Application of Soy Flour Modified Resins to Hot and Cold Pressed Veneer*

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Abstract

Soy flour can be substituted in polymeric diphenylmethane diisocyanate (pMDI) resin for bonding plywood. Resin bleed-through is avoided by prepressing at 95°C. The boards have greater wet and dry strength than do those prepared from melamine-urea-formaldehyde (MUF) resin. Soy flour can also be substituted in emulsion polymer isocyanates for cold-press applications. The soy increases dry strength but keeps the wet strength unchanged. The optimal level of soy flour substitution is about 20 percent in all cases as determined by infrared spectroscopy.

Bonding wood panels with biobased adhesives is a priority in the forest products industry (Dunky 2020). Although the literature is replete with reports on the synthesis and performance of these adhesives (Moubarik et al. 2010, Damodaran and Zhu 2016), few have seen commercial adoption, presumably because of cost. A notable exception is the soy–kymene combination of Li (2007), which is commercially used for decorative hardwood panels. We have shown that partial substitution of soy flour in polymeric diphenylmethane diisocyanate (pMDI) resin provides cost and operational benefits for bonding medium-density fiberboard, oriented strand board, and particleboard panels as demonstrated in pilot and full-scale trials (Cheng et al. 2019). The cost of soy flour is presently less than half that of pMDI, so that partial soy substitution reduces the overall resin cost as well as its hydrocarbon content. Operationally, soy substitution increases cold tack (Asafu-Adjaye et al. 2020) and reduces platen sticking of pMDI bonded boards (Asafu-Adjaye et al. 2022). It also increases the internal bond (IB) of strandboard. The upper limit of soy substitution is about 20 percent, beyond which wet properties begin to deteriorate.

In the above applications the soy flour was simply mixed in with pMDI resin and sprayed on or blended in with the furnish, the only constraint being that the viscosity of the mixture be manageable. However, there are additional restrictions when the resin is applied as a film or a layer, e.g., to veneer, where resin bleed is a consideration. In this paper we discuss the additional factors that must be considered to adapt soy–resin mixtures to both hot and cold pressed products.

Materials and Methods

Defatted soy flour (7B) was provided by Archer Daniels Midland at a dry-basis moisture content of 6.2 percent. The pMDI resin was MONDUR 541 from Covestro. Melamine-urea-formaldehyde (MUF) resin obtained from a Kronospan facility was catalyzed with 3 percent ammonium chloride.

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The Isoset resin (A320) and hardener (A322) were donated by Great Southern Wood. The soy–pMDI mixture was prepared by stirring soy flour into pMDI at 40°C; the mixture was used within 1 hour of preparation.

Three-ply hardwood and softwood boards (607 by 607 mm) were made with the core layer perpendicular to the surface layers using PMDI resin with soy flour substitution. Unless noted otherwise, the level of soy flour substitution was 20 percent. The resin was applied with a hand-roller on both sides of the core layer. The boards were prepressed at 95°C and 0.7 MPa for 5 minutes and then pressed at 180°C and 1.4 MPa for 2 minutes. The spread rate was 180 or 200 g/m^2. Boards bonded with MUF resin were prepressed at room temperature for 5 minutes and then hot-pressed for 2 to 3.5 minutes at 140°C. For the cold-pressed boards, Isoset mixed at 1 part resin to 1.3 parts hardener was substituted with soy flour at various levels. Water was added to the soy flour (2:1) prior to mixing with Isoset in order to reduce the viscosity and facilitate mixing. The samples were pressed at 2 MPa for 30 to 90 minutes at room temperature. For the wet tests, the boards were soaked in water for 24 hours at room temperature prior to testing.

Internal bond (IB), water absorption (WA), and thickness swell (TS) were measured according to ASTM D1037-12 (2012). Three-point bending tests were run on 279- by 76-mm samples cut parallel to the grain direction. Shear strength measurements followed the ASTM D906-64 protocol. Three-cycle water resistance tests were run as per ANSI/HPVA HP-1-2020 (American National Standard for Hardwood and Decorative Plywood 2020). Eighteen 5.08- by 12.7-cm^2 test specimens were cut from each set of panels and soaked in water at 24°C for 4 hours and then dried at 52°C for 19 hours for a complete cycle. Delamination of the test specimens were evaluated with ANSI/HPVA HP-1-2020, which defines delamination as any continuous opening between two layers longer than 50 mm, deeper than 6.25 mm, and wider than 0.075 mm. Panels meet water resistance criteria if only 5 percent of the test pieces delaminate after the first soaking–drying cycle and only 15 percent after the third cycle.

Infrared (ATR) spectra were collected with mixtures of pMDI and soy flour soy at different substitution levels. The mixtures were weighed into aluminum pans and heated for 2 hours at 80°C, then for 2 hours at 140°C, and finally for 1 hour at 180°C. These conditions were used to control foaming.

Results and Discussion

Hot-press applications

Hardwood veneer.—Pressing veneer with PMDI or soy-modified PMDI resin led to resin bleed-through because the low-viscosity resins penetrated the thin surface layer of the wood. Decreasing viscosity increases resin penetration into wood (Hong and Park 2017). We reasoned that partial curing of the resin by prepressing the boards at moderate temperature would increase the viscosity and inhibit breakthrough. Prepressing at ambient temperature is known to improve board properties (Bekhta et al. 2012). Shear strength results of various 3-ply boards are provided in Figure 1. No resin bleed-through or delamination occurred. Reducing the prepress temperature from 95°C to 80°C reduced strength. For example, the dry strength of red gum (*Eucalyptus camaldulensis*) and white oak (*Quercus alba*) dropped to 1.0 MPa and 0.84 MPa, respectively, at the 200 g/m^2 spread rate. The wet strength was correspondingly reduced. Hence, 95°C seemed to be an optimal value.

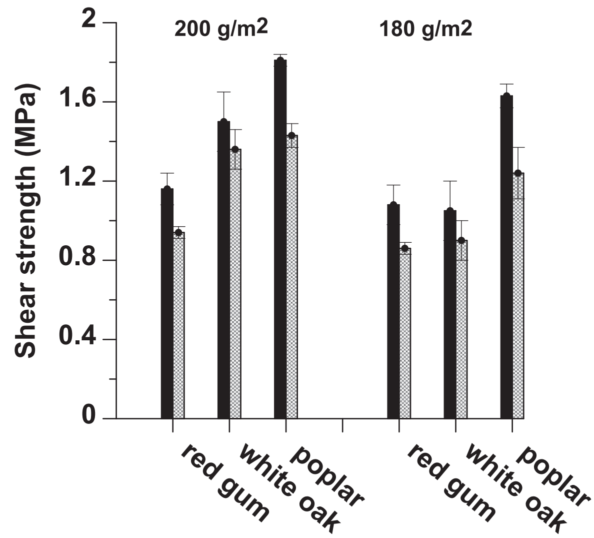

Figure 1.—Shear strength of veneer panels. The dark and hatched bars reflect dry and wet strength, respectively.

Increasing the time interval between resin application and prepressing from a few minutes to 3 hours increased both dry and wet strength by 5 to 10 percent. It is likely that the larger time delay increased the viscosity of the resin. Surprisingly, the wet strength values in Figure 1 are only slightly lower than their dry equivalents. The results from 3-cycle water resistance are listed in Table 1. Except for one instance with yellow poplar (*Liriodendron tulipifera*), all the panels passed the test. Hence, prepressing at 95°C and 0.7 MPa for 5 minutes provides a no-added-formaldehyde board with acceptable wet and dry properties. However, wet strength may not be a major consideration for decorative hardwood veneer, in which case the soy–kymene composition of Li (2007) will be cheaper.

Softwood veneer.—Results for the panels prepressed at room temperature and at 95°C are presented in Figure 2. The 95°C was found to be optimal from lap shear studies. The pMDI (0% soy flour) values are only provided as a baseline and have no practical value because the resin bleeds through the wood; no bleed-through occurred for the resins containing soy. The slopes in Figure 2 are mostly positive, indicating that the soy–pMDI mixtures provide more strength than does pMDI alone. This claim is not supported by the statistics for each subplot, which show no significant difference among the points along each line in Figure 2, but the collective results suggest a small increase in strength.

The strength of boards made with the soy–MDI resin used above were compared with those pressed with conventional MUF resin catalyzed with 3 wt % ammonium chloride. Comparison of the results (listed in Table 2) with the values for the soy–pMDI resin in Figure 2 show that the soy–pMDI boards are clearly stronger.

Cold press applications

Emulsion polymer isocyanates are commonly used for cold pressing wood. They are two-component systems consisting of water-based emulsions cured with an isocyanate cross-linker (Sonnenschein and Wendt 2005, Grstad and Pedersen 2010). In a typical two-part polyurethane (2C

Table 1.—Water resistance testing of veneer (percent which passed the delamination test).

Veneer lumber type	20% soy (200 g/m^2)			25% soy (180 g/m^2)			25% soy (200 g/m^2)		
	Cycle 1	Cycle 3	Pass or fail	Cycle 1	Cycle 3	Pass or fail	Cycle 1	Cycle 3	Pass or fail
White oak	100	100	P	100	83	F	100	94	P
Yellow poplar	100	89	P	100	78	F	100	100	P
Red gum	100	100	P	100	94	P	100	100	P

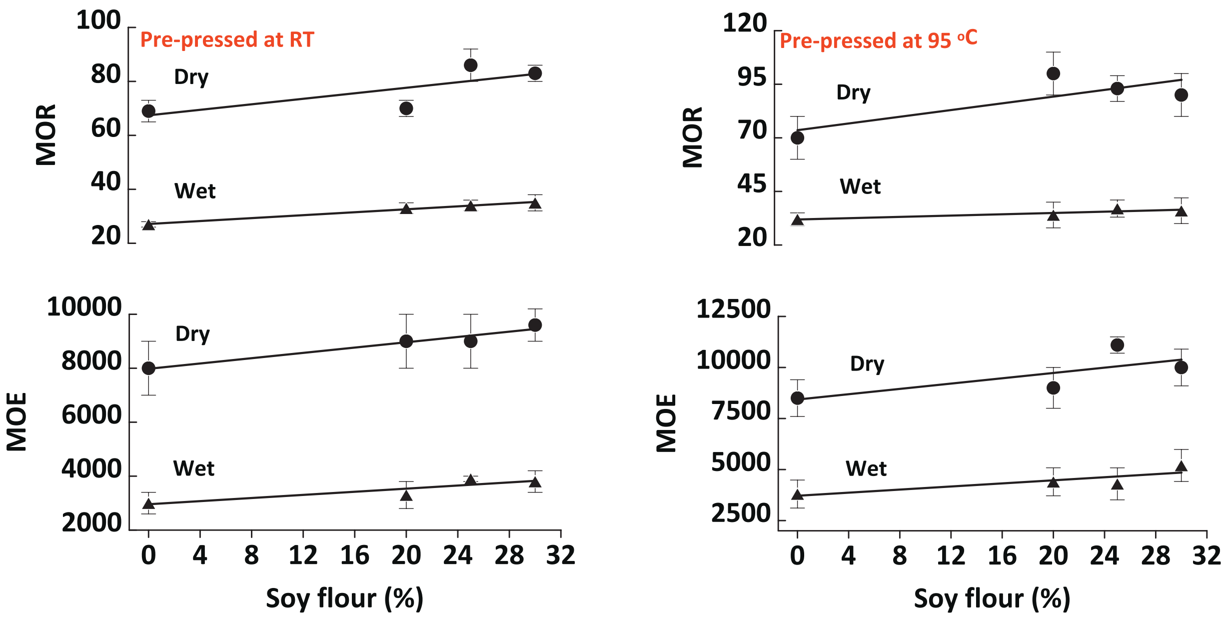

Figure 2.—Effect of soy flour substitution on panel strength.

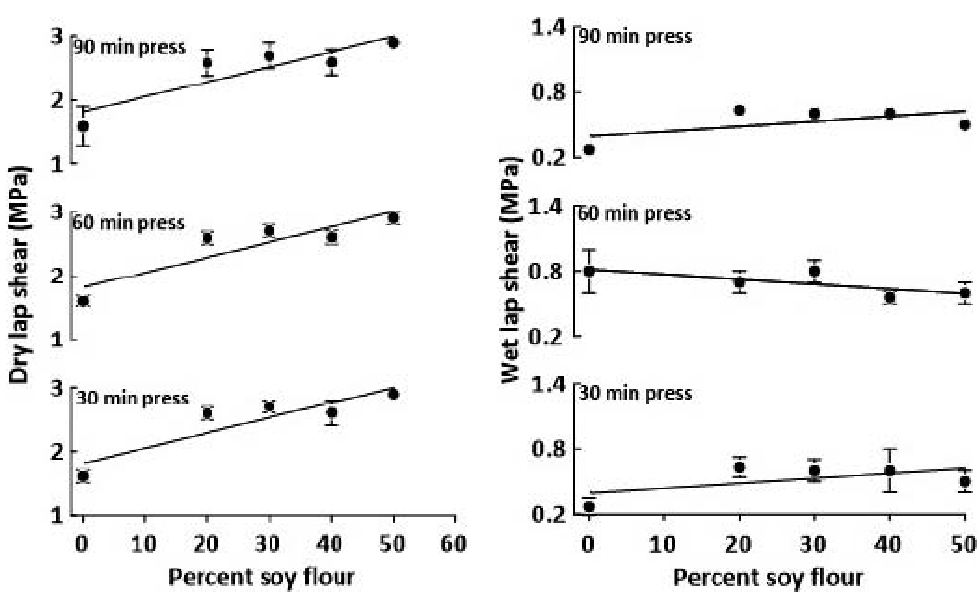

Figure 3.—Lap shear strength of boards made with soy flour substituted resin.

Table 2.—Strength of control boards made with melamine-urea-formaldehyde (MUF) resin.

Press time (min)	MOE (MPa)[a]		MOR (MPa)[b]	
	Dry	Wet	Dry	Wet
2	5,870 ± 60	2,600 ± 100	47.0 ± 0.8	22 ± 2
3.5	6,020 ± 60	2,900 ± 70	49 ± 1	27 ± 2

[a] Modulus of elasticity ± standard deviation.
[b] Modulus of rupture ± standard deviation.

PUR) adhesive the hydroxyl groups of the polyol react with the isocyanate groups of the hardener resulting in urethane formation. The reaction between urethane and isocyanate leads to cross-linking (Bockel et al. 2018). Soy-based binder formulations for cold-pressing have been proposed, but they are based on soy protein isolates (Mousavi et al. 2021) or require chemical derivatization of soy flour (Zheng et al. 2019); both options are expensive.

Lap shear results from samples prepared with soy-modified Isoset resin are provided in Figure 3. No delamination occurred. In all cases, the soy-amended resin increased the dry shear strength over that of the control. The wet strength was relatively unchanged. Over 20 percent soy flour substitution in the Isoset resin did not affect board properties. The strength of cold press wood increases over time, so boards prepared with 20 percent soy flour substitution were tested over several days. The results, provided in Figure 4, show that the strength levels off after about 16 days and that soy flour substituted resin provides the same performance as the unamended resin. This contrasts with the results from Figure 3, where the soy increases strength. The implication is that initial bonding in the soy-amended boards is more rapid but that it reaches the same strength endpoint as the control boards.

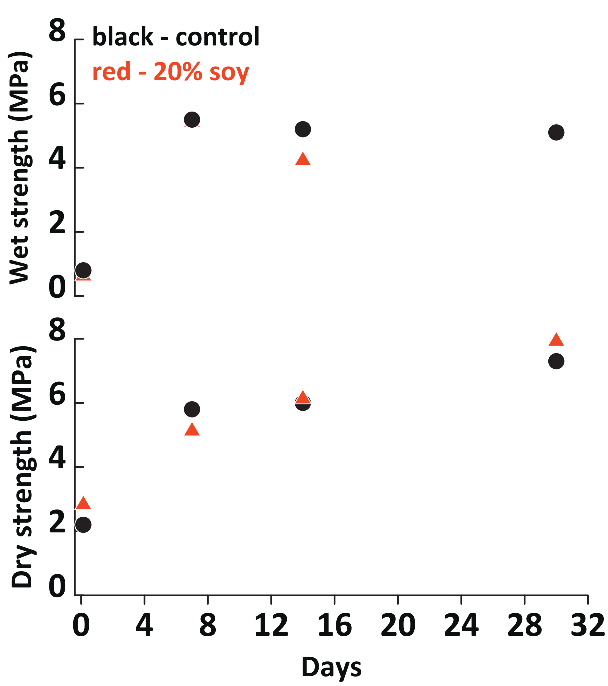

Figure 4.—Strength of boards pressed for 60 minutes, measured after various holding periods.

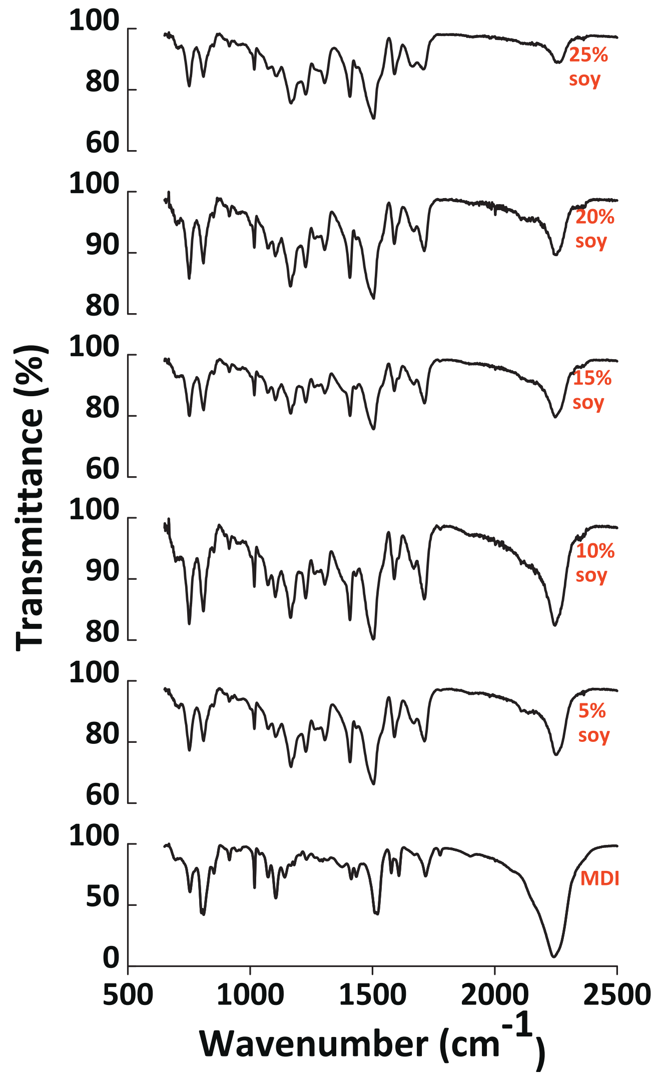

Figure 5.—Infrared spectra of mixtures of polymeric diphenylmethane diisocyanate (pMDI) and soy flour at various levels of soy substitution.

Optimum level of soy flour substitution in pMDI

In all our work to date the operational maximum of soy flour in pMDI has been about 20 percent, beyond which wet properties suffer. The reaction of pMDI with soy flour was followed by Fourier transform infrared. The resulting ATR spectra are illustrated in Figure 5. The ordinate scale is expanded in some of the panels to amplify small changes in signal intensity that would otherwise be obscured. The 2,250 cm^{-1} signal is characteristic of the isocyanate group and it decreases with progressive soy flour substitution; signals in the 1,200 to 1,400 cm^{-1} region that correspond to pMDI–soy adducts increase concomitantly. The most significant change occurs at 5 percent soy flour substitution. Beyond about 20 percent substitution, the changes in the signals are relatively small. It is likely that soy flour added in excess of 20 percent remains largely unreacted and absorbs water.

Conclusions

The feasibility of including soy flour in resins used to bind veneer has been demonstrated. Soy-modified pMDI resins cannot be used in hot pressing because of resin bleed-through. However, prepressing at 95°C removes this limitation by increasing the viscosity of the resin, and the resulting boards have greater dry and wet strength. Soy flour can also be substituted in emulsion polymer isocyanates for cold press applications. Infrared analysis shows that the reaction of soy flour with pMDI maximizes at about 20 percent flour substitution. Additional soy substitution leads to water absorption by the unreacted soy flour.

Acknowledgment

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