Robert L. Geimer; Mário Rabelo de Souza; Ali A. Moslemi

Low-Density Cement-Bonded Wood Composites Made Conventionally and With Carbon Dioxide Injection

Ubrzano starenje lakih cementnih drvnih ploča proizvedenih konvencionalno i uz injekciju ugljik-dioksida

Izvorni znastveni ***članak*** *- Original scientific paper*
Prispjelo - received: 20.11.1996. • Prihvaćeno - accepted: 12.03.1997.
UDK 634.0.839.1 i 634.0.862.1

SUMMARY • *The purpose of this study was to evaluate the durability of low-density cement-bonded wood composites using an accelerated aging process. Low-density cement-bonded wood composites were made with two types of wood particles (excelsior and splinter) and pressed either conventionally or with carbon dioxide injection. In the conventional boards, calcium chloride and sodium silicate were tested as additives to improve wood to cement bonding. Calcium hydroxide and a mixture of calcium hydroxide and sodium silicate were added to portions of the* CO_2*-injected boards. All the boards were tested before and after 10 cycles of a 3-day soak/freeze/thaw/dry cycle. Boards injected with carbon dioxide showed better initial physical and mechanical properties and also better performance after accelerated aging than did conventionally pressed boards, Excelsior board outpeformed splinter board in all conditions tested. No difference could be attributed to additives in either the conventional or the* CO_2*- injected boards. In all treatments, flexural modulus of elasticity*

Robert L. Geimer, Ph. D., Forest Products Tehnologist, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, USA
Mário Rabelo de Souza, Ph.D., Wood Technology Researcher, Institoto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, Laboratorio de Produtos Florestais, Brasilia, DF. Brazil
Ali A. Moslemi, Ph. D., Professor Forest Products Department University of Idaho, Moscow, ID, USA

retention was less than 50% after 10 cycles of aging, and modulus of rupture was less than 75%. The analysis indicated that freezing had no effect on aging.

Key words: *excelsior board, mineral board, cement, carbon dioxide, durability, cyclic test, accelerated aging, sodium silicate.*

SAŽETAK • Ploče od drvne vune (ili od excelsior iverja, kako se to naziva u SAD) nazivaju se po vrsti usitnjenog drva koje se koristi u njihovoj proizvodnji. Drvo se usitnjava struganjem okoranih drvnih trupčića, približno dugih 50 cm, u duge uvijene trake. Te trake odstupaju u debljini od 0,08 mm do 0,50 mm a širina im može biti od 0,60 do 12,5 mm. Duge kovrčave trake imaju vrlo malu prostornu gustoću, što omogućuje izradu lakih ploča usprkos velikoj specifičnoj gustoći cementnog veziva (3,0 g/cm^3). Lake cementne drvne ploče (engl. low-density cement-bonded wood composites, LD-CBWC) općenito imaju gustoću u rasponu od 0,48 do 0,58 g/cm^3. U SAD-u se za ploče drvne vune najčešće koristi borovina (Pinus spp) i jasikovina (Populus spp) koje se miješaju s portland slaine cementom ili magnezijskim cementom. Cementne ploče drvne vune koriste se za izolaciju krovova, stropova i zidova. Ploče imaju vrlo dobru dimenzijsku stabilnost i izvrsnu otpornost na gljive, insekte i gorenje. Nadalje, njihova mala gustoća smanjuje provodljivost topline i povećava zvučnu izolaciju.

Cilj ovog istraživanja bila je procjena trajnsoti lakih cementnih drvnih ploča primjenom ubrzanih metoda starenja. Cementne drvne ploče male gustoće načinjene su od dvije vrste drvnih čestica (drvne vune - excelsior i dugog iverja - splintera), a prešane su ili uobičajenim - konvencionalnim načinom ili uz ubrzigavanje ugljikova dioksida. U konvencionalnim pločama su kalcijev klorid i natrijev silikat iskušani kao veziva da bi se poboljšalo vezanje drva i cementa. Kalcijev hidroksid i mješavina kalcijeva hidroksida i natrijeva silikata dodavani su dijelovima ploča koje su bile injektirane sa CO_2. Sve su ploče ispitivane prije i nakon 10 ciklusa koji su se sastojali od trodnevne izmjene potapanja, smrzavanja, taljenja i sušenja. Ploče injektirane ugljikovim dioksidom pokazale su bolja početna fizička i mehanička svojstva kao i bolju postojanost pri izlaganju nego konvencionalno prešane ploče. Ploče drvne vune nadmašile su ploče od drugog iverja u svim ispitivanim uvjetima. Aditivima se ne može pripisati nikakvo značajno poboljšanje ni u konvencionalnim ni u injektiranim pločama. Pri svim tretmanima je nakon 10 ciklusa starenja smanjenje modula elastičnosti bilo veće od 50%, a modul loma je umanjen za više od 25%. Analiza je pokazala da smrzavanje nema utjecaja na ubrzavanje starenja.

Ključne riječi: *ploče drvne vune, mineralne ploče, cement, ugljikov dioksid, postojanost, ubrzano starenje, cikličko ispitivanje, natrijev silikat.*

INTRODUCTION

Excelsior board, or "wood-wool" as it is referred to in Europe, is named after the type of particle used in its manufacture. The particle is produced by shredding debarked wood bolts, approximately 50-cm long, into long curly strands. Strands vary in thickness from 0.08 to 0.50 mm and in width from 0.60 to 12.5 mm. The long curly strands have a very low bulk density, which permits the construction of a low-density board despite the 3.0 specific gravity (SG) of the cement binder. Low-density cement-bonded wood composites (LD-CBWC) generally range in density from 0.48 to 0.58 g/cm^3 (10). In the United States, southern pine *(Pinus* spp.) and aspen *(Populus* spp.) are favored for excelsior and are mixed with Portland cement and magnesia cement (5,8,18). The LD-CBWCs are used in roof decking, ceilings, and walls (8,15). Like their high-density counterparts, LD-CBWCS have very good dimensional stability and excellent resistance to fire, fungi, and insects (15,19). In addition, their reduced density lowers thermal conductivity and increases sound insulation (7),

Many publications on LD-CBWC discuss the problem of wood-cement compatibility (2,3,6,9-11). The hydration-inhibiting effect of wood sugars and extractives can be reduced by seasoning the logs, washing the excelsior, or adding chemicals such as calcium chloride and sodium silicate. Studies have shown that the use of carbon dioxide injection to promote cement cure also improves the effective compatibility of wood and cement (13,16,18).

Studies on strength properties of LD-CBWC by Lee (5) indicated that the modulus of elasticity (MOE) of low-density boards increased almost linearly when the wood/cement ratio was increasd from 0.38 to 0.50. Modulus of rupture (MOR) also increased with increasing wood/cement ratio. Pablo and Geimer (14) obtained similar results with wood/cement ratios of 0.45 to 0.65.

In comprehensive work on durability of agro-fibei-cement composites, Gram (4) concluded that durability is greatly affected by soaking/drying cycles. According to Gram, fiber degradation and board embrittlement caused by elevated pH (between 11 and 12) is aggravated by cement pore water movement. He suggested that an accelerated aging test that incorporates soaking/drying cycles is appropriate forcement composites. Soroushian et al. (17) and Moslemi et al. (13) investigated the durability of high-density cement-bonded wood composites. Durability studies on LD-CBWC, however, are somewhat limited. Lee (6) investigated the bending and thickness swelling properties of a commercially produced excelsior board tested before and after 48 h water soaking. Bending properties tested after reconditioning the boards in a 65% relative humidity chamber were not significantly affected. Lee concluded that the boards were very stable.

OBJECTIVES

The overall purpose of this study was to evaluate the durability of low-density cement-bonded particleboard using an accelerated aging process. Specific objectives were to determine the effect of two wood particles (excelsior and splinter), two press systems (conventional and carbon dioxide injection), and two additives (calcium chloride and sodium silicate) on bending and compression-shear strength retention and dimensional stability following a 10-cycle wet/dry exposure.

EXPERIMENTL METHODS

Wood Preparation

Two different wood particles were used in this study: commercial aspen *(Populus* sp.) excelsior and aspen splinters. The excelsior, commercially specified as excelsior 604, was 0.3 mm thick and 6 mm wide. The original particle was shortened from about 500 mm to between 100 and 150 mm, to facilitate blending and also achieve better cement coverage over the particles. Splinters were obtained by crushing freshly harvested aspen logs. The logs were first reduced to splinters by passing them several times lengthwise through a specially designed crushing device. The 300- to 500-mm-long splinters were then cross-cut to approximately 80 mm long, and finally passed crosswise through a commercial grain-crushing machine. The second reduction generated rough splinterlike particles with low bulk density, similar to those described by Marra (12). The grain-crushing machine imparted a singificant amount of cross-grain damage to the splinters. However, we felt that development of commerical machines could improve splinter quality and that the potential utilization of large quantities of forest residues as splinters warranted investigation of the material. The furnish was screened on a 1.6- mm mesh to separate the fines. Prior to board fabrication, all particles were soaked in water for 24 h to reduce the amount of water-soluble sugars and tannins and were finally dried to approximately 1% moisture content.

Board Fabrication

Three replications were made of eight board types. Variables included two particle types (excelsior and splinters), two pressing methods (conventional and CO_2 injection), and two additives (calcium chloride ($CaCl_2$) and sodium silicate (Na_2SiO_3) for conventional boards and calcium hydroxide ($Ca(OH)_2$) and a mixture of $Ca(OH)_2$ and Na_2SiO_3 for CO_2-injected boards). Type I Portland cement was used as the binding agent. All boards had a wood/cement ratio of 0.5, with additives considered part of the cement binder. Additive quantities based on total weigh(of the binder were as follow~:

Conventional boards:
2% $CaCl_2$
2% Na_2SiO_3

Co-injected boars:
5% $Ca(OH)^2$
5% $Ca(OH)_2$ and 2% Na_2SiO_3.

All boards measured 660 by 600 mm and were fabricated to a specific gravity (SG) of 0.5 based on ovendry hydrated weight. Board thickness was 25 mm, and water/cement ratio was 0.6. Boards made in the conventional manner were cold pressed to target thickness; at this thickness they were restrained by clamps for 24 h, Boards made using CO_2 injection were pressed in a sealed gas injection press. After target thickness had been attained and following 220 s of gassing at a gas pressure of 400 kPa, the CO_2 supply was terminated ant the gas in the system allowed to disperse into the board. Total press time was 400s. More information about CO_2 injection can be found in Souza (14).

Testing

Bending stiffness of the whole board was obtained immediately after pressing by measuring deflection directly beneath a concentrated load at the center of the board, which was supperted on a 61-cm span. This test was repeated after curing the board at 27°C and 80% relative humidity (RH) for 28 days.

Each board provided three sets of four specimens each. Each set included a static bending specimen (76.2 by 355.6 mm), linear expansion (LE) specimen (76.2 by 304.8 mm), 24-h water absorption and thickness swell specimen (152.4 by 152.4 mm), and compression-shear (also called Minnesota shear) specimen (50.8 by 57.1 mm). Except for the water absorption and thickness swell specimens, which were reduced in size, all testing was performed according to ASTM D 1037-89 (1). Toughness (work to maximum load) was calculated from the bending data and is presented without adjustment for sample volume. Bending, compression-shear, water absorption, and thickness swell specimens were tested after conditioning to equilibrium at 27°C, 80% RH. The LE specimens were measured after conditioning once to 23°C, 50% RH and again to 23°C, 90% RH. Linear expansion was measured using an optical gauge capable of reading, to the nearest 0.0025-mm, the distance between two brass pins embedded approximately 254-mm apart. The water absorption and thickness swelling specimens were measured before and after horizontal immersion in water for 24 h.

The first set of specimens was used as the control. The second set of specimens was subjected to 10 cycles of accelerated aging. The accelerated regime was based on work published by Gram (4) and modified to suit our conditions. Each cycle consisted of the following:

1. immersion in water at 20°C for 24 h
2. freezing at- 17°C for 24 h
3. thawing at room temperature for 2 h
4. ovendrying at 100°C for 22 h

After accelerated aging, the specimens were equilibrated again at 27°C and 80% RH prior to testing.

The third set of specimens was subjected to 10 cycles of an alternative regime similar to that just described but with the elimination of the freezing/thawing steps. The third set of specimens was tested in the same way as the second set.

Experimental Design

The small number of sample replications (one sample from each of three replicated boards) coupled with large variations between samples, characteristic of LD-CBWC, lessened confidence in statistical analysis. However, a Ryan-Einot-Gabriel-Welsh (REGWF) multiple F test was conducted to check differences in test results of boards made with various additives. The effect of freezing was studied in a separate one-way ANOVA.

RESULTS AND DISCUSSION

A major concern in the development of aging tests in the proper selection of the type and extent of exposure conditions that permit measurable degradation of selected properties in a reasonable time. A harsh exposure sequence that reduces a specific property to zero in one cycle is of no more value than a mild one that has no effect on the property in question. Time and space limitations, associated with the research reported here, dictated only one evaluation of the exposed specimens. Preliminary testing had indicated that 10 cycles of the previously described exposure conditions would result in a measurable degradation of the strength properties in question. The exposure program used was indeed useful in determining the relative effect of fabrication variables (press type, particle type, and additives) on loss of bending, shear, and toughness properties. In general, the cyclic exposure had little effect on thickness swell and water absorption of the LD-CBWCS. However, surface erosion of the low-density boards disrupted the LE measuring pins and prevented precise measurement of LE changes attributed to the exposure. There was no attempt to correlate the extent of degradation in the aging tests to any meaningful long-term weatherability factor,

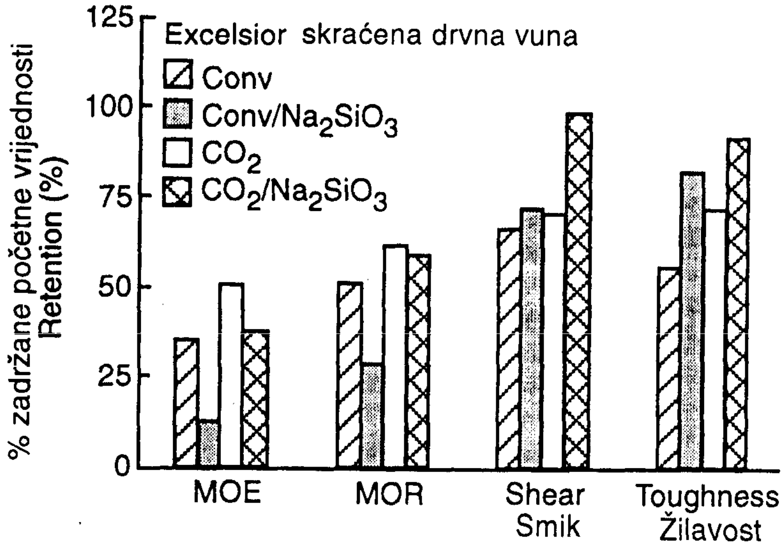

Figure 1.
Retention values for MOE, MOR, shear, and toughness obtained for excelsior boards after 10 cycles of accelerated aging. • *Postoci zadržanih početnih vrijednosti modula elastičnosti (MOE), modula loma (MOR), čvrstoće na smicanje i žilavosti za ploče od drvene vune ("excelsior") nakon 10 ciklusa ubrzanog starenja.*

Initial Stiffness and Weight Gain

Initial bending stiffness, measured on the whole board after 24 h of conventional pressing, was 54% of final stiffness measured after 28 days of curing. The CO_2-injected boards measured after 400 s of pressing reached 30% of their final stiffness. In both cases, the initial cure was adequate to prevent springback from occurring and permitted easy handling of the boards after pressing,

Average board weight gain (based on cement weight) during pressing for all CO_2-injected boards was 10%. This represents the amount of gas that was incorporated into the board. Typical CO_2 system efficiency (weight gain/measured gas consumption) was 32%. The additional gas was used to fill the system or was lost through leakage.

Excelsior Boards

Data on physical and mechanical properties are presented in Table 1. The CO_2-injected boards consistently showed higher mean values than did the conventionally pressed boards for MOE, MOR, shear, and toughness. No consistent difference in the thickness swell, water absorption, and LE properties of the control excelsior boards could be attributed to pressing method, The effect of $Na2SiO_3$ addition varied with press mode and particle type- detrimental to some properties and favorable to others. Statistical analysis did not detect any difference between the four additive treatments for any of the variables tested. Coefficients of variation for this test were 21%, 30%, 28%, and 48% for MOE, MOR, shear, and toughness, respectively.

After 10 cycles of aging, strength properties were substantially reduced inmost cases (Table 1). The extent of loss varied considerably, depending on the strength property under consideration (Fig. 1). The CO_2-injected boards retained higher properties after aging.

Sample thickness was not obtained in a saturated conditon, i.e., immediately after the soaking portion of the cyclic exposure, However, no warping, delamination, or twisting of the specimens was observed. Aging did not generate any unrecoverable thickness swell, as measured for conditioned specimens before and after aging, As mentioned previously, surface deterioration suffered by the samples prevented measurement of linear expansion after cyclic exposure. Efflorescence, the movement of free $Ca(OH)_2$ to the surface creating a white "blush", was very noticeable in the conventionally pressed boards. This phenomenon did not occur in the CO_2-injected pressed boards.

Data for boards subjected to a cyclic exposure without freezing indicate that the frezing portion of the 10-cycle aging exposure had a negligible effect on mechanical properties (Table 1).

Table 1. *Physical and mechanical properties of low-density aspen excelsior boards after 28 days of curing and 10 cycles of aging*[a] • *Fizikalna i mehanička svojstva "excelsior" lakih cementnih ploča od jasikovine nakon 28 dana stezanja i 10 ciklusa starenja*

	Property[b] - *Svojstvo*[b]						
Treatment *Postupak izrade*	MOE *Modul elasticiteta* (GPa)	MOR *Modul loma* (MPa)	Shear *Čvrstoća na smicanje* (kPa)	Toughness *Žilavost* (N.mm)	Thickness swell *Debljinsko bubrenje* (%)	Water adsorption *Nakuplja-nje vode* (%)	Linear expansion *Linearno istezanje* (%)
	Before aging[c] *Prije starenja*[c]						
Conventional *Konvencionalno*	0,84a	1.28a	383a	383a	2.6a	63a	0.13a
Conv/Na_2SiO_3	0.75a	1.39a	260a	268a	3.1a	66a	0.11a
CO_2	0.94a	2.29a	404a	630a	2.9a	63a	0.10a
CO_2/Na_2SiO_3	0.93a	2.04a	409a	564a	3.1a	62a	0.11a
	After 10 cycles of aging with freezing[c] *Nakon 10 ciklusa starenja sa smrzavanjem*[c]						
Conventional *Konvencionalno*	0.3	0.9	213	252	2.9	54	-
Conv/Na_2SiO_3	0.1	0.4	214	192	1.2	75	-
CO_2	0.48	1.42	290	450	3.5	70	-
Co_2/Na_2SiO_3	0.34	1.21	373	552	1.7	61	-
	After 10 cycles of aging without freezing[c] *Nakon 10 ciklusa starenja bez smrzavanja*[c]						
Conventional *Konvencionalno*	0.2	0.71	238	237	-	-	-
Conv/Na_2SiO_3	0.11	0.40	163	197	-	-	-
CO_2	0.37	1.16	365	337	-	-	-
Co_2/Na_2SiO_3	0.25	0.97	415	350	-	-	-

[a] Mean values with the same letter, in the same group, are not significantly different at 5% level, using REGWF-F test

[b] 24-h thickness swell, 24-h water adsorption, and linear expansion from 50% to 90% relative humidity.

[c] Average specific gravity was 0.46 for conventional boards and 0.52 for CO_2-injected boards before aging and 0.52 and 0.54 after aging, respectively.

[a] *Srednje vrijednosti s istim slovom u istoj grupi nisu signifikantno različite na niovu 5%, upotreobm REGWF-F testa.*

[b] *24-satno debljinsko bubrenje, 24-satno nakupljanje vode i linearno istezanje od 50% do 90% relativne vlažnosti zraka.*

[c] *Prosječna specifična težina je prije starenja za konvencionalne ploče iznosila 0.46 a 0.52 za CO_2 injektirane ploče, dok su te vrijednosti nakon starenja iznosile 0.52 i 0.54 g cm^{-3}.*

Splinter Boards

Property values for splinter boards are given in Table 2. In almost all cases, strength properties of splinter boards were lower than those of excelsior boards. Similar to that experienced with excelsior boards, CO_2 injection resulted in higher strength properties of the splinter boards compared to conventional pressing. Thickness swell appeared to be slightly less and water absorption slightly more than that observed in the excelsior boards. Statistical analysis showed some effect of additive treatment, but no pattern was apparent.

Strength properties were in most cases considerably reduced by the cyclic exposure (Fig. 2). Shear and toughness suffered less than bending MOE and MOR. Aging did not affect board thickness or density, and it had little effect on 24-h thickness swelling and water absorption, indicating the very stable characteristics of inorganic bonded boards. Analysis again indicated that the freezing portion of the 10 aging cycles has little effect on mechanical property reduction.

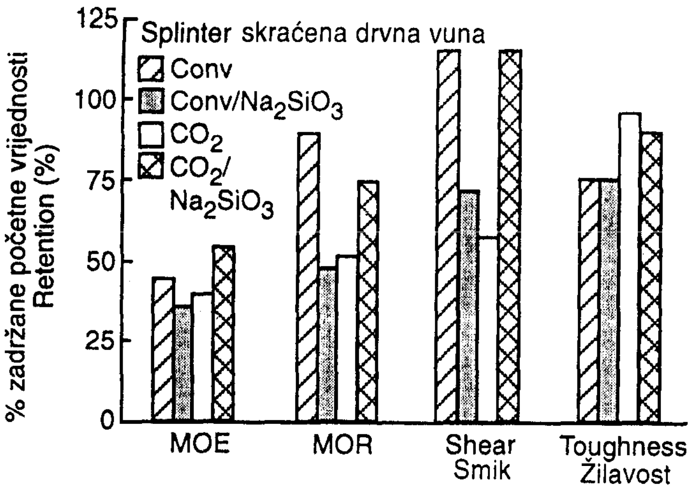

Figure 2

Retention values for MOE, MOR, shear, and toughness obtained for splinter boards after 10 cycles of accelerated aging. • Postoci zadržanih početnih vrijednosti modula elastičnosti (MOE), modula loma (MOR), čvrstoće na smicanje i žilavosti za ploče od dugog iverja ("splinter") nakon 10 ciklusa ubrazanog starenja.

Table 2.

Physical and mechanical properties of low-density aspen splinter boards after 28 days of curing and 10 cycles of aging • Fizikalna i mehanička svojstva lakih cementnih ploča od jasikovog dugog iverja ("splinter") nakon 28 dana stezanja i 10 ciklusa starenja.

	Property - *Svojstvo*						
Treatment *Postupak izrade*	MOE *Modul elasticiteta* (GPa)	MOR *Modul loma* (MPa)	Shear *Čvrstoća na smicanje* (kPa)	Toughness *Žilavost* (N.mm)	Thickness swell *Debljinsko bubrenje* (%)	Water adsorption *Nakuplja-nje vode* (%)	Linear expansion *Linearno istezanje* (%)
	Before aging^a *Prije starenja*^{a}						
Conventional *Konvencionalno*	0.47a	0.80b	319a	206b	1.9a	82a	0.12a
Conv/Na$_2$SiO$_3$	0.51a	1.04ab	340a	218b	2.4a	78a	0.10ab
CO$_2$	0.70a	1.76a	398a	588a	1.5a	77a	0.09ab
CO$_2$/Na$_2$SiO$_3$	0.42a	1.01b	377a	274b	1.3a	74a	0.07b
	After 10 cycles of aging with freezing^a *Nakon 10 ciklusa starenja sa smrzavanjem*^{a}						
Conventional *Konvencionalno*	0.21	0.72	243	238	0.8	99	-
Conv/Na$_2$SiO$_3$	0.19	0.50	258	160	1.1	92	-
CO$_2$	0.29	0.92	387	348	1.5	86	-
Co$_2$/Na$_2$SiO$_3$	0.23	0.76	342	317	0.4	82	-
	After 10 cycles of aging without freezing *Nakon 10 ciklusa starenja bez smrzavanja*						
Conventional *Konvencionalno*	0.17	0.58	180	236	-	-	-
Conv/Na$_2$SiO$_3$	0.12	0.39	114	257	-	-	-
CO$_2$	0.26	0.90	362	306	-	-	-
CO$_2$/Na$_2$SiO$_3$	0.14	0.47	215	254	-	-	-

[a] Average specific gravity was 0.48 for conventional boards and 0.49 for CO$_2$-injected boards before aging and 0.50 and 0.53 after aging, respectively.

[a] *Prosječna specifična težina je prije starenja za konvencionalne ploče iznosila 0.48 a 0.49 za CO$_2$ injektirane ploče, dok su te vrijednosti nakon starenja iznosile 0.50 i 0.53 g cm^{-3}.*

CONCLUDING REMARKS

Excelsior produced stronger boards than did splinters. The CO_2-injected boards had consistently higher bending and shear strength mean values after 28 days of curing than those of conventionally pressed boards. However, statistical analysis did not identify consistent significant inital strength differences resulting from either pressing technique or the addition of Na_2SiO_3. Strength properties were severely affected by the 10-cycle soaking, freezing, thawing, and drying test. Modulus of elasticity and MOR retention after aging was, in most cases, below 50% and 75%, respectively, for both the excelsior and splinter boards. No unrecoverable thickness swelling appeared during aging, nor was thickness swelling or water absorption of the reconditioned boards affected. The data indicate that freezing has no effect on aging.

LITERATURE CITED

1. American Society for Testing and Materials. 1989. Standard methods of evaluating the properties of wood-base fiber and particle panel materials. ASTM D 1037-87. Annual Book of ASTM Standards, 04.09 Wood, ASTM, Philadelphia, PA. pp. 226-272.
2. Fisher, V.F., Wienhaus, O., Ryssel, M., Olbrecht, J.F. 1974. Water soluble carbohydrates in wood and their influence on the manufacture of wood-wool light building slabs. Holztechnologie (1):12-19.
3. Gnanaharan, R. and Dhamodaran, T.K. 1985. Suitability of some tropical hardwoods for cement-bonded wood-wool board manufacture. Holzforschung 39:337-340.
4. Gram, H.-E. 1983. Durability of natural fibers in concrete. Research report, Swedish Cement and Concrete Research Institute. Stockholm. 255p.
5. Lee, A.W.C. 1984. Effect of cement/wood ratio on bending properties of cement-bonded southern pine excelsior board. Wood and Fiber Science 17(3):361-364.
6. __, 1984. Physical and mechanical properties of cement-bonded southern pine excelsior board. Forest Products Journal 34(4):30- 34.
7. __, 1984. Bending and thermal insulation properties of cement-bonded cypress excelsior board. Forest Products Journal 35(11/12):57-58.
8. __, 1990. The latest development in the cement-bonded wood excelsior (wood-wool) board industry. Proceedings, Inorganic Bonded Wood and Fiber Composite Materials, A.A. Moslemi, ed. Forest Products Research Society, Madison, WI.
9. __, and Hong, Z. 1986. Compressive strength of cylindrical samples as indicator of wood-cement compatibility. Forest Products Journal 36(11/12):87-90.
10. __, and Hse, C.Y. 1993. Evaluation of cement-excelsior boards made from yellow-poplar and sweetgum. Forest Products Journal 43(4):50-52.
11. __, and Short, P.H. 1989. Pretreating hardwood for cement- bonded excelsior board. Forest Products Journal 39(10):68-70.
12. Marra, A. 1972. Rigid composite products and process for the preparation thereof. U.S. patent 3,671,377. June 20.
13. Moslemi, A.A., Souza, M., and Geimer, R. 1994. Accelerated aging of cement-bonded particleboard. Proceedings, Inorganic-bonded wood and fiber composite material. Forest Products Society, Madison, WI.
14. Pablo, A. and Geimer, R. 1994. Accelerated pressing of low- density cement-bonded board. Proceedings, Inorganic-bonded wood and fiber composite material. Forest Products Society, Madison, WI.
15. Shigekura, Y. 1988. Wood fiberboards bonded with inorganic binders in Japan. Proceedings, Fiber and particleboards bonded with inorganic binders. A.A. Moslemi, ed. Forest Products Research Society, Madison, WI.
16. Simatupang, M.H. and Geimer, R.L. 1990. Inorganic binder for wood composites: Feasibility and limitations. Proceedings, Wood adhesives symposium, Madison, WI.
17. Soroushain, P., Shah, Z. and Wo, J.-P. 1992:, Durability characteristics of wastepaper fiber-cement composites. Proceedings, Inorganic-bonded wood and fiber composite material. Forest Products Society, Madison, WI.
18. Souza, M.R. 1992. Effect of carbon dioxide gas in manufacturing cement-bonded particleboard. Master thesis. University of Idaho, Moscow, ID.
19. Souza, M.R., Geimer, R.L., and Moslemi A.A. Degradation of conventional and CO_2-injected cement-bonded particleboard by exposure to termites and fungi. Journal of Tropical Forest Products, Malaysia. In preparation.