ACCELERATED PRESSING OF LOW-DENSITY CEMENT-BONDED BOARD

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Abstract

Low-density cement-bonded boards were constructed with excelsior or planer shavings using carbon dioxide gas injection techniques. The effects of board specific gravity, wood/cement ratio, and water/cement ratio on bending and thickness swell properties were determined. Modulus of rupture and modulus of elasticity increased with increases in specific gravity and wood/cement ratio. Bending properties of excelsior boards were reduced with increase in water/cement ratio. Higher water/cement ratios also inhibited the carbon dioxide reaction in planer shavings boards, but in some cases higher ratios increased final board strength by permitting more uniform cement distribution on the shavings. Thickness swelling was very low in both types of boards but did increase slightly with increase in wood/cement ratio.

Introduction

The 8 to 24 h of press time necessary for initial set of cement-bonded particleboard can be reduced to only 4 min if carbon dioxide is injected into the mat (2). However, proper press schedules and some special techniques are necessary to ensure even distribution of the gas and elimination of wet spots in high-density boards (specific gravity (SG) of 1.2) (4). The gas injection technique is readily adapted to the rapid pressing of a low-density cement-bonded excelsior board (SG, 0.5) in which adequate gas permeability is easily attained. The procedure would provide a means to mass-produce panels suitable for the construction of low-cost housing (8). Preliminary investigations indicated that planer shavings might provide suitable face material for a three-layer board, thus simplifying and reducing the cost of applying a mortar finish-coat.

Research was conducted to obtain basic physical and mechanical values of both low-density excelsior boards and low-density planer shavings boards. This study investigated the effect of board SG, wood/cement ratio, and water/cement ratio on the properties of CO_2-injected boards.

Background

Work by Pablo (7) demonstrated the feasibility of using low-density cement-bonded excelsior boards for panelized construction of low-cost housing. This method is currently being considered by various governmental agencies as the most appropriate construction technique for meeting the housing demand. The severe housing shortage in many tropical countries has heightened the need for rapid production of panels for housing; one study (1), for example, estimated a need for 3.4 million units in the Philippines. Results of research conducted at the USDA Forest Service, Forest Products Laboratory, indicated that press times could be significantly shortened by injecting boards with carbon dioxide. Besides reducing press times, the injection of carbon dioxide also reduced inhibition of cement cure attributed to wood sugars and increased final bending strength of the boards compared to boards processed with conventional pressing methods. The boards achieved full strength in 14 to 28 days, in a manner similar to that achieved by conventionally pressed boards. Further exploratory work provided information on press variables and indicated that continuous pressing may be possible, thus providing the means to mass-produce the low-density boards .

Construction specifications for demonstration housing built in the Philippines required that both the inside and outside surfaces of the excelsior cement board walls be plastered with a cement paste. Reduction in the porosity of the surfaces would reduce the amount of labor and materials needed to finish the surfaces. A search for a suitable face-layer material indicated that bulk density must be high enough to prevent the material from filtering down through the mat during forming and pressing (5). At the same time, board faces must provide a trade-off of high gas permeability to permit the injection of carbon dioxide and low porosity to reduce the use of mortar. Our investigations showed that planer shavings met these requirements.

We consequently directed our effort at obtaining the relationships between fabrication variables and board layer properties necessary to design a three-layer CO_2-cured board suitable for low-cost housing in the tropics.

Procedure

Excelsior Boards

To obtain information on the board core, a series of homogeneous, 26–mm- (1–in.-) thick boards were constructed using aspen excelsior. Test variables are listed in Table 1. The factorial design for this part of the study was as follows: 2 SG levels x 2 water/cement ratios x 3 wood/cement ratios, with three replications, for a total of 36 boards.

The commercially produced excelsior, designated as 6-04, was 0.457–mm- (0.01 8–in.-) thick, 6.35–mm- (0.25–in.-) wide, and 457–mm- (18–in.-) long. Moisture content of the excelsior was approximately 15%. The excelsior ribbons were reduced in length to approximately 152 mm (6 in.) before they were mixed with the cement. The wood was first sprayed with a calcium hydroxide ($Ca(OH)_2$) solution while being tumbled in a 7km- (30–in.-) diameter pin-type blender at 40 rpm. The amount of water used in blending was equivalent to the water/cement ratio designated in Table 1 plus that needed to raise the wood moisture content to 30%. The $Ca(OH)_2$ replaced 5% of the required cement. The cement was sifted onto the tumbling excelsior through a coarse screen. After removal from the blender, the furnish was manually laid in a 60- by 664m (23.6- by 26–in.) box and pressed to target thickness in a press provided with a sealing ring. The press schedule is shown in Table 2. Gas pressure was regulated at 400 kPa (58 lb/in^2).

Upon removal from the press, the boards were weighed, measured for thickness, and tested for bending stiffness. Center deflection of the untrimmed board, supported on a 61-cm (24–in.) span, was measured during successive center loading with 1-kg (2.2–lb) increments to a maximum of 8 kg (17.2 lb). The boards were then cured for a minimum of 28 days in a controlled 26.6°C (80°F), 80% relative humidity (RH) environment and finally brought to equilibrium at 26.6°C (80°F), 65% RH. Before boards were cut into specific test specimens, a selected number of the untrimmed boards were retested for bending stiffness as described in this section.

Two 63.5- by 7.6-cm (25- by 3–in.) bending specimens and two 15.2- by 15.2–cm (6- by 64.) water-soak specimens were cut from each board. The bending specimens were tested on a 58.4–cm (23–in.) span according to ASTM D–1037 (3). The water-soak specimens were measured for thickness swell and water absorption after 2 and 24 h of submersion, as prescribed by ASTM D–1037.

Planer Shavings Boards

To obtain face-layer properties, another series of 60- by 66- by 1.4-cm (23.6- by 26- by 0.55–in.) boards were made with 0.254–mm- (0.10–in.-) thick aspen planer shavings (Table 1). Problems encountered during pressing prevented the completion of a full factorial experiment. Boards were constructed to nine combinations of 2 SG levels, 3 water/cement ratios, and 2 wood/cement ratios. Three replications were made of each combination for a total of 27 boards. The boards were constructed in a manner similar to that for the excelsior boards except that a 0.8-m3 (3-0 commercial paddle mortar mixer was used as a blender. The press schedule was similar to that used for the excelsior boards (Table 2). With few exceptions, conditioning and testing were also similar to that for the excelsior boards. The 33- by 7.6-cm (13- by 3–in.) bending specimens were tested on a 30.5-cm (12–in.) span.

Results and Discussion

We used aspen rather than a tropical species because of its availability. We thought that the relative effect of process parameters on board strength would be applicable in most cases regardless of species. The target specification parameters for the excelsior and planer shavings boards were determined after extensive exploratory studies (5). Planer shavings boards were constructed with a higher SG range and a lower woodcement range than the excelsior boards because we felt these conditions would be representative of the surface layer in a three-layer board.

Excelsior Boards

Boards subjected to a CO_2 pressing treatment will gain weight equal to the amount of CO_2 that reacts with $Ca(OH)_2$, according to Equation (1).

$$CO_2 + Ca(OH)_2 = CaCO_3 + H_2O \quad (1)$$

The amount of weight gained by the excelsior boards averaged 9.1% of the cement-calcium hydroxide mixture (Table 3), indicating that the reaction proceeded far beyond that afforded by the 5% addition of $Ca(OH)_2$. Since only 0.594 parts of CO_2 were required for 1 part of $Ca(OH)_2$, a weight gain of approximately 3% was sufficient to consume the added $CA(OH)_2$. No major differences in weight gain could be attributed to differences in either board SG or woodcement ratio. However, a slight but consistent increase in weight gain occurred when the water/cement ratio was reduced from 0.8 to 0.6, a relationship previously reported by Geimer et al. (4). Actual CO, consumption was not measured during this part of the study. However, gas flow measurements taken during later investigations (9) indicated that efficiency (weight increase/gas consumption) would be above 50%.

As indicated in the procedures, the "green" untrimmed panels were tested for bending immediately after pressing . Although theoretical and empirical methods relating whole-board to small-specimen bending values have been described (6,10), a more reliable method to compare green and fully cured stiffness is simply to retest the whole boards after cure and conditioning. Whole-board green–modulus of elasticity (MOE) is shown as a percentage of cured–MOE for selected panels in Table 3. The data indicated that between 24% and 46% of the final strength was reached after 10 min of pressing in a CO, atmosphere. This strength is similar to the bending stiffness obtained after 24 h of conventional pressing (9). It is important to remember that the board tested immediately out of the press is still quite warm (press temperatures can exceed 100°C (212°F), and the bending stiffness of the wood is reduced to below that at room temperature. The ratio of whole-board green MOE/cured MOE is consequently a very conservative estimate of the extent of cement cure. No major differences in greedcured stiffness could be attributed to SG or woodcement ratio. Similar to the weight gain results, a slight but consistent increase in greedcured stiffness occurred when the water/cement ratio was reduced from 0.8 to 0.6.

Table 3 shows bending modulus of rupture (MOR) and MOE values obtained on the small, cured test specimens, averaged by board type. The MOR was relatively well-correlated to MOE, as shown in Figure 1. Bending properties of low-density boards, like those of high-density boards (4) improved with the addition of material and consequently tended to increase with an increase in SG (Figs. 2 and 3). The MOR and MOE increased an average of 40% and 47%, respectively, when SG of the core boards increased from 0.55 to 0.65. With few exceptions, both MOR and MOE were dependent on the amount of wood and increased an average of 46% as the wood/cement ratio increased from 0.45 to 0.65 (Figs. 2 and 3). This relationship was different than that observed previously with high-density boards (4), where MOR increased but MOE decreased with an increase in wood/cement ratio. The structure of a low-density board resembles that of mesh consisting of stiffened interwoven strands; it is considerably different from the structure of a high-density board, in which isolated wood fibers are encased in a continuous cement matrix. Increases in the bending MOR of a high-density board are obtained by decreasing the amount of within–wood cellular void spaces. On the other hand, the MOE of high-density boards is dependent on the total amount of the stiff and incompressible cement matrix present. Relatively little fiber compression occurs in a low-density excelsior board, and the bending strength and stiffness properties primarily depend on the number of fiber intersections and the distance between them.

Although not consistent between board types, bending MOR properties improved an average of 7% as the water/cement ratio decreased from 0.8 to 0.6. This correlates with the out-of-press weight gain discussed previously in this report, implying that the same variables that affect the initial reaction also influence the final degree of cure. However, the ratio of green MOE/cured MOE was not constant. Reduction of the water/cement ratio, while improving the CO_2 reaction, resulted in poorer strand coverage and required a compromise in the fabrication of the low-density boards.

The 24-h thickness swelling of boards made with a wood/cement ratio at or below 0.55 averaged less than 1% (Table 3). Thickness swelling increased as the wood/cement ratio increased above 0.65. Maximum thickness swelling was 3.2% for excelsior boards constructed to 0.55 SG, 0.80 water/cement, and 0.65 wood/cement. No major differences in thickness swelling could be attributed to SG.

Planer Shavings Boards

The large surface area of the 0.254–mm-(0.10 in.-) thick aspen shavings caused problems with cement distribution and gas entry. Boards made with a 0.40 water/cement ratio experienced adequate weight gain but had low bending properties. We attributed this to poor cement distribution and/or inadequate coverage of the flakes. These boards had marginal out-of-press bending properties and required care in handling. Average green board stiffness was low for boards constructed to target SG of 0.60, water/cement of 0.80, and wood/cement ratio of 0.35. One board in the group did not survive the out-of–press handling. Increasing the water/cement ratio greatly improved the cement distribution, as evidenced by visual observation and high final bending properties. However, when the water/cement ratio was increased from 0.6 to 0.8, the carbon dioxide reaction, as measured from weight gain, was reduced.

As experienced with the excelsior boards, increasing the wood/cement ratio enhanced the bending properties of the fully cured boards made with planer shavings. Somewhat surprisingly, increasing the wood/cement ratio increased weight gain in some cases. This interaction of the variables favored the carbon dioxide reaction and permitted us to make boards with a SG of 0.80, water/cement ratio of 0.80, and wood/cement ratio of 0.50 when all boards made with the same SG and water/cement ratio but a wood/cement ratio of 0.35 failed when removed from the press.

A maximum 24-h thickness swelling of 4.4% occurred in boards with a water/cement ratio of 0.4. Even with poor cement coverage of the flakes, the thickness swelling of these boards were well below the 10% to 20% values typical of flakeboard bonded with thermosetting resin.

Conclusions

Low-density cement-bonded aspen excelsior boards, manufactured using a carbon dioxide injection technique, attained between 25% and 45% of their final cured bending stiffness after 10 min of pressing. Approximately 10% of the cement-$Ca(OH)_2$ binder reacted with the carbon dioxide. As with other wood composites, the bending modulus of rupture (MOR) of the excelsior boards was directly related to modulus of elasticity (MOE). The bending MOR increased approximately 40% with increases in specific gravity (from 0.55 to 0.65) and 45% with increases in wood/cement ratio (from 0.45 to 0.65). The MOE increased 47% and 19% with the same changes in specific gravity and wood/cement ratio, respectively. Slight improvements in final bending properties were noted when the water/cement ratio was reduced.

Properties of low-density boards made with aspen planer shavings, like those of low-density excelsior boards, increased with increases in specific gravity and wood/cement ratio. However the planer shavings boards were more sensitive to water/cement ratio, which not only retarded the carbon dioxide reaction but made major differences in cement distribution.

Dimensional stability of the cement-bonded boards was excellent compared to that of boards bonded with thermosetting resin. Maximum 24-h thickness swell was 3.2% for the excelsior boards and 4.4% for the planer shavings boards.

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Table 1–Processing variables

Material	Board SG[a]		Water/Cement			Wood/Cement		
Excelsior	0.55	0.65	0.60	0.80	–	0.45	0.55	0.65
Planer Shavings	0.60	0.80	0.40	0.60	0.80	0.35	0.50	–

[a] Specific gravity (SG) based on oven-dry weight of wood and cement including hydration water (25% of cement).

Table 2–Press schedule

Accumulative time (s)	Position/pressure (mm)	Position/pressure (kPa)	Manifold mode
0	100	–	Closed
22	28	–	Closed
35	–	4,000	Vacuum
95	–	4,000	Vacuum
275	–	4,000	CO_2
575	–	4,000	Closed
595	–	100	Vent
600	–	100	Vent
615	100		Closed

Table 3–Board properties

Board specifications[a]										
Ovendry SG	Water/C ratio	Wood/C ratio	Weight gain (%)	Stiffness green/cured[b] (%)	MOR[c] (MPa)	MOE[c] (MPa)	Conditioned SG[d]	Water soak[e] (%)	Thickness swell[e] (%)
				Excelsior boards					
0.55	0.60	0.45	8.6	33.6	2.90	1,151	0.570	41	0.6
0.55	0.60	0.55	10.4	46.1	3.33	1,076	0.610	42	0.9
0.55	0.60	0.65	10.4	45.2*	3.34	1,091	0.600	45	2.3
0.55	0.80	0.45	7.9	32.4	2.59	1,018	0.610	40	−0.4
0.55	0.80	0.55	9.8	37.8	3.35	1,175	0.630	41	0.2
0.55	0.80	0.65	8.0	24.3*	3.75	1,322	0.580	44	3.2
0.65	0.60	0.45	9.6	39.6*	3.64	1,618	0.700	32	0.8
0.65	0.60	0.55	9.3	29.9*	5.08	1,894	0.709	33	0.6
0.65	0.60	0.65	9.9	43.7*	5.60	1,716	0.695	31	1.3
0.65	0.80	0.45	6.7	26.7*	3.17	1,324	0.673	33	0.8
0.65	0.80	0.55	9.0	–	4.17	1,562	0.658	34	0.7
0.65	0.80	0.65	9.2	35.9*	5.25	1,961	0.692	39	2.4
				Planer shavings boards					
0.60	0.40	0.35	9.8	27.1	0.73	241	0.660	57	4.2
0.60	0.40	0.50	11.6	29.2	1.80	866	0.700	33	4.4
0.60	0.60	0.35	12.6	24.0*	2.16	1,053	0.730	33	1.3
0.60	0.60	0.50	13.5	19.8	2.23	1,054	0.700	40	4.1
0.60	0.80	0.35	7.5	9.6*	2.57	1,139	0.710	48	3.0
0.80	0.60	0.35	10.3	–	3.32	1,282	0.890	17	1.4
0.80	0.60	0.50	10.2	–	4.43	1,493	0.870	18	1.7
0.80	0.80	0.35	1.6	–	–	–	–	–	–
0.80	0.80	0.50	5.9	–	5.13	1,813	0.870	26	1.8

[a] C is cement.

[b] Ratio of out-of-press whole-board MOE to MOE of fully cured and conditioned whole-board. Asterix indicates test for one board in the group. Other values are average of three boards per group.

[c] Values are average of two specimens for each of three boards, except for planer shavings boards made to specifications of 0.60-0.40-0.35 and 0.60-0.80-0.35 (two specimens for two boards).

[d] conditioned at 27°C and 65% relative humidity.

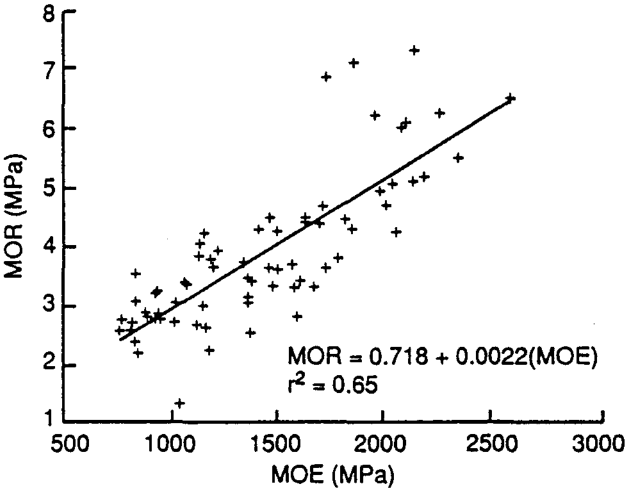
[e] 24-h tests.

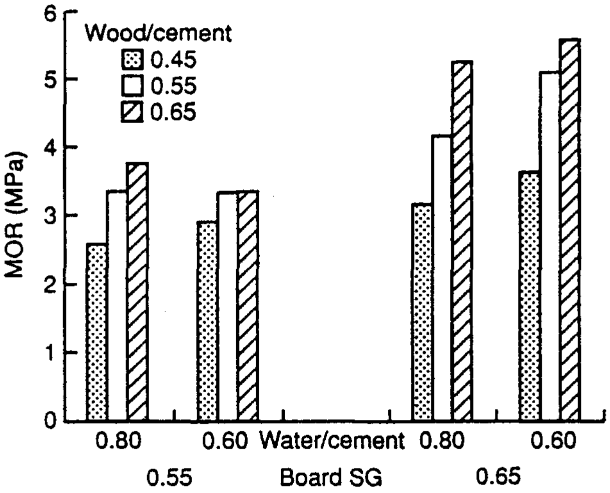
Figure Captions

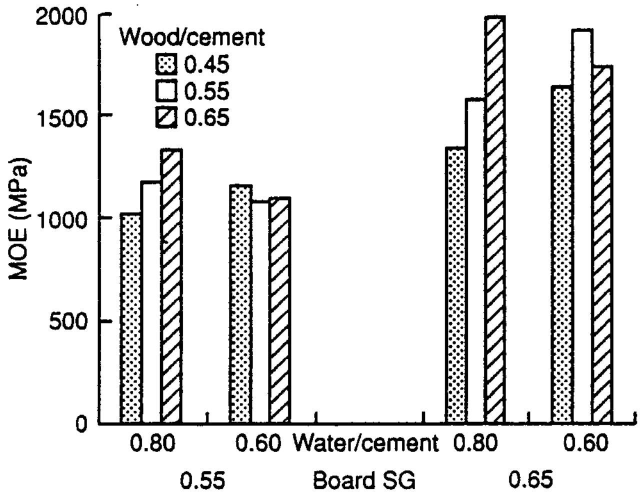
Figure 1. Relationship of modulus of rupture (MOR) to modulus of elasticity (MOE) in low-density cement-bonded boards made with excelsior. 1 lb/in2 = 6.894 kPa.

Figure 2. Effect of fabrication variables on MOR of excelsior boards. Water/C is water/cement ratio; wood/C, wood/cement ratio; SG, specific gravity.

Figure 3. Effect of fabrication variables on MOE of excelsior boards.


8
7
6
5
4
3
2
1
MOR (MPa)
500
1000
1500
2000
2500
3000
MOE (MPa)
MOR = 0.718 + 0.0022(MOE)
r² = 0.65


MOR (MPa)
6
5
4
3
2
1
0
Wood/cement
0.45
0.55
0.65
0.80
0.60
Water/cement
0.80
0.60
0.55
Board SG
0.65



2000
1500
1000
500
0
MOE (MPa)
Wood/cement
▨ 0.45
☐ 0.55
▨ 0.65
0.80
0.60
Water/cement
0.80
0.60
0.55
Board SG
0.65