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Effect of the Sequence of Wax Addition, Wax Level and Type on Properties of Isocyanate-Bonded Particleboard*1

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왁스添加 順序, 添加量, 種類가 Isocyanate 接着 PB의 性質에 미치는 影響*1

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要　約

본 연구는 왁스添加順序, 添加量, 왁스種類가 Isocyanate 接着 PB의 性質과 耐水性에 미치는 影響을 究明하기 위해서 實施되었다. 왁스添加順序는 PB의 機械的 性質 및 耐水性에 有意的인 影響을 미치지는 않았다. 왁스에멀젼 添加量을 增加시킴으로써 接着力 및 휨強度의 耐水 MOR은 減少되었지만 常態 MOR 및 MOE는 減少되지 않았다. 常態接着力, 常態 및 耐水 MOR과 MOE는 솔리드왁스量을 增加시킴으로써 減少되지 않았지만 耐水接着力은 減少되었다. 1% 및 1.5% 왁스量을 添加한 보드는 0.5% 왁스를 添加한 보드와 比較해 보았을 때 耐水性이 增加되지는 않았다. 솔리드왁스를 添加한 보드의 接着力은 왁스에멀젼을 添加한 보드보다 더 좋은 結果를 나타내었다. 휨強度의 MOR 및 MOE, 耐水性은 솔리드왁스와 왁스에멀젼간에 有意的인 差異를 보이지는 않았다.

ABSTRACT

Research was conducted at the Wood Materials and Engineering Laboratory, Washington State University, Pullman, WA to evaluate the effects of the sequence of wax addition, wax level, and wax type on mechanical properties and water resistance performance of isocyanate-bonded particleboard. Mechanical properties and water resistance performance were not influenced significantly by the sequence of wax addition. Internal bond and wet modulus of rupture in bending strength were decreased significantly by increasing the wax emulsion level, but dry modulus of rupture and modulus of elasticity in bending strength were not decreased significantly by increasing the wax emulsion level. Dry internal bond, dry and wet moduli of rupture, and modulus of elasticity were not decreased by increasing the solid wax level except for wet internal bond. The addition of 1.0 and 1.5% wax level did not produce any significant additional water resistance effect when compared to the addition of 0.5% wax level. Internal bond values of boards with solid wax addition showed significantly better results than boards with just a wax emulsion added. Modulus of rupture, modulus of elasticity, and water resistance performance did not show significant difference between solid wax and wax emulsion.

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1. INTRODUCTION

Over the years, wax has been used for many reasons in composition board manufacture because of the advantage it imparts. The addition of wax in composition board manufacture decreases the rate of water absorption, and therefore, it gives a short-term water repellency and resistance to the boards. It has also been reported (Albrecht, 1968) that wax plays an important role in assisting in the release of boards in the press from the caul plates. Wax also helps in keeping particles from sticking in blow pipes.

Wax has been applied before, with, and after the spraying of resin on the particles. When using a powdered resin such as phenol-formaldehyde resins in making waferboard and oriented strand board, slack wax should be applied before the resin application because the sticky wax helps the dry powdered resin adhere to the wafers.

Wax emulsion is a more efficient sizing material than molten wax due to a better distribution of the material on the wood particles. By preblending the wax emulsion with the resin, a better wax distribution may be achieved. Heebink(1967), on the other hand, has reported that there is no fundamental difference found as a result of when the wax is applied, although a review of the limited work published gives inconclusive results.

Isocyanate binder is different from phenol- and urea-formaldehyde resins. Loew and Sachs(1977) have reported that normally a wax emulsion cannot be preblended with isocyanate binder. Therefore, they should be applied separately. It is possible to apply wax before, simultaneously with, or after isocyanate binder application, but there has been no published material that is available to see when the wax was applied.

The primary purpose of the current research was to study the effects of the sequence of wax addition, wax level and type on properties of particleboard when using an isocyanate binder.

2. Procedure

2.1 Particle Production

Dry scrap Douglas fir lumber was used in the study. The scrap lumber was first reduced to 0.75 in. long chips in a chipper. Particles were made from the chips by hammer milling with 0.25 in. screen. All particles were screened on a rotary screen with two screen sizes (+6 and -32 mesh). The oversize material (+6 mesh) and the fines (− 32 mesh) were removed and discarded. The average moisture content of all particles was 8.0%.

2.2 Particleboard Manufacture

Particleboard was made following laboratory procedures and techniques. Pressing was done using a computer-controlled press. Special spraying equipment with a heating system was used to maintain a constant temperature for uniform and smooth spraying of the solid wax.

Board parameters used in this research were :

Species: Douglas fir

Particle size: − 6 +32

Binder: isocyanate (Mobay corporation)

Binder content: 4% (based on oven dry weight of wood)

Wax type: wax emulsion and solid wax (Casco)

Wax content: 0%, 0.5%, 1.0% and 1.5% (based on oven dry weight of wood)

Binder heating temperature: 90°F (32°C)

Automizing pressure for spraying: 35 lb/in^2
Target board specific gravity: 0.70
Mat moisture content: 6.2 ~ 9.8%
Press temperature: 350°F (177°C)
Press closing time: 1 minute
Press time: 4 minutes
Board size: 0.5 by 20 by 28 in.
(12.7 by 508 by 711 mm)
Replication: 3

Due to problems with the heating system for the spray equipment, only two replications were made for the 1.5% solid wax addition.

2. 3 Property Testing

After pressing, the boards were stacked for two weeks and trimmed to 18 by 25 in. Test specimens were then cut according to ASTM D 1037-87. The properties evaluated were dry and wet moduli of elasticity and rupture (dry MOE, dry MOR, wet MOE and wet MOR), dry and wet internal bond strengths (dry and wet IB), linear expansion (LE), water absorption (WA) and thickness swelling (TS).

Three dry IB and three wet IB specimens, two dry bending and two wet bending specimens, two LE specimens, one WA specimen, and one TS specimen were prepared per particleboard. WA and TS specimens were placed in a conditioning chamber maintained at a relative humidity of 65 ± 1% and a temperature of 68±6°F(20±3°C) for 3 weeks. All tests were performed according to procedures described in ASTM D 1037-87 except for the wet IB test. The wet IB test was performed according to procedures recommended by Lehmann(1977) as follows : Specimens were saturated with a short vacuum-pressure-soak [30 minutes under 70°F water and 28 inch Hg vacuum, 60 minutes at 60 psi, boiled 2 hours, dried under mild conditions (120°F) with forced air circulation], and tested.

2. 4 Statistical Analysis

An analysis of variance (ANOVA) was conducted to evaluate the effect of wax addition order, level and type on the properties of particleboard when using an isocyanate binder. Duncan's multiple range test was used to test for differences between means. All statistical analyses were carried out using computer software procedures described in the Statistical Analysis System (SAS 1985).

3. RESULTS & DISCUSSION

3. 1 Effect of the Sequence of Wax Addition

Tables 1 through 3 present Duncan's multiple range test results. The tests showed that all properties of the boards were not influenced sig-

Table 1. Duncan's multiple range test results of IB, MOR, and MOE as designated by the sequence of wax emulsion addition (α=0.05).

Property	Control Boards	Wax Added Before Isocyanate	Wax Added With Isocyanate	Wax Added After Isocyanate
Internal Bond(psi)	198.50 A	167.23 B	171.56 B	160.77 B
Wet Internal Bond(psi)	87.35 A	49.73 B	54.38 B	53.96 B
Modulus of Rupture(kpsi)	2.547 A	2.425 B	2.356 B	2.311 B
Wet Modulus of Rupture(kpsi)	0.972 A	0.870 B	0.900 B	0.859 B
Modulus of Elasticity(kpsi)	555.9 A	566.21 A	559.96 A	550.38 A

* Means with the same letter are not significantly different.

Table 2. Duncan's multiple range test results of IB, MOR and MOE as designated by the sequence of solid wax addition (α=0.05).

Control Property	Wax Boards	Added Before Isocyanate	Wax Added With Isocyanate	Wax Added After Isocyanate
Internal Bond(psi)	198.50 A	182.81 B	176.38 B	174.92 B
Wet Internal Bond(psi)	87.35 A	59.07 B	60.68 B	55.95 B
Modulus of Rupture(kpsi)	2.547 A	2.194 B	2.235 B	2.149 B
Wet Modulus of Rupture(kpsi)	0.972 A	0.921 B	0.907 B	0.855 B
Modulus of Elasticity(kpsi)	555.88 A	542.41 A	546.64 A	523.96 A

* Means with the same letter are not significantly different

Table 3. Duncan's multiple range test results of TS, WA and LE as designated by the sequence of solid wax addition (α=0.05).

Property (%)	Control Boards	Wax Before Isocyanate	Added With Isocyanate	Wax Added After Isocyanate
Thickness Swelling (Wax Emulsion)	10.18 A	8.07 B	7.95 B	8.16 B
Thickness Swelling (Solid Wax)	10.18 A	8.56 B	8.97 B	8.58 B
Water Absorption (Wax Emulsion)	20.40 A	13.81 B	13.64 B	13.61 B
Water Absorption (Solid Wax)	20.40 A	13.81 B	13.64 B	13.61 B
Linear Expansion (Wax Emulsion)	0.238 A	0.228 A	0.228 A	0.232 A
Linear Expansion (Solid Wax)	0.238 A	0.231 A	0.231 A	0.228 A

* Means with the same letter are not significantly different

nificantly by the sequence in which the wax was added to the particles. This would indicate that wax could be applied before, simultaneously with, or after the isocyanate binder application. However, a wax emulsion cannot be mixed together with isocyanate binder (Loew & Sachs, 1977). MOE and LE did not show a significant difference between the control boards (no wax) and boards made with wax. A significant difference was shown, however, between control boards and boards made with wax in IB, wet IB, MOR, TS, and WA. Interestingly, the wet IB and wet MOR values from the control boards showed better results than those boards made with wax, but TS, WA, and LE values of the boards made with wax were better than those of the control boards. This result implies that wax is needed for good water resistance and repellency of the boards, although the addition of wax in manufacturing flakeboard results in reduced bending strength and internal bond strength.

3. 2 Effect of Wax Level

Table 4 and 5 show the effect of the addition of different wax levels (%) compared to mean values of IB, wet IB, MOR, wet MOR, and MOE.

IB (dry and wet) and MOR (dry and wet) values were decreased with an increase in wax

Table 4. Duncan's multiple range test results of IB, wet IB, MOR, wet MOR, and MOE as designated by the levels of wax emulsion added to Douglas fir particles (α=0.0001).

Levels of Wax Added(%)	0	0.5	1.0	1.5
Internal Bond	198.50	186.36	167.03	146.18
(psi)	A	B	C	D
Wet Internal Bond	87.35	68.14	49.03	40.91
(psi)	A	B	C	D
Modulus of Rupture	2.547	2.597	2.316	2.178
(kpsi)	A	A	A B	B
Wet Modulus of Rupture	0.972	1.025	0.859	0.745
(kpsi)	A	A	B	C
Modulus of Elasticity	555.88	580.78	563.69	532.07
(kpsi)	A	A	A	A

* Means with the same letter are not significantly different.

Table 5. Duncan's multiple range test results of IB, wet IB, MOR, wet MOR, and MOE as designated by the levels of solid wax added to Douglas-fir particles (α =0.0001).

Levels of Wax Added(%)	0	0.5	1.0	1.5
Internal Bond	198.50	180.15	179.10	173.27
(psi)	A	B	B	B
Wet Internal Bond	87.35	63.96	56.62	53.38
(psi)	A	B	B	B
Modulus of Rupture	2.547	2.262	2.219	2.050
(kpsi)	A	B	B	B
Wet Modulus of Rupture	0.972	0.917	0.890	0.866
(kpsi)	A	A	A	A
Modulus of Elasticity	555.88	539.77	543.17	526.27
(kpsi)	A	A	A	A

* Means with the same letter are not significantly different.

level. But MOE (dry) values did not show significant difference with an increasing wax level. The IB of boards made with wax emulsion was sharply decreased with an increase in the wax level while that of boards made with solid wax was not influenced by the wax level (Tables 4 and 5). As seen in tables 4 and 5, the wet IB of boards made with both wax emulsion and solid wax was affected by the wax level. However, the wet IB of the wax emulsion-added boards were decreased more sharply with the increasing wax levels than was that of boards made with solid wax. This was probably related to the reactions of isocyanate binder with the water included in the wax emulsion.

MOR values were decreased with increasing wax level, but not significantly so. Wet MOR performance of boards with wax emulsion was decreased significantly with increasing wax level, but boards with solid wax did not show a significant difference with an increase in wax level(Table 4, 5)

MOE, TS, WA, and LE were not affected significantly by wax level (Tables 4, 5 and 6). However, WA and TS values did show a significant difference between the control board (no wax) and those boards made with wax. It might be assumed, therefore, that a 0.5% wax addition could be economical and would be suitable for making water resistant particleboard.

Deppe (1977) has reported that the addition of MDI (4.4' diphenyl methanediisocyanate) in excess of 10% (based on oven dry wood), an incorporation of wax does not yield any additional water repellent effect. Therefore, the effect of wax in reducing thickness swelling and water absorption would be in effect only when isocyanate were used in levels of less than 10%.

3. 3 Effect of Wax Type

Wax emulsion and solid wax were used as treatments (Tables 7 and 8). Generally, the particleboard produced had much higher IB values than the minimum requirements specified in the ANSI/208.1-1987 (1987) (50 psi). A significant difference was seen in IB and wet IB results between the control boards and those boards that had an application of wax emulsion or a solid wax. Solid wax applications gave better dry IB and wet IB results than did the wax emul-

Table 6. Duncan's multiple range test results of TS, WA, and LE as designated by the levels of wax added to Douglas fir particles (α=0.05).

Property(%)	0	0.5	1.0	1.5
Thickness Swelling	10.18	8.28	8.07	7.83
(Wax Emulsion)	A	B	B	B
Thickness Swelling	10.18	8.86	8.85	8.45
(Solid Wax)	A	B	B	B
Water Absorption	20.40	12.68	12.56	12.13
(Wax Emulsion)	A	B	B	B
Water Absorption	20.40	13.44	13.71	13.91
(Solid Wax)	A	B	B	B
Linear Expansion	0.238	0.236	0.224	0.229
(Wax Emulsion)	A	A	B	B
Linear Expansion	0.238	0.232	0.231	0.227
(Solid Wax)	A	A	A	A

* Means with the same letter are not significantly different.

Table 7. Duncan's multiple range test results of IB, wet IB, MOR, wet MOR, and MOE as designated by the wax addition type (α=0.05).

Property	Control Boards	Solid Wax	Wax Emulsion
Internal Bond	198.5	178.0	166.5
(psi)	A	B	C
Wet Internal Bond	87.4	58.6	52.7
(psi)	A	B	C
Modulus of Rupture	2.547	2.193	2.364
(kpsi)	A		A
		B	B
Wet Modulus of	0.972	0.894	0.876
Rupture (kpsi)	A	A	
		B	B
Modulus of Elasticity	555.88	527.67	558.85
(kpsi)	A	A	A

* Means with the same letter are not significantly different.

Table 8. Duncan's multiple range test results of TS, WA, and LE as designated by the wax addition type (α=0.05).

Property (%)	Control Boards	Solid Wax	Wax Emulsion
Thickness Swelling	11.27 A	8.70 B	8.06 B
Water Absorption	20.4 A	13.69 B	12.46 B
Linear Expansion	0.238 A	0.230 A	0.230 A

* Means with the same letter are not significantly different.

sion. It might be assumed from the results that the water present in wax emulsion interfered with the curing and bonding quality of the isocyanate binder. Hsu (1990) reported that when using powdered phenol resin in waferboard manufacture, wax applied as an emulsion was more effective than solid wax in reducing thickness swelling at low wax contents. Dry and wet MOR values did not show a significant difference between the type of application, but significant differences were seen between the control boards and the boards made with wax emulsion in dry and wet MOR results. In MOE and LE results, there was no significant difference between control boards and boards made with wax emulsion and solid wax. There was, however, a significant difference found between control boards and boards made with wax in TS and WA. No significant difference was found between the two types of wax, although boards made with wax emulsion gave better results than boards made with solid wax.

4. CONCLUSIONS

The following conclusions have been drawn from the research study ;

1. Mechanical properties and water resistance performance were not influenced significantly by the sequence of wax addition. Therefore, it can be concluded that wax can be applied before, with or after the isocyanate binder application.
2. IB (dry and wet) and wet MOR were decreased significantly with increasing wax levels, but dry MOR and MOE, TS, WA, and LE did not show a significant differ-

ence with an increase in wax level.

3. IB (dry and wet) values for boards made with solid wax were significantly better than for boards made with a wax emulsion.
4. MOR, MOE, and water resistance performance did not show a significant difference between boards made with solid wax and wax emulsion.

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