Mokchae Konghak 35(5) : 38~45, 2007

Effects of Species on the Isocyanate-bonded Flakeboard Properties*[1]

Jin Heon Kwon*[2]†

ABSTRACT

Flakeboards made from ring- and drum-cut flakes of Douglas-fir, hemlock, red lauan and kapur using two kinds of resin levels were evaluated for the selected properties according to flake thickness. The pH and buffering capacity of four species were determined. Those of kapur were extremely different from the other three species. These pH and buffering capacity values result in the poor internal bond strength of kapur flakeboard. The internal bond strength was affected significantly by flake thickness, resin content and species. MOR and MOE in bending strength were maximized at medium drum-cut flake thickness. Screw holding strength was not consistent for flake thickness, but it was influenced by species. Thickness swelling and water absorption of Douglas-fir and hemlock flakeboard were minimized at medium drum-cut flake thickness.

Keywords : buffering capacity, flakeboard, internal bond strength, ring-cut, drum-cut, screw holding strength, bending strength

1. INTRODUCTION

The use of flakeboard in exterior and structural application is becoming more and more important year by year due to the shortage of raw materials for structural plywood and lumber. Flakeboard and waferboard are characterized by greatly improved mechanical and physical properties at relatively low density and resin content compared to the other compositionboard. A number of factors affect these board properties and interact with each other (Maloney, 1993). Considerable study on such parameters has been done to evaluate the effect on the properties of flakeboard and waferboard using urea formaldehyde and phenol formaldehyde resins (Maloney, 1993; Price *et al.*, 1978; Schwarz *et al.*, 1968; Shuler *et al.*, 1976).

The pH value and buffering capacity of wood or woody materials are important criterions of its suitability for making structural board. The ability of the resin to cure on a substrate depends greatly on the condition of the surface. Since the rate of cross-linking of most thermo-

---

*1 Received on March 20, 2007; accepted on May 23, 2007.
This study was supported by Kangwon National University.

*2 Department of Wood Science and Engineering, College of Forest and Environmental Sciences, Kangwon National University, Chuncheon 200-701, Korea.
† Corresponding author : Jin Heon Kwon (kwon@kangwon.ac.kr)

setting adhesives is pH dependent, theses adhesives will be sensitive to the pH of the substrate (Blomquist *et al.*, 1981).

Resistance of wood and woody materials to the change in its pH level is called the buffering capacity (Ahmad and Kamke 2004). According to Maloney (1993), a larger quantity of acid catalyst is required to decrease the pH to the level for an ideal resin cure when the wood material possesses a high variability of buffering capacity. A single species of wood, or any woody material, that possesses high variability of buffering level could be an important issue, but becomes a critical factor when multiple species are used.

Isocyanate resins are used over 20 percent of the high growth OSB (oriented strand board) industry worldwide and are in common production in MDF mills in Europe and North America. MDI is a tough, water-resistant chemical bond that creates the classic benefits of MDI-bonded composite panels: low resin dosage; extreme moisture resistance; low swelling; and high strength (Deppe 1977; Adams 1980; Papadopoulos *et al.*, 2002)

However, little work has been done so far on the relationship among pH, buffering capacity and properties of the boards using MDI binders. It is the purpose of the present study to find out if such a relationship can be established.

2. MATERIALS AND MATHOD

2.1. Flake Production

Green slabs and edgings of Douglas-fir (*Psedotsuga menciesii Franco*) and hemlock (*Tsuga heterophylla Sarg.*) were sent to the Laboratory for experimentation by “A” Lumber Company. Dried finished lumber of kapur (*Dryobalanops spp.*) and red lauan (*Shorea negrosensis Foxw*) were bought from “B” Company. Materials of each species were randomly divided into the two types of flaking. Dried finished lumber used for drum flaking was soaked in water for several days for easier flaking. The drum flaker was calibrated to produce flakes 6.35 cm long, 0.381 mm thick and of random width and then wood was flaked. Material to be flaked with the ring flaker was first chipped in a Chipper that produced chips 19 mm long. Before ring flaking, the chips of dried kapur and red lauan finished lumber were submerged in water for several days for better flaking. All flakes were dried and separated on the specific gravity table into overthick, thick, medium, thin flakes and fines. Overthick flakes and fines were removed because such overthick flakes and fines may present areas of stress concentration resulting in points of weakness in high strength and structural boards. All flakes were dried below 5% before blending with binder and wax.

2.2. Board Manufacture

Flakeboard manufacturing conditions were:
Board size: 30 by 38 by 1 cm^3
Binder: 5% and 3% isocyanate (pMDI)
(based on OD weight of flakes)
Wax: 1% emulsion
(based on OD weight of flakes)
Binder heating temperature: 27°C
Atomizing pressure for spraying: 35#
Target board specific gravity: 0.68
Mat moisture content: 6～10%
Press temperature: 182°C
Press closing time: 30 seconds
Press time: 3 minutes
Total boards: 4 species × 2 binder level × 3 flake thickness × 2 flake type × 3 replications = 144 boards

2.3. Buffering Capacity and pH Determination

The pH and buffering capacity determination were made using the procedure done by John and Niazi (1980). Air-dried flakes of each species were ground in a Wiley mill with a 3.175 mm screen and stored in polyethylene bags until used. An aqueous wood extract was prepared by refluxing 25 g of wood material in 250 g of distilled water for 20 min. After refluxing, the mixtures were filtered through Whatman #1 filter paper with an aspirator vacuum. The mixtures were then cooled to room temperature. A pH meter (Model 310, Fischer Accumat, USA) was used for all pH and buffering capacity measurements. Exactly 50 ㎖ of wood extract solution was pipetted into a 150 ㎖ beaker, the pH of the extract solution noted, and then titrated to a pH of either 3 or 8 with 0.025 N NaOH or H_2SO_4 solutions in a closed system. The pH of the constantly stirred solutions was noted after each incremental ㎖ addition of acid or base.

2.4. Property Testing

After pressing, all flakeboards were trimmed to 28 by 33 cm. Test specimens were then cut according to ASTM D 1037-98. Water absorption and thickness swelling specimens were placed in a conditioning chamber maintained at a relative humidity of 65 ± 1% and temperature of 20 ± 3°C (68 + 6°F) for 3 weeks. The properties evaluated were modulus of rupture (MOR) and modulus of elasticity (MOE) in bending; internal bond strength (IB); water absorption; thickness swelling and screw withdrawal. Five IB specimens, two bending and screw withdrawal specimens, and one water absorption and thickness swelling specimens were prepared per flakeboard. After completion of the bending tests, screw withdrawal specimens were cut from each bending specimen and then tested. All tests were performed according to procedures described in ASTM D 1037-98 (1998).

2.5. Statistical Analysis

Analysis of variance (ANOVA) was conducted to determine the effect of flake thickness, species and resin content on the physical and mechanical properties of flakeboards. All were carried out using computer software procedures described in the Statistical Analysis System (SAS)

3. RESULT and DISCUSSION

3.1. Flake Separation Analysis

A specific gravity table was used to separate the flakes into the overthick, thick, medium, thin flakes, and fines. For each species, 20 flakes of each classification (thick, medium and thin) were randomly selected and measured for thickness. Table 1 presents this data showing the average thicknesses and percentage of each flake thickness type. The average thickness of each flakes varied by flaker and species. Ring-cut flakes (from 0.432 to 0.990 mm thick) are thicker than drum-cut flake (from 0.203 to 0.610 mm thick). Ring-cut flakes of Douglas-fir and kapur are thicker than those of hemlock and red lauan while drum-cut flakes of red lauan and kapur are thicker than those of Douglas-fir and hemlock. In the case of Douglas-fir and hemlock drum-cut flakes, more fines (18% and 16%) were generated compared to the other species and to ring-cut flaking (5% to 8%). Overthick flakes and fines were not used for making flakeboard.

Table 1. Average thickness and percentage of each flake thickness type

Species	Flake thickness			
	Thick	Medium	Thin	Fines
Douglas-fir ring-cut flakes	0.990 (38)	0.686 (29)	0.533 (27)	(6)
Douglas-fir drum-cut flakes	0.406 (30)	0.279 (26)	0.203 (26)	(18)
Hemlock ring-cut flakes	0.864 (36)	0.660 (30)	0.432 (27)	(7)
Hemlock drum-cut flakes	0.432 (26)	0.305 (29)	0.279 (29)	(16)
Red lauan ring-cut flakes	0.889 (35)	0.559 (28)	0.457 (30)	(7)
Red lauan drum-cut flakes	0.533 (36)	0.381 (31)	0.279 (28)	(5)
Kapur ring-cut flakes	0.965 (34)	0.635 (31)	0.508 (27)	(8)
Kapur drum-cut flakes	0.610 (33)	0.508 (24)	0.381 (35)	(8)

Unit : mm
These flake thickness values are an average of 20 measurements.
( ) means percentage of each flake thickness types.

3.2. Internal Bond, pH and Buffering Capacity

Tables 2 and 3 show the internal bond information for the various flakeboards produced. The IB property was affected significantly by flake thickness, species and resin content ($p < 0.001$). IB values of ring cut flakeboard were significantly increased with decreasing flake thickness with the exception of red lauan. It is also seen that IB values of drum-cut flakboards have different trend compared to ring-cut flakeboards. This may be partially explained by the fact that surface area per pound of flakes and bulk density of the flakes may have affected resin distribution. Also this is probably due to the low compressibility

The IB properties of the boards made from kapur flakes show lower values compared to Douglas-fir, hemlock and red lauan. All IB values of kapur flakeboards don't exceed the specifications of the ANSI standard (50 psi) except for thin drum-cut flakeboards. But all IB values of the other three species exceed the specification of the ANSI standard except for thick ring-cut flakes of Douglas-fir. To evaluate the exact reason for this, pH and buffering capacity were determined. The pH and buffering capacity results are graphically shown in Fig. 1. Initial pH values of Douglas-fir, hemlock, red lauan and kapur were 5.24, 4.97, 4.42, and

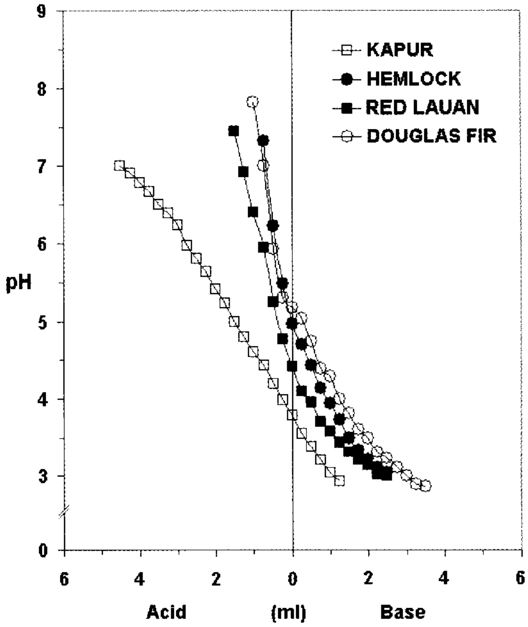

Fig. 1. The pH, acid and base buffering capacity for Douglas-fir, hemlock, red lauan and kapur.

Table 2. Physical properties of boards made ring-cut flakes using isocyanate binder

Species	Flake thickness	MOE (kpsi)	MOR (psi)	IB (psi)	Screw withdrawal		24 hrs. H_2O ABS	
					// (psi)	⊥ (psi)	WA (%)	TS (%)
	Ring-cut flakes 3% ISO binder							
D-fir	Thick	346	1126	16	170	208	21.3	22.3
	Med.	475	2812	72	276	280	17.3	13.7
	Thin	473	3401	126	324	310	11.3	8.3
Hemlock	Thick	354	1960	86	320	286	23.7	16.7
	Med.	414	2670	96	326	291	19.3	12.0
	Thin	400	2698	110	299	273	16.5	10.0
R. lauan	Thick	578	3728	146	251	368	30.3	24.3
	Med.	636	4628	157	300	388	26.7	19.0
	Thin	622	4660	144	362	401	26.0	15.7
Kapur	Thick	305	1156	18	52	139	25.7	36.0
	Med.	334	1353	28	110	132	25.7	32.7
	Thin	364	1611	38	104	141	28.7	28.0
	Ring-cut flakes 5% ISO binder							
D-fir	Thick	340	1353	23	185	249	15.7	17.0
	Med.	463	3157	76	279	310	12.7	9.7
	Thin	481	3544	138	345	310	9.7	7.7
Hemlock	Thick	512	2410	118	319	329	23.0	16.3
	Med.	451	3048	116	360	334	16.0	9.3
	Thin	449	3177	153	307	320	13.3	7.0
R. lauan	Thick	464	2991	135	275	354	24.7	17.3
	Med.	607	4509	186	360	457	19.3	13.0
	Thin	632	5351	177	338	475	19.7	11.7
Kapur	Thick	254	938	10	58	134	22.7	23.7
	Med.	346	1427	24	90	162	24.7	25.7
	Thin	391	2112	44	153	185	25.3	25.0

3.80, respectively. Kapur had the lowest value of pH. Also Fig. 1 shows that acid equivalent value of kapur was extremely different from those of the other species. These different values result in poor internal bond strength of kapur. Extreme values of wood pH have been reported to be troublesome for achieving good adhesive bonds (Narayanamurti 1957 and Rayner 1965). Johns and Niazi (1980) found that a strong correlation between gelation time of wood flour and either pH or acid buffering capacity of water extract exists. These were in agreement with the poor internal bond strength of kapur when using isocyanate binder. Isocyanate binder is very sensitive to pH, buffering capacity and wood extractives. Therefore, it might be assumed that kapur is not suitable for making flakeboard using isocyanate binder.

3.3. Modulus of Elasticity and Modulus of Rupture

The average values of MOE tested at the air-dry condition are shown in Tables 2 and 3. MOE results of the ring-cut flakeboards gave a significant difference between thick and medium

Table 3. Physical properties of boards made from drum-cut flakes using isocyanate binder

Species	Flake Thickness	MOE (kpsi)	MOR (psi)	IB (psi)	Screw withdrawal		24 hrs. H_2O ABS	
					// (psi)	⊥ (psi)	WA (%)	TS (%)
	Drum-cut flakes 3% ISO binder							
D-fir	Thick	682	4008	60	402	270	12.3	9.0
	Med.	697	4799	72	339	310	11.7	8.7
	Thin	545	3950	94	258	261	15.7	8.7
Hemlock	Thick	755	5036	111	331	363	14.5	9.5
	Med.	795	5831	105	375	273	9.0	6.5
	Thin	615	4316	121	266	269	11.7	8.7
R. lauan	Thick	754	5439	110	441	367	26.7	15.0
	Med.	782	5670	107	467	389	24.0	13.3
	Thin	692	5184	125	396	370	22.0	11.7
Kapur	Thick	460	1876	18	99	186	27.3	34.7
	Med.	433	1867	30	128	161	31.0	36.7
	Thin	428	2104	59	163	161	34.3	34.7
	Drum-cut flakes 5% ISO binder							
D-fir	Thick	668	4345	62	354	302	10.3	8.0
	Med.	783	6262	118	407	370	8.3	6.0
	Thin	610	4519	109	361	361	10.0	6.7
Hemlock	Thick	818	6331	157	527	470	8.7	6.0
	Med.	869	6782	132	339	382	10.7	5.3
	Thin	630	5091	143	496	380	10.0	6.3
R. lauan	Thick	755	5975	148	371	471	19.7	11.0
	Med.	832	7370	143	456	433	18.3	9.0
	Thin	751	6050	165	445	425	17.3	9.0
Kapur	Thick	441	1704	20	148	197	22.0	23.7
	Med.	525	2349	30	119	168	27.3	30.0
	Thin	455	2370	66	236	177	25.0	24.7

flake thickness ($p < 0.001$), but didn't give a significant difference between medium and thin flake thickness. MOE values of all flakeboards gave the best performance in the medium flake thickness except for kapur. Drum- cut flakeboards were stiffer than ring-cut flakeboards. Also MOE values of kapur flakeboards gave the lowest performance due to poor bond quality. All MOE values of drum-cut flakebards exceed the specification of the ANSI standard (500×10^3 psi) except for kapur. But only ring-cut flakeboard of red lauan exceed the specification.

MOR values obtained at the air-dry condition are presented in Tables 2 and 3. They show that MOR values of ring-cut flakeboards are significantly increased with a decrease in flake thickness ($p < 0.001$). But MOR values of drum-cut flakeboards show the highest in the medium flake thickness. This indicated that MOR tends to be maximized at flake thickness of approximately 0.254 to 0.508 mm. These results in agreement with the general relationships found in the other studies (Maloney 1993, Mottet 1967, and Post 1958, 1961). As shown in the Tables, MOR results of the flakeboards made from kapur flakes show the lowest values due to poor internal bond strength. All MOR values of kapur don't exceed the specification of the ANSI standard (3000 psi).

3.4. Screw Withdrawal Strength (Perpendicular and Parallel to the Face of the Board)

Screw withdrawal strength results are shown in Tables 2 and 3. Screw withdrawal resistance was not consistent for flake thickness. Statistical analysis shows that screw withdrawal strength results were affected by species and resin amount ($p<0.001$). Flake thickness is not a statistically significant factor in either case (perpendicular and parallel to the face of the boards), but species and resin amount are a significant factor. The highest values were obtained with hemlock drum-cut flakeboards using 5% isocyanate resin amount.

3.5. Thickness Swelling (TS) and Water Absorption (WA)

The comparisons of average TS values of all flakeboards are shown Tables 2 and 3. Statistical analysis shows that TS values of ring-cut flakeboards are significantly affected by flake thickness, species and resin level ($p<0.001$), but those of drum-cut flakeboards are significantly affected by species and resin level ($p<0.001$). The TS values of the boards made from ring-cut flakes were decreased with a decrease in flake thickness except for kapur at the 5% resin amount while those of the boards made from drum-cut flakes were not consistent for flake thickness. Kapur flakeboards have poor TS values, which correspond to the poor IB values.

The average values of WA of all flakeboards were included in Tables 2 and 3. Species and resin level have a significant effect on the WA of all flakeboards ($p<0.001$). In comparing species, red lauan yielded the highest WA values. The best WA results were obtained with Douglas-fir and hemlock drum-cut flakes using 5% binder amount. The WA values of the boards made from ring-cut flakes were decreased with a decrease in flake thickness, but those of the boards made from drum-cut flakes were not consistently decreased with a decrease in flake thickness.

4. CONCLUSION

The following conclusions can be drawn from the results :

1. The internal bond strength values were significantly affected by flake thickness, resin content and species. The pH and buffering capacity of kapur species were extremely different from those of the other species with a corresponding poor IB strength.
2. MOE and MOR reached maximum with the medium drum-cut flake thickness (approximately 0.254 to 0.508 mm), and significantly affected by flake thickness, species and resin amount.
3. Screw withdrawal strength (parallel and perpendicular to the surface) did not significantly vary by flake thickness, but it was influenced by species and resin level.
4. The thickness swelling and water absorption of Douglas-fir and hemlock flakeboard reached minimum at drum-cut medium flake thickness, and those of red lauan and kapur flakeboard were not consistent for it.

REFERENCES

1. Adams, A. D. 1980. EMDI binder for particleboard and waferboard. Proceedings of the 14th international particleboard symposium. Washington State University, Pullman, WA pp. 195-205.

2. Ahmad, M. and F. A. Kamke. 2004. Wettability and pH value related to gluability of Calcutta bamboo. ICCFOP1 International Conference on Environmentally-Compatible Forest Products. Oporto, Portugal, 22-24.
3. American National Standard "Mat-Formed Wood particleboard." ANSI/208.1-1997. National Particleboard Association. Gaithersburg, MD.
4. American Society for Testing and Materials. 1998. Standard method of evaluating the properties of wood-base fiber and particle panel materials. ASTM D 1037-78. part 2. American Society for Testing and Materials. Philadelphia, PA.
5. Blomquist, R. F., A. W. Christiansen, R. H. Gillespie, and G. E. Myers. 1983. Adhesive bonding of wood and other structural materials. Volume III, Clark C. Heritage Memorial Series on Wood, Madison, Wis. 12-110.
6. Deppe, H. J. 1977. Technical progress in using isocyanates as an adhesive in particleboard manufacture. Proceedings of 11th Washington State University Symposium on particleboard, T. M. Maloney, Ed. Washington State University. Pullman, WA.
7. Johns, William E. and Khan, Niazi A. 1980. Effect of pH and buffering capacity of wood on the gelation time of urea-formaldehyde resin. *Wood and Fiber* 12(4): 255-263.
8. Maloney T. M. 1993. Modern particleboard and dry-process fiberboard manufacturing. Miller Freeman Publication. San Francisco, CA.
9. Mottet, A. L. 1967. The particle geometry factor in particleboard manufacturing. Proceedings of First Symposium on Particleboard, T. M. Maloney, Ed. Washington State University. Pullman, WA.
10. Narayanamurti, D. 1957. Die Bedeutung der Holzextrakstoffe. Holz Roh-Werkst. 15:370.
11. Papadopoulos, A. N., C. A. S. Hill, E. Traboulay, and J. R. B. Hague. 2002. Isocyanate Resins for Particleboard: PMDI vs EMDI. Holz als Roh- und Werkstoff 60: 81-83.
12. Post, P. W. 1958. Effect of particle geometry and resin content on bending strength of oak board. *Forest prod. J.* 8(10): 317-322.
13. Post, P. W. 1961. Relationship of flake size and resin content to mechanical and dimensional properties of flakeboard. *Forest Prod. J.* 11(1): 34-37.
14. Price, Eddie W. and Lehmann, F. William. 1978. Flaking alternatives. Structural Flakeboard from Forest residues GTR WO-5. USDA, Forest Service.
15. Rayner, C. A. A. 1965. Synthetic organic adhesives, pp. 186-352. In: Houwink, R. and G. Salmon eds. Adhesion and adhesives, Vol. 1. Elsevier Publishing Company, New York.
16. SAS® User's Guide : Statistics, Version 5, 1985. SAS Institute, Cary NC.
17. Schwarz, F. W., R. L. Anderson, and A. G. Kageler. 1968. Resin distribution and how variations affect board quality. Proceedings of Second Symposium on Particleboard, T. M. Maloney, Ed. Washington State University. Pullman, WA.
18. Shuler, Craig E. and Robert, Kelly A. 1976. Effect of flake geometry on mechanical properties of eastern spruce flake-type particleboard. *Forest Prod. J.* 26(6): 24-28.