natural products are altering the performance of these adhesives. For proteins, intrachain interactions are more critical than they are for other polymers (3). The hydrophobic folding of the proteins may also limit the number of available reactive groups accessible for cross-linking reactions. To better assess the influence of various parameters, we have studied the effect of heat denaturation on soy flour and compared the performance on wood-bond strength of soy flour to the more purified concentrate and isolate versions.

Soybean products

- Whole Soybeans
  ≈ 16-17¢/lb, 36% protein, 18% oil, 36% carbohydrates, 10% moisture
- Defatted Meal
  ≈ 15¢/lb, 48% protein, 0% oil, 44% carbohydrates, <10% moisture
- **Soy Flour**
  ≈ 18-25¢/lb, 50% protein, 0% oil, 40% carbohydrates, <10% moisture
  High (90%) to low (20%) PDI (dispersible protein)
- Soy Protein Concentrate
  ≈ 50-90¢/lb, 65+% protein, 0% oil, up to 35% carbohydrates
- **Soy Protein Isolate**
  ≈ $1.50-2.00+/lb, 90+% protein, 0% oil, up to 10% carbohydrates

Figure 1. Many soybean products are available, but soy flour is used for commercial adhesive products and soy protein isolate has been used for most of the literature studies.

Experimental

The soy materials were the following: soy flours were Prolea™ 100-90 and 100-20 (Cargill Inc., Cedar Rapids. IA); soy concentrate was Arcon® AF (Archer Daniels Midland Co., Decatur, IL); and soy protein isolate was Pro-Fam® 974 (Archer Daniels Midland Co., Decatur, IL). Soy flour, concentrate, or protein isolate were dissolved in water with mixing for 30 minutes prior to testing. When PAE CA 1920 (Ashland Hercules, Wilmington, DE) was used, it was added at the beginning of the mixing.

Apparent viscosities were measured on a Brookfield Digital Viscometer Model LVTD (Stoughton, MA) by vigorously mixing the sample for 30 seconds, allowing it to stand for 10 seconds, inserting the spindle into the sample, and then recording the viscosity value 10 seconds later. Bond strength was determined using maple veneers 20 mm wide by 117 mm long by 0.8 mm thick equilibrated at 22°C and 50% relative humidity with a 5-mm overlap using an Automated Bond Evaluation System (ABES) Model 311c tester (Adhesive Evaluations Systems, Inc., Corvallis, OR). After applying adhesive to one veneer surface, the samples were bonded at 0.25 MPa of pressure for 120 seconds with the platens heated to 120°C. The samples were allowed to equilibrate at 22°C and 50% relative humidity for at least one day and then tested at either ambient conditions (dry) or after one hour of water soak (wet).

Results and Discussions

Soy flour in its native state is quite dispersible in water, as illustrated by the observation that most of the protein stays dispersed in water after vigorous agitation followed by centrifugation. In processing soy, the protein dispersibility index (PDI) is used to measure the alteration or denaturation of the protein. PDI is high (soluble or dispersible) in the native state and low (precipitates) after heat treatment. Commercial soy flours are available in high (90 PDI) with the most native protein, medium (70 PDI), and low (20 PDI) with the greatest heat treatment. These different PDI products are made to provide diverse textures, flavors, water retention abilities, and digestibility that are important qualities for human foods or animal feeds. For bonding, it is natural to consider that the higher PDI flour should be better at wetting the wood surface and should also provide better protein reaction with the curing agents (such as PAE) to afford stronger wood bonds. Thus, we examined the bonding ability of 90 and 20 PDI soy flour of

100 mesh size (Prolea 100-90 and 100-20) with and without the PAE curing agent.

Because PAE has the ability to bond wood on its own, we used only 5% of PAE solids based upon soy solids to place more emphasis on the soy or soy–PAE bonding mechanism. The results in Table 1 show that at 30% solids, there was not a significant difference between the 20 and 90 PDI flours in most of the conditions tested; however, the PAE does improve the wet bond strength for both. For commercial usage, wet strength is more important than dry is because most soy adhesives typically give high wood failure under dry conditions but not under wet conditions. The data are contrary to expectations that as the higher PDI is more water dispersible, it should therefore wet the wood surface and cure better with PAE than with the lower PDI soy flour. In addition, the viscosity differences would support the 90 PDI being a better adhesive because the 90 PDI flour dispersion is only 120 Pa•s, while the 20 PDI flour dispersion was 483 Pa•s. Thus, the flour type did not have a large influence on the strength properties in the ABES testing, although ABES testing can be less sensitive to flow and penetration properties than is observed in conventional plywood testing.

Table 1. Wood bond strengths (MPa) of 30% aqueous soy flour adhesives with and without PAE curing agent.

Soy flour	Without PAE		With PAE	
	Dry	Wet	Dry	Wet
90 PDI	5.0 ± 1.2	0.3 ± 0.2	6.6 ± 1.3	2.2 ± 0.2
20 PDI	6.2 ± 2.4	0.8 ± 0.1	6.2 ± 0.7	2.4 ± 0.1

Normally, studying the components of a mixture can allow a better understanding of the properties of the mixture, but this assumes no interaction of components. This has been the assumption with soy in that most of the research has been with the soy protein isolate and glycinin and conglycinin protein products. However, studies have reported that the protein conformations are influenced by the presence of carbohydrates (4, 5), and the isolation processes for the proteins can influence their properties. Thus, the comparison of soy flour, concentrate, and isolate with comparable protein content in the dispersions is shown in Table 2. Higher solids content was used in the flour and concentrate to keep the protein content of each adhesive constant. The added carbohydrates appear to diminish the wet strength of the soy-bonded samples, both with and without added PAE. One assumption has been that the soluble carbohydrates cause more of a problem than the insoluble carbohydrates, but the concentrate, containing only insoluble carbohydrates, is still significantly worse than the isolate that has had virtually all carbohydrates removed. It is also surprising that the soy protein isolate is so vastly improved over both the soy flour and soy concentrate with no added PAE under wet conditions. Perhaps the isolation process employed for the production of protein isolates is also providing some beneficial denaturing and/or is highly effective at concentrating the most advantageous wood-bonding proteins.

Table 2. Wood bond strengths (MPa) of aqueous soy adhesives with and without PAE curing agent.

Soy flour	Without PAE		With PAE	
	Dry	Wet	Dry	Wet
30% 90 PDI	5.0 ± 1.2	0.3 ± 0.2	6.6 ± 1.3	2.2 ± 0.2
20% soy concentrate	6.2 ± 0.4	0.4 ± 0.1	7.2 ± 1.0	3.4 ± 0.3
15% soy protein isolate	7.2 ± 1.3	3.0 ± 0.4	7.6 ± 0.8	5.0 ± 0.3

Conclusions

Soy adhesives using soy flour and polyamidoamine-epichlorohydrin (PAE) curing agents have made inroads into some of the wood adhesive markets, such as interior plywood, engineered wood flooring, and particleboard, but aspects of these adhesives are not completely understood. In order to better understand the critical parameters, we have examined some hypotheses using the ABES and found the following:

- The protein dispersibility index of soy flour has little influence on the dry and wet strength properties with and without added PAE. This is not true in all soy formulations and under other adhesive testing where flow properties may be more critical, such as in plywood or engineered wood flooring production.
- Soy concentrate is, in some cases, stronger than soy flour, but is inferior to soy protein isolate (in some cases by a vast margin); therefore, simply removing the soluble carbohydrates does not provide the best soy product.
- Caution needs to be exercised in drawing too many conclusions about soy flour performance from the adhesive performance using soy protein isolate and other purified soy proteins.

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References

1. J.M. Wescott, M.J.Birkeland, J. Yavorski, and R. Brady, in: Wood Adhesives 2009. South Lake Tahoe, CA, C.R. Frihart, C.G. Hunt and R.J. Moon, (Eds.), 2010, Forest Products Society, Madison, WI. pp. 136–141.

2. X.S. Sun, in: *Bio-Based Polymers and Composites*, R. P. Wool and X. S. Sun (Eds.), Elsevier-Academic Press, Burlington, MA, 2005. pp. 327–368.
3. C.R. Frihart, M.J. Birkeland, A.J. Allen, and J. M. Wescott, in: *Society of Wood Science and Technology Proceedings*, Geneva, Switzerland 2010, Society of Wood Science and Technology, Madison, WI.
4. J. I. Boye, C.-Y. Ma and V.R. Harwalkar, in: *Food Proteins and Their Applications,* S. Damodaran and A. Paraf (Ed.), Marcel Dekker, Inc., New York, 1997. pp. 25–56.
5. C.G. Hunt, J. O'Dell, C.R. Frihart, in: *Wood Adhesives 2009*. South Lake Tahoe, CA, C.R. Frihart, C.G. Hunt and R.J. Moon, (Eds.), 2010, Forest Products Society, Madison, WI. pp. 214–219.

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