Effect of Maleic Anhydride Polypropylene Copolymer Addition on the Physical and Mechanical Properties of Polymeric Diphenylmethane Diisocyanate–Bonded Oriented Strand Board Panels

Thomas C. Ruffing* Nicole R. Brown* Vikram Yadama* Jone S. Cionni
Timothy Takah Timothy S. McCracken William J. Nicola

Abstract

The effect of varying proportions of maleic anhydride polypropylene (MAPP) on the physical and mechanical properties of polymeric diphenylmethane diisocyanate (pMDI)–bonded oriented strand board panels was investigated. Additionally, two forms of MAPP (powder and emulsion) were used to determine the effect of MAPP type on panel properties. Panels were produced by combining southern yellow pine (*Pinus* spp.) flakes with 4 percent pMDI binder and 0, 1.5, 3, 4.5, or 6 percent powdered or emulsified MAPP. Addition of emulsified MAPP decreased panel mechanical properties regardless of addition level. Powdered MAPP had a negligible effect on panel modulus of elasticity and only produced significant decreases in panel modulus of rupture and internal bond strength at the highest addition level (6%). Emulsified MAPP effected greater reductions in panel mechanical properties relative to powdered MAPP. Increasing levels of emulsified MAPP caused undesirable increases in both 24-hour water absorption and thickness swelling. Powdered MAPP did not provide a significant improvement over control panels in water absorption and thickness swell tests. Addition of either powdered or emulsified MAPP appeared to have a negligible effect on panel permeance.

Strength, uniformity, workability, and low cost make oriented strand board (OSB) an ideal material for many sheathing and flooring applications in the construction of residential and commercial buildings. However, like many wood products, the hygroscopic nature of OSB leaves the finished panels susceptible to in-service moisture damage.

One means of improving the dimensional stability of wood composites is to chemically modify the wood substrate to reduce hydroxyl content (Rowell et al. 1986, 1989, 1995; Clemons et al. 1992; Chow et al. 1996; Mahlberg et al. 2001). A common method of chemical modification is acetylation—the treatment of wood with organic acid anhydrides (Rowell et al. 1986, 1989, 1995; Clemons et al. 1992; Chow et al. 1996; Mahlberg et al. 2001). However, some researchers have reported that chemical modification decreases mechanical properties (Rowell et al. 1989, Chow et al. 1996, Mahlberg et al. 2001). Thus, the search continues for an effective method to improve the dimensional stability of composite panel products.

Maleated polypropylene waxes may improve dimensional stability while avoiding reductions in mechanical properties. Maleic anhydride modified polypropylene (MAPP) has been used as a coupling agent in wood plastic composites (WPCs). The maleic anhydride (MA) in these coupling agents facilitates bonding to wood fibers. Garcia et

The authors are, respectively, Graduate Research Assistant and Associate Professor of Wood Chemistry, School of Forest Resources, Pennsylvania State Univ., University Park (tcr131@psu.edu, nrb10@psu.edu); Assistant Professor and Extension Specialist, Dept. of Civil Engineering, Washington State Univ., Pullman (vyadama@wsu.edu); and Senior Technical Service Specialist, Senior R&D Specialist, Technical Service Specialist, and Technical Manager, Bayer MaterialScience LLC, Pittsburgh, Pennsylvania. This paper was received for publication in April 2008. Article no. 10478.
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al. (2005) and Lu et al. (2002) have reviewed the use of MAPP in WPCs. Clemons et al. (1992) found that esterification (bond formation between MA and the hydroxyl group of wood) resulted in decreased thickness swelling and water absorption for fiberboards. Garcia et al. (2005) studied the effect of MAPP on the dimensional stability and mechanical properties of medium-density fiberboard. Chowdhury (2006) blended emulsified MAPP with phenol-formaldehyde (PF) resin and produced oriented strand composites (OSCs) with varying levels of PF resin and MAPP. Their results showed that low levels of MAPP significantly improved moisture resistance of OSC panels; reduced water absorption was observed following long- and short-term water soak tests. Reduced water vapor transmission and permeance were also noted. However, addition of MAPP had detrimental effects on mechanical properties, particularly modulus of rupture (MOR) and internal bond (IB). Chowdhury (2006) also showed that particle size of the reactive copolymer blended into the adhesive plays a critical role in its distribution; larger particles lead to agglomeration of particles, causing weak bonding.

The objectives of the current study were to determine the effect of varying proportions of MAPP on physical and mechanical properties of OSB produced with a polymeric diphenylmethane diisocyanate (pMDI) binder. Specific tasks to achieve this objective included (1) comparing powdered MAPP vs. emulsified MAPP to determine the effect of application method and MAPP type on physical and mechanical properties of pMDI-bonded panels, (2) determining the effect of increasing levels of MAPP on the mechanical properties of pMDI-bonded OSB, and (3) investigating the effect of varying levels of MAPP on the physical properties of pMDI-bonded OSB via 24-hour soak tests and permeance testing.

Experimental

Materials

Commercially available, unscreened southern yellow pine (*Pinus* spp.) strands were donated by a Georgia Pacific mill in Hosford, Florida. Flakes were passed over a wire screen with openings of 30 by 10 mm (1 by ½ in.) to remove fines. MAPP anionic emulsion (30% solids content) was supplied by Honeywell Specialty Chemicals. Powdered MAPP with an average particle size of 106 μm (4.17 mil) was also supplied by Honeywell. The pMDI binder, Mondur® 541 Light, was supplied by Bayer MaterialScience LLC.

Board fabrication

Test panels were 81 by 81 by 1.9-cm (32 by 32 by ⅓-in.), three-layer OSBs with a target density of 640 kg/m^3 (40 pounds per cubic foot [pcf]). All boards contained 4 percent pMDI binder in the face and core layers. The face layers contained emulsified MAPP, solid MAPP, or no MAPP (control). Core flakes were not treated with MAPP. Face and core flake moisture contents (MCs) were 10 ± 0.5 and 4 ± 0.5 percent, respectively. High face MC was chosen to facilitate rapid heat transfer to the core through steam production. Blending was conducted in a 0.9 by 2-m (3 by 6-ft) laboratory blender (Blender Systems; Coil Mfg. Ltd., Vancouver, Canada) with a blender speed of 20 rpm. Resin was applied after MAPP treatment (described below), and application was achieved via a spinning disk atomizer with 30 orifices (orifice diameter of 1 cm [⅜ in.]) spinning at 9,700 rpm. Boards were hand formed using a forming box with vertical, metal slats spaced 4.7 cm (1⅞ in.) apart. A Dieffenbacher 410-ton (450-t) laboratory press was used. The press cycle consisted of a 40-second closing time with 240 seconds under pressure and a 20-second degas time. The press platen temperature was 200°C (400°F). This pressing schedule was selected because it provided internal board temperatures that exceeded the melting point of MAPP (152°C [306°F]). The finished boards were stored at ambient conditions until the boards were cut into samples for physical testing.

Emulsified MAPP treatment.—Screened face flakes were loaded into the blender and sprayed with the MAPP emulsion to obtain the desired level of MAPP loading. Emulsified MAPP was applied with a three-orifice, air-pressurized spray nozzle. MAPP loading was based on the ovendry weight of the flakes. After spraying, each batch of flakes was dried in a large oven at 82°C (180°F) to the desired MC of 10 ± 0.5 percent. Flakes were then loaded into the blender and sprayed with 4 percent pMDI resin.

Powdered MAPP treatment.—Screened face flakes were adjusted to an MC of 10 ± 0.5 percent and loaded into the blender with the desired amount of powdered MAPP. The flakes and MAPP were blended for approximately 2 minutes before the pMDI resin was applied.

Statistical design and analysis

An experimental design strategy was formulated in Design-Expert® (Stat-Ease 2007) to conduct preliminary screening on the effects of two types of MAPP treatment (powder and emulsion) and five levels of MAPP treatment (0%, 1.5%, 3%, 4.5%, and 6%). The output determined the number of boards to be pressed for each treatment type and treatment level. Following the testing, all data were analyzed in Design-Expert® and SAS (SAS Institute 1999) using proc GLM.

Board testing

Test samples from each of the 31 boards were prepared and tested according to ASTM D1037-06a (ASTM International 2006). Boards were tested to determine the effect of MAPP on panel density, IB strength, modulus of elasticity (MOE), MOR, and 24-hour thickness swell and water absorption. Ten IB, two soak, and two flexural samples were prepared from each of the panels. All samples were conditioned at 50 percent humidity and 20°C (68°F, 24 h minimum) before testing. Thirty-one permeance samples were prepared, one from each of the test boards. Permeance testing was conducted according to ASTM E96/E96M-05 (ASTM 2005) except chamber relative humidity was 61 percent. Preparation of permeance samples was conducted according to the method used by Chowdhury (2006).

Results

Panel mechanical properties

Unbalanced analysis of variance results indicate statistically significant differences between the two forms of MAPP for every property tested. The effect of MAPP content varied, depending on the form and level of MAPP added. Table 1 summarizes the results while showing which means are statistically significant. With the exception of panels having 4.5 percent emulsified MAPP, densities of all

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Table 1.—Summary of test panel physical and mechanical properties.[a]

Property	n	Control	MAPP powder level				MAPP emulsion level			
			1.5%	3.0%	4.5%	6.0%	1.5%	3.0%	4.5%	6.0%
Density (pcf)	24–48	44.7 (3.0)	45.5 (3.2)	44.0 (3.4)	44.0 (3.5)	43.5 (3.6)	44.0 (2.8)	45.4 (2.8)	42.9 (2.1)	44.7 (3.6)
MOE ($\times 10^6$ psi)	4–8	1.142 (7.9) A	1.055 (11.7) ABC	1.126 (3.5) A	1.094 (8.3) AB	1.030 (12.2) ABC	0.819 (27.7) BCD	0.673 (32.2) D	0.876 (13.5) ABCD	0.796 (17.6) CD
MOR (psi)	4–8	7,570 (12.8) A	6,330 (28.6) ABC	6,570 (9.1) AB	6,980 (12.2) A	4,630 (26.3) BCD	4,250 (33.7) CD	2,665 (32.0) D	4,175 (21.6) CD	2,760 (43.7) D
IB (psi)	20–40	99.6 (35.2) A	92.4 (36.0) A	89.6 (33.3) A	93.6 (37.8) A	42.5 (89.6) BC	54.6 (45.5) B	24.2 (64.9) C	41.0 (29.2) BC	30.3 (133) BC
Water absorption (%)	4–8	64.2 (7.3) DE	64.7 (5.8) DE	61.5 (7.1) E	65.3 (6.8) CDE	66.7 (8.1) CDE	74.0 (4.6) BC	81.1 (5.7) AB	73.1 (2.2) BCD	84.6 (9.1) A
Thickness swell (%)	4–8	24.9 (3.6) C	25.5 (6.9) C	24.1 (6.6) C	22.2 (6.6) C	30.3 (27.3) C	32.8 (15.7) BC	51.8 (22.7) AB	32.8 (6.7) BC	65.5 (35.8) A
Permeance (perms, $\times 10^4$)	2–5	5.44 (26.73) A	5.03 (46.01) A	3.92 (30.22) A	5.22 (6.58) A	5.00 (33.51) A	6.02 (21.42) A	5.57 (35.01) A	4.57 (7.52) A	5.68 (28.92) A

[a] Based on Tukey's studentized range test at an α level of 0.05. Means with the same letter are not significantly different. n = number of samples. Values in parentheses are coefficients of variation expressed in percentages.

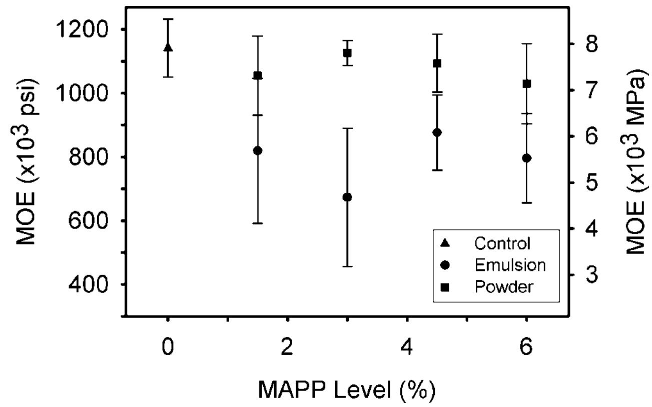

Figure 1.—Effect of MAPP on panel modulus of elasticity. Error bars represent standard deviations.

groups were not statistically significant; thus, density was not considered a covariate.

Apart from density, the mechanical properties of greatest importance include MOE, MOR, and IB. In general, emulsified MAPP treatments caused reductions in panel properties, whereas properties were largely unchanged by powdered MAPP treatments. Copolymer type (emulsion or powder) had a statistically significant effect on panel MOE for the 1.5 and 3 percent MAPP addition levels; powdered MAPP offered higher MOE values (Fig. 1). Differences in the binding agent (PF was used in Chowdhury 2006), treatment protocol, and pressing schedule may explain the discrepancies between the data presented here and those of Chowdhury (see ''Discussion'').

The effect of varying levels of MAPP content on panel MOR is presented in Figure 2. Emulsified MAPP caused a statistically significant decrease in panel MOR at all addition levels; no clear trend was observed as MAPP content increased from 1.5 to 6 percent. These results agree with the findings of Chowdhury (2006), who reported the addition of MA and MAPP caused statistically significant reductions in MOR values. Powdered MAPP performed much better, only significantly reducing panel MOR at the highest addition level (6%).

Results of the IB testing (Fig. 3) show a trend similar to that of MOR. Emulsified MAPP caused a statistically significant decrease in panel IB strength at all addition

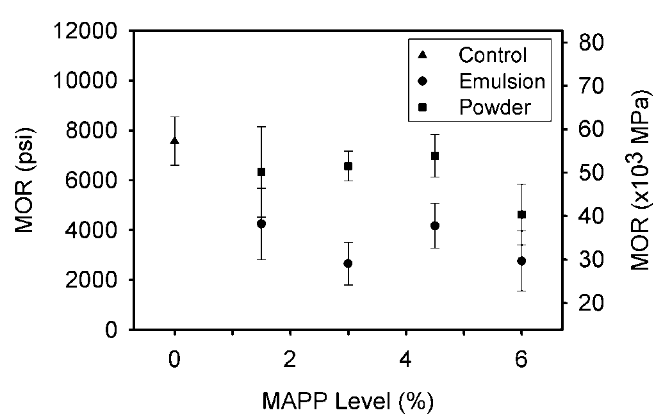

Figure 2.—Effect of MAPP on panel modulus of rupture. Error bars represent standard deviations.

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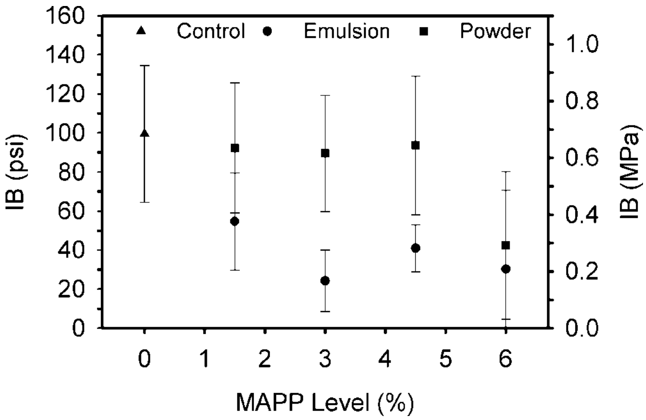

Figure 3.—Effect of MAPP on panel internal bond strength. Error bars represent standard deviations.

levels, and no clear trend was observed as MAPP content increased from 1.5 to 6 percent. Copolymer type had a significant effect on IB strength at the 3 and 4.5 percent addition levels, with powdered MAPP providing better panel performance than emulsified MAPP. The observed decrease in IB values, both here and in Chowdhury (2006), may be the result of MAPP blocking resin penetration. Another explanation in the present study may be a competing reaction of the pMDI resin with the MAPP.

The most relevant benchmark for our results is the work of Chowdhury (2006), who explored the performance of OSCs in which strands were treated with emulsified MAPP treatments then bonded with PF resin. Our results are similar to those of Chowdhury with respect to MOR and IB results (emulsified MAPP caused lower MOR and IB values). With respect to MOE, Chowdhury found no significant effect due to the emulsified MAPP treatment, whereas our results show a distinct decline (see ‘‘Discussion’’). To our knowledge, the literature contains no relevant studies utilizing powdered MAPP treatments.

Panel physical properties

Statistically significant differences exist between the powdered and emulsified MAPP in terms of both water absorption (Fig. 4) and thickness swelling (Fig. 5). In powdered form, MAPP did not significantly affect water absorption or thickness swelling for any of the addition levels investigated here. Increasing levels of emulsified MAPP content produced undesirable increases in both 24-hour water absorption (Fig. 4) and 24-hour thickness swelling (Fig. 5).

The addition of MAPP in either emulsified or powdered form has a negligible effect on panel permeance (Table 1). However it is important to note that this conclusion is based on a limited number of samples; therefore, these data can only be viewed as a preliminary investigation.

In sum, our results contradict the primary hypothesis that addition of MAPP would improve panel dimensional stability. The work of Chowdhury (2006) is again an interesting benchmark. His study showed mixed success at achieving moisture resistance through MAPP treatments. Chowdhury noted the MAPP treatments caused a 23 percent decrease in panel permeance and a 12 percent decrease in water absorption, indicating positive effects (in contrast to our results). However, Chowdhury did show increased

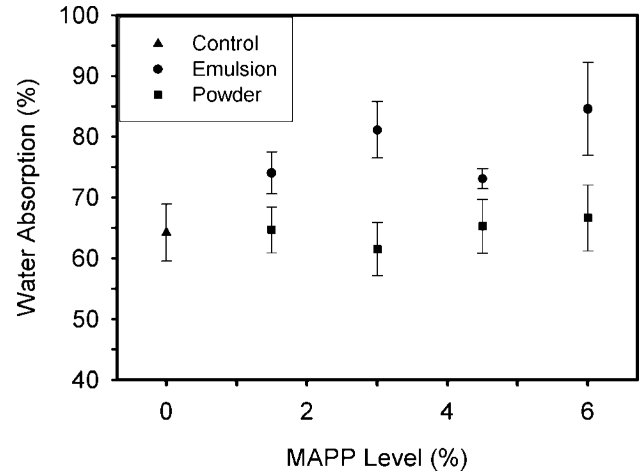

Figure 4.—Effect of MAPP on panel water absorption. Error bars represent standard deviations.

thickness swelling with increasing MAPP concentration, which is consistent with our findings and inconsistent with the general notion that MAPP treatments improve moisture resistance.

Discussion

The pattern of poor performance for the samples receiving the emulsified MAPP treatment was likely caused by a lack of sufficient bond development within the panels. Two factors support this claim, including poor IB performance (Fig. 3) and examination of test panels following water absorption studies, which revealed that high levels of emulsified MAPP treatment were consistent with poorly bound flakes (results not shown).

Several factors may have contributed to these results, as similar treatments by Chowdhury (2006) led to far better performance. First, key differences exist in the experimental approach. Chowdhury used liquid PF, and it was co-added with MAPP via a second spray nozzle, causing very high furnish MC that required long press times (30 min total [8 min close time, 20 min hold, and 2 min vent] at 182°C

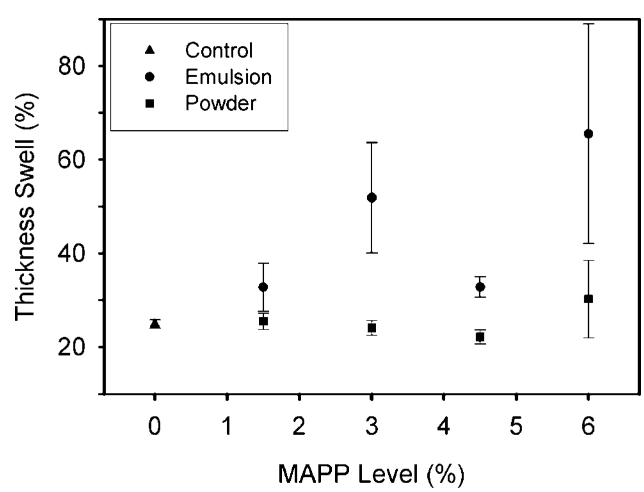

Figure 5.—Effect of MAPP on panel thickness swelling. Error bars represent standard deviations.

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[360°F]). The nature of pMDI resin required a different atomization and pressing approach. Emulsified MAPP-treated flakes were dried at 82°C (180°F) before pMDI application to achieve the control flake MC of 10 percent. Hence, areas of the flake surface containing the MAPP were physically blocked before the addition of pMDI, which may have limited resin wetting and penetration. Second, flake drying (after addition of emulsified MAPP) was not replicated for control or powdered MAPP flakes; this likely deactivated the wood fiber surface. Similarly, the high-temperature drying may have allowed the emulsified MAPP to wet more of the flake surface, limiting the area where pMDI binder could wet or penetrate the flakes. Future work revealing the relationship between emulsified MAPP surface wetting and pMDI wetting would be of interest to document the hypothesized behavior.

To our knowledge, no other study has been completed using powdered MAPP. Here, the powdered MAPP had minimal effect on panel mechanical properties, but it also showed no improvement in moisture resistance. Incorporating the powdered resin into the panels was difficult at such low resin loading (4%). Future studies using this approach should be conducted with higher resin loading.

Conclusions

Addition of emulsified MAPP caused a statistically significant reduction in all panel mechanical properties, regardless of addition level. No significant trend in panel mechanical properties was observed as emulsified MAPP content was increased from 1.5 to 6 percent. Increasing levels of emulsified MAPP caused undesirable increases in both 24-hour water absorption and thickness swelling. We hypothesize that emulsified MAPP may reduce physical and mechanical properties by preventing pMDI binder penetration into flakes. Powdered MAPP had a negligible effect on panel MOE and only showed significant decreases in panel MOR and IB strength at the highest addition level (6%). However, panels treated with powdered MAPP did not show any improvements in water resistance; the findings of 24-hour thickness swelling and water absorption testing remained similar to those of the control at all MAPP levels. Results indicate that the method of MAPP addition used here does not provide a feasible method of improving panel dimensional stability. Based on preliminary data, addition of MAPP in either powdered or emulsified form has a negligible effect on the permeance of pMDI-bonded OSB panels; however, more work is needed to confirm this relationship.

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