Effect of hygroscopic treatments and load applications on engineering properties of flakeboards

M.C. Yeh
R.C. Tang
C.Y. Hse

Abstract

The study of mechanical properties of hardwood structural flakeboards (white oak, red oak, and sweetgum) as affected by hygroscopic treatments and load applications, individually or collectively, is reported. The shear moduli and moduli of elasticity determined by stress waves (E_{sw}) are drastically reduced by cyclic conditions of 65/95/65 percent relative humidity (RH). These reductions were quite large after the first cycle. Only 51 percent and 49 percent of the original bending and internal bond (IB) properties were retained when the RH was increased from 65 to 95 percent, respectively. The engineering performance of sweetgum and red oak specimens was better than those of white oaks, and moderate improvement resulted in all three species groups when resin content was increased from 5 to 7 percent. No significant difference in bending modulus of elasticity (MOE) and modulus of rupture (MOR) was observed between the groups subjected to the long-term load applications and those not subjected to long-term loads under constant RH conditions of 65 and 95 percent. Reduction of the residual bending properties, MOR and MOE, in the specimens subjected to long-term loadings under fast cycles of 65/95/65 percent RH was the same as those loaded under constant 95 percent RH, but greater than those loaded under the identical RH cycles at a slowly changing rate. Improved engineering performance of the boards under severe environmental conditions was achieved by increasing the resin content. The residual bending properties of the boards were further reduced when the long-term loading level was increased. The hygroscopic treatments imposed a greater reduction effect on the residual mechanical properties of the boards than did the load applications. However, bending properties were further reduced when cyclic RH treatments were applied during the load application.

Wood composite panel products are known to be hygrothermal-viscoelastic materials. Therefore, moisture, temperature, load, and time factors should be considered collectively and dependently when assessing the serviceability or durability of these products upon exposure to changing environments. The stress-strain relationship of wood composite panels can be altered by imposing different levels of hygroscopic treatments when they are used in the shear-web of box and I-beams or in roofing and flooring applications. Furthermore, the load-carrying capacity of wood composite panels will be changed substantially when they are subjected to changing relative humidity (RH). However, information concerning the combined effect of moisture, temperature, load, and time on the bending properties, shear, and internal bonding of wood composite panels is very limited.

Accelerated-aging tests have commonly been used to quickly determine or predict the physical and mechanical performance of wood composite panels that are directly or indirectly related to the material durability (3,5,8,10,13,16,18,27,33). Attempts to correlate the results from natural weathering tests to those

The authors are, respectively, former Graduate Research Assistant, School of Forestry, Auburn Univ., now Associate Professor, Dept. of Wood Science and Technology, National Pingtung Inst. of Agri., Pingtung, Taiwan, ROC; Professor, School of Forestry and Alabama Agri. Expt. Sta., Auburn Univ., AL 36849; and Principal Wood Scientist, USDA Forest Service, Southern Forest Expt. Sta, Pineville, LA 71360. The investigation reported in this paper was supported by the USDA Competitive Grants Program and the Alabama Agri. Expt. Sta. in cooperation with the USDA Forest Serv., Southern Forest Expt. Sta. and is published as AAES Journal No. 9-902723P. This paper was received for publication in October 1990.

Forest Prod. J. 41(10):44-50.

TABLE 1. – *Description of RH treatments and testing conditions.*

Type of test	Load application	Hygroscopic treatment
IB	None	65 and 95 percent RH at 75°F
Plate shear	None	65/95/65/95/65 percent RH at 75°F
E_{SW}	None	65/95/65/95/65 percent RH at 75°F
Bending I	None	65 and 95 percent RH at 75°F
Bending II[a]-C1	Creep-relaxation	Constant 65 percent RH
Bending II-C2	Creep-relaxation	Constant 95 percent RH
Bending II-C3	Creep-relaxation	Slow cycle of 65 to 95 percent RH
Bending II-C4	Creep-relaxation	Fast cycle of 65 to 95 percent RH
Bending II-C5	Creep-relaxation	Constant 65 percent RH

[a] Groups C1 to C4 were loaded at one-fourth of MOR level and group C5 was loaded at one-half of MOR level.

obtained from accelerated-aging methods in wood composite panels have been reported (6,7,22). Furthermore, the dimensional stability of wood composite panels under accelerated/controlled and natural weathering exposure have been extensively studied during the past two decades (9,17,21,31,32,34,35).

The mechanical properties of wood composite panel products are known to be highly influenced by their moisture content (MC) and the RH of their environment (4,11,14,19,20,23). In reviewing the literature related to the residual strength and stiffness of wood-based panel products subjected to cyclic RH treatments, McNatt (24) concluded that 1) properties of urea-formaldehyde (UF) particleboards are more affected by cyclic exposure than those of phenol-formaldehyde (PF) boards; 2) board properties will be affected more severely by cyclic exposure at higher temperature; and 3) little difference exists in property retention for 5, 12, and 50 cycles or 2-week and 2-month exposures per RH cycle in PF boards.

Alexopoulos (1) reported that the bending properties of PF- or PF/methylolated kraft lignin (MKL) waferboards were not affected after being loaded at different constant stress levels for a period of 2 months at constant 65 percent RH in a creep test. However, Bryan and Schniewind (4) tested the bending strength of UF particleboards subjected to 0, 1, 2, and 3 cycles of humidity exposures (20% to 6% EMC) but without load application, and indicated that the bending strength of boards dropped as the number of humidity cycles increased. Lee and Biblis (19) reported that the retention of both the bending modulus of elasticity (MOE) and plate shear modulus (G) of southern yellow pine particleboard, after a cycle of 65/30/65 percent RH, but without load application, was 95 percent. Only 80 percent of MOE and 84 percent of G were retained by a further treatment of 65/95/65 percent RH. Srpcic and Moody (30) have reported, however, that residual strength of 12-foot long glulam beams fabricated with phenol-resorcinol adhesive did not appear to be affected by a 1-year load application under constant high RH (90% to 95%) or normal climate even under loads chosen to cause bending stress equal to working stress for laminated elements.

The bending strength of thick structural flakeboards subjected to a 90-day loading was evaluated by McNatt and Hunt (25). Bending strength and stiffness of flakeboard under 65 percent RH were 74 to 99 percent of those for control specimens not subjected to loading. Furthermore, groups subjected to a 2-day RH cycle exposure, ranging from 25 to 85 percent, did not consistently show additional reductions as compared to those under constant 65 percent RH. The time-dependent mechanical properties of flakeboards made with a mixture of southern species were investigated by Price (26). Flakeboard's internal bond (IB), modulus of rupture (MOR), and MOE did not change when the specimens received RH treatments of 4-day, 8-day, or 16-day cycles (50% to 85%) for a 32-day loading period. All of these findings suggested that the effect of moisture on the time-dependent mechanical properties of flakeboard subjected to external forces may be less critical if the RH treatment is no higher than 85 percent RH. However, wood and wood composite panels are highly hygroscopic and anisotropically viscoelastic. It is expected, therefore, that results would be substantially different if RH levels higher than 85 percent are utilized. To verify this suggestion, specimens in the current study were exposed to different levels of constant or cyclic RH conditions during the loading, and tested to determine their residual engineering properties. Furthermore, variables such as species and the levels of resin content were also considered.

Materials and methods

Three southern hardwood species, white oak (*Quercus alba*), red oak (*Quercus falcata*), and sweetgum (*Liquidamba styracifiua*) were chosen for this study. In order to minimize the property variations caused by diversity of raw materials, selected trees grown in the same areas were cut into logs for the preparation of testing materials. These logs were kept in the green condition and later crosscut into disks for flaking. The flakes were prepared by using a laboratory disk flaker. The experimental design of panel fabrication was chosen as follows:

1. Flake dimensions: approximately 3 inches long by 0.02 inch thick and random width
2. Flake MC: 3 percent
3. Flake orientation: random
4. Resin type and content: liquid phenol formaldehyde, 5 and 7 percent based on ovendry weight of flakes
5. Press temperature: 350°F
6. Panel dimensions: 42 inches by 40 inches by 0.5 inch
7. Panel density: oaks = 42 to 45 pcf; sweetgum = 40 to 42 pcf
8. Total press time: 6 minutes
9. Pressure and press cycle: 512 psi (2 min.), 375 psi (2 min.), 179 psi (1 min.), 60 psi (1 min.), and 0 psi (release).

For each species (SP) and resin content (RC) combination, 12 randomly oriented flakeboards were made for the evaluation of the effect of RH and load applications on the modulus of elasticity determined by stress wave (E_{SW}), static bending, IB, and plate shear proper-

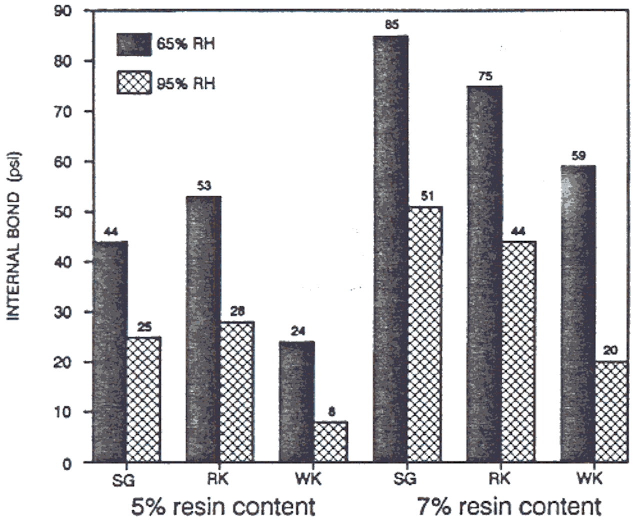

Figure 1. — Variation of internal bond as affected by relative humidity, resin content, and species.

ties as indicated in Table 1. IB and flatwise static bending MOR and MOE were evaluated according to ASTM D-1037 (2) using an Instron testing machine. Two groups of specimens were tested. One group was conditioned to equilibrium under 65 percent RH at 75°F while the other was conditioned and equilibrated under 95 percent RH and 75°F. There were 168 2- by 2-inch IB specimens (14 replications (R) by 3 SP by 2 RC by 2 RH) and 144 3- by 20-inch bending specimens (12 R by 3 SP by 2 RC by 2 RH).

Seventy-two (12 R by 3 SP by 2 RC) plate shear specimens were conditioned under cyclic RH of 65/95/65/95/65 percent at 75°F. The period of each RH level was approximately 4 weeks and at the end of each RH period all the specimens were tested according to ASTM D-3044 (2) by using an Instron testing machine. The dimension of the specimens was approximately 16 inches square. Exact dimensions of each specimen were measured for each plate shear test. All the specimens were nondestructively tested in plate shearing under a maximum load of 20 pounds. This arrangement guaranteed that the specimens were loaded far below their proportional and elastic limits. After the test, specimens were returned to the environmental room for a 4-week relaxation period and conditioned at the next RH level. The shear modulus was calculated as:

$$G = 3\mu^2 p / 2h^3 s \qquad [1]$$

where:

G = shear modulus (psi)
p = load applied at each corner (lb.)
h = thickness of the plate (in.)
s = deflection relative to the center (in.)
μ = distance from the center of the plate to the point where the deflections are measured (in.)

Seventy-two 3- by 20-inch specimens (12 R by 3 SP by 2 RC) were tested using a stress wave timer (Metriguard 239) to determine their E_{sw} as affected by the change of RH. The RH cycle was the same as that used in the plate shear test. The dimensions, as well as the weight, of each specimen were recorded after 4 weeks of conditioning, and afterward the E_{sw} was evaluated. The results were compared with the MOE determined from static bending. The equation used for the calculation of E_{sw} was:

$$E_{sw} = (d/t)^2 (w/v)/g \qquad [2]$$

where:

d = distance between two transducers (in.)
t = propagation time (sec.)
w = weight of specimen (lb.)
v = volume of specimen (in.^{3})
g = acceleration due to gravity (386 in./sec.^{2})

In determining the residual bending properties of flakeboards as affected by the coupling of load and humidity, 3- by 20-inch specimens were subjected to long-term concentrated load under either constant RH (65% or 95%) or cyclic RH (65% to 95%) (Table 1). Two rates of RH changes (65% to 95%) were chosen in this study, a slow cycle with a 33-day duration at each RH level and a fast cycle with a 2-day duration at each RH level. The total loading history included 100 days or longer for creep and 30 days for a relaxation period. The loading level applied was based on one-fourth of the average MOR of the weakest flakeboards conditioned under constant 65 and 95 percent RH. In this study, the white oak group was the weakest. An additional group was tested at the higher load level of one-half of the average MOR to observe the effect of load level during creep on the residual bending properties. Each group consisted of six replications, which were destructively tested in static bending after being subjected to creep and relaxation. The details for the creep tests and results were given in the authors' previous work (36,37).

Results and discussions

Internal bond

The results of IB evaluated at constant 65 percent and 95 percent RH at 75°F are plotted in Figure 1. Regardless of the RC level and the type of hygroscopic treatment, flakeboards made of red oak and sweetgum flakes performed more or less equally in IB strength, but white oak boards showed considerably lower values. Such a discrepancy may be due to the poor quality of white oak flakes. Also the cell walls of latewood vessels in white oak are thinner than those in the red oaks. Furthermore, white oak contains a very large volume of rays and broad rays, which may affect the IB as discussed in previous studies (15,33). IBs of all three species groups measured at both 65 and 95 percent RH were substantially increased as expected when resin content level was increased from 5 to 7 percent. The effect of density on IB was not measured, but it was discovered that IB decreased considerably after the specimens were conditioned and equilibrated at 95 percent RH and 75°F. This suggests that both the release of the pressing-induced compressive strain and boards, due to the change of RH from 65 to 95 percent, showed considerable influence on the plate shear moduli regardless of SP and RC. However, boards fabricated with 7 percent RC had lower reduction of plate shear moduli than those bonded with 5 percent RC.

The average reduction of plate shear moduli of all six groups was 46.5 percent when the specimens were conditioned and equilibrated from 65 to 95 percent RH. Further, the change of the RH level back to 65 percent resulted in a slight recovery of the plate shear moduli, but the values are still considerably lower than those evaluated at the end of the first 65 percent RH. Results showed that at least 34.8 percent of the plate shear moduli (average of six groups) was permanently lost due to the first cyclic treatment of 65/95/65 percent RH. An additional RH cycle showed only a slight further decrease in the plate shear moduli. This information should be useful to wood engineers for the development of structural applications of flakeboards in wood composite structural systems, and the evaluation of engineering reliability when shear is considered to be critical to the system's long-term performance.

Nondestructive MOE

The E_{sw} determined from stress wave testing is plotted in Figure 3. The average values of E_{sw} for the red oak and sweetgum boards are approximately equal to each other but higher than those of white oak. The increase of RC from 5 to 7 percent substantially increased the E_{sw} in white oak boards, but such treatment had less effect in the groups of red oak and sweetgum. The values of MC recorded at the second and third 65 percent RH conditions were slightly higher than those observed for the first one, perhaps due to sorption hysteresis. Regardless of SP and RC, the E_{sw} decreased approximately 33 percent as the RH was increased from 65 to 95 percent. A slight recovery of E_{sw} was observed after the RH condition was returned to 65 percent RH. However, after an additional cycle, only a slight further reduction of E_{sw} was observed.

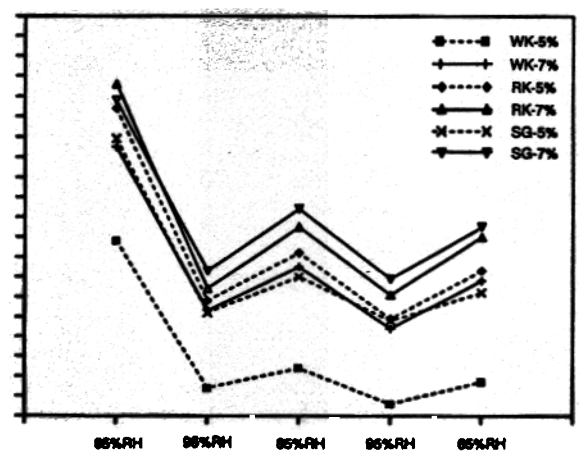

Figure 2. — Variation of plate shear modulus as affected by cyclic conditions of RH.

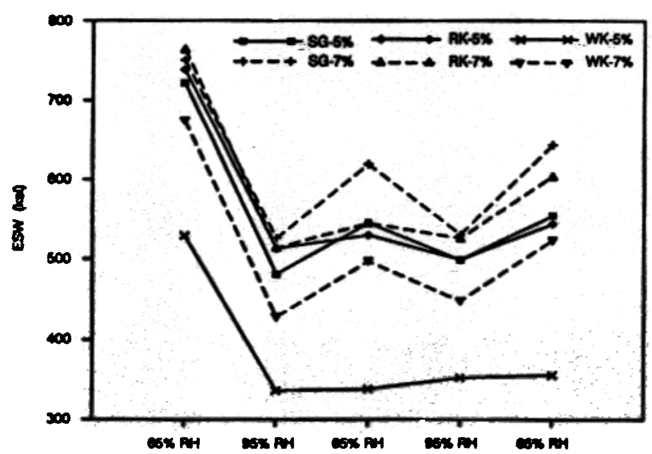

Figure 3. — Variation of E_{sw} as affected by cyclic conditions of relative humidity.

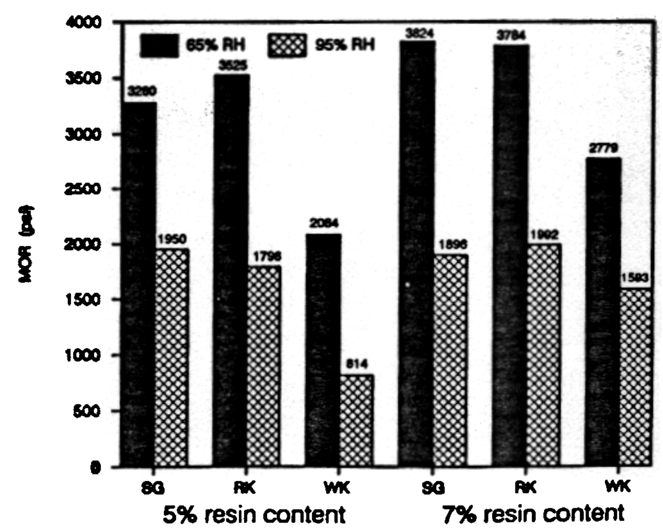

Figure 4. — Variation of modulus of rupture as affected by relative humidity, resin content, and species.

Bending properties prior to long-term loading

The results of flatwise bending properties, MOR and MOE, are plotted in Figures 4 and 5, respectively. It is evident from Figure 4 that, regardless of the level of RC and the type of hygroscopic treatment, red oak and sweetgum boards had approximately equal MOR values, while white oak boards exhibited considerably poorer performance. A similar trend was discovered in MOE (Fig. 5). The increase of RC did not improve the MOR greatly, except in the white oak group. Similar trends appeared in the MOE. As expected, the increase of RH from 65 to 95 percent substantially reduced the MOR and MOE in all specimens, and unexpectedly, the average reduction (6 groups) in both properties is identical at 48 percent. Apparently the reduction of these bending properties, due to the increase of RH, is not strongly affected by the level of RC except in the white oak specimens. The percentages of reduction of these properties for the white oak, red oak, and sweetgum specimens ranged from 41 to 61 percent, 47 to 51 percent, and 40 to 50 percent, respectively. It was discovered, however, that the static bending MOE, regardless of SP and RC, was substantially lower than in boards evaluated from nondestructive tests (stress wave timer), as reported by other investigations (12,26,29). This may be due to the equation used in the calculation of E_{sw}, which was originally designed for isotropic materials. Ross and Pellerin (28) also indicated that stress wave speed was less sensitive to the bonding characteristics of wood composite panels, which may affect static bending MOE. Furthermore, the reduction of E_{sw} due to RH treatment was found to be much less than in these tests than in static bending tests (33% vs. 48%).

Bending properties after long-term loading

The residual bending properties, including MOR and MOE, were evaluated in all five groups (Table 1) that were subjected to the long-term loading, i.e., creep and relaxation. The effect of testing environments on the residual MOR and MOE of the creep-tested specimens were studied by comparing each group (C2 to C5) with the C1 group, which was tested under constant 65 percent RH. The percent reduction of MOR and MOE for all C2 to C5 groups is illustrated in Figures 6 and 7.

Comparing the bending results of the C1 group (load applied and relaxed under constant 65% RH) to those which received no creep and no relaxation (i.e., flatwise bending only) showed that the bending MOR and MOE of flakeboards were not affected by the creep and relaxation under constant 65 percent RH. For the specimens that received creep and relaxation under constant 95 percent RH (C2 group), the average percent reduction of bending MOR of white oak, sweetgum, and red oak groups was found to be approximately 53 percent, 44

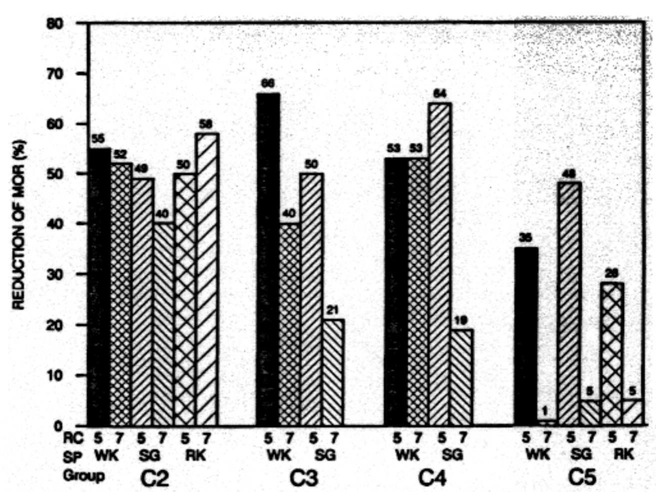

Figure 6. — Reduction of modulus of rupture of flakeboards subjected to creep and relaxation (difference between C1 group and groups C2 to C5).

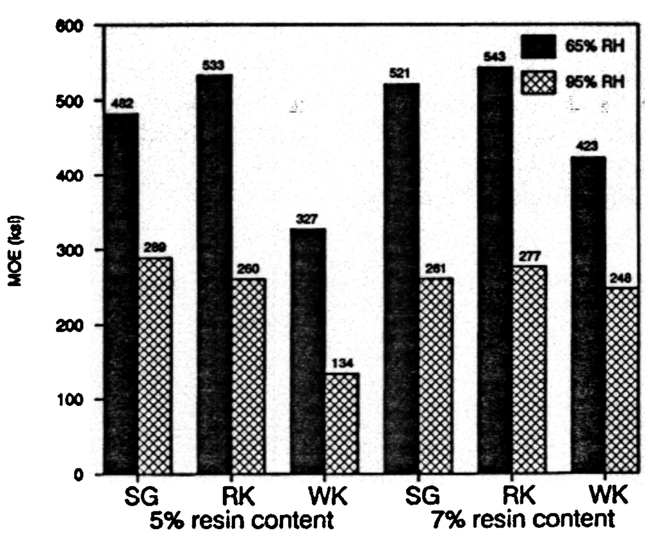

Figure 5. — Variation of modulus of elasticity as affected by relative humidity, resin content, and species.

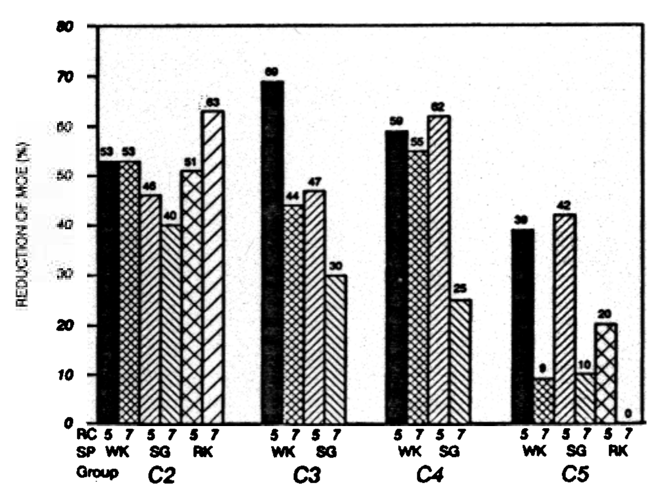

Figure 7. — Reduction of modulus of elasitiсy of flakeboards subjected to creep and relaxation (difference between C1 group and groups C2 to C5).

percent, and 54 percent, respectively, in comparison to the C1 group. The magnitude of MOR reduction seems approximately equal to that obtained from the flatwise bending tests conducted at 65 and 95 percent RH. Furthermore, the average percent reduction of MOE in the C2 group was almost identical to that of MOR. This finding indicates that the creep tests of flakeboards, if conducted under constant 65 and 95 percent RH, may provide only partial information on the load-carrying properties and the board durability as affected by the change of environments. However, the effect of the increase of RC on the improvement of residual bending properties was not observed in the C2 group.

For specimens with 5 percent RC in the C3 group (slow cyclic RH of 65% to 95% for creep, constant 65% for relaxation period), the residual MOR for white oak specimens was 66 percent lower than the C1 group; and for sweetgum specimens, it was 50 percent lower. An improvement on the residual MOR can be made by increasing the RC. There were 40 percent and 21 percent reductions in the residual MOR for the 7 percent RC white oak and sweetgum specimens in the C3 groups, respectively, as compared with those of the C1 groups. Similar reductions in MOE are shown for each RC and SP, as indicated in Figure 7. In general, the boards fabricated with sweetgum flakes had higher residual MOR and MOE and less reduction in residual properties than those fabricated with the white oak flakes.

For the flakeboards subjected to the fast cyclic RH of 65 to 95 percent for creep and constant 65 percent RH for relaxation period (C4 group), a beneficial effect of RC on the bending MOR and MOE was found only in the sweetgum specimens. The average reduction in the MOR and MOE was 53 and 57 percent, respectively, for the white oak specimens as compared with those of the C1 groups. There were 64 percent and 62 percent reductions in MOR and MOE, respectively, for the 5 percent RC sweetgum specimens, and 19 and 25 percent for the 7 percent RC groups. No substantial differences in the effect of rate of RH change on the residual MOR and MOE between the groups of C3 and C4 was observed. It was noted that the residual MOR and MOE of white oak specimens in the C2 group were about the same as in the C4 group. However, the reduction of MOR and MOE in the C2 groups might be mainly due to the gains of MC of the boards under constant 95 percent RH, while in the C4 groups it might be mainly due to the fatigue-effect induced by the rapidly changing RH conditions of 65 to 95 percent.

A moderate influence of long-term loading level on the residual bending properties was observed in the C5 group that was subjected to a load twice that applied to groups C1 to C4. As shown in Figures 6 and 7, the residual MOR of white oak, sweetgum, and red oak boards fabricated with 5 percent RC in the C5 group is 35, 48, and 28 percent, respectively, lower than those of the C1 group, while the values for MOE are 39, 42, and 20 percent, respectively. Little reduction in both MOR (1%, 5%, and 5%) and MOE (9%, 10%, and 0%) was observed in specimens fabricated with 7 percent RC in the C5 group. These discoveries suggest that for flakeboards fabricated with 5 percent PF resin content and subjected to long-term loadings under constant RH, residual mechanical properties will be decreased substantially when the load applied is at the level of one-half of the static MOR. However, such strength and stiffness losses can be significantly reduced if RC is increased.

As shown in Figures 6 and 7, the rate of degradation in bending properties as affected by the methods of RH treatment can be estimated. It appears that the C4 group (fast cyclic RH of 65% to 95% for creep, constant 65% RH for relaxation period) and the C2 group (creep under constant 95% RH) had the highest rates of degradation in bending properties, followed in order by groups of C3 (slow cyclic RH of 65% to 95% for creep, constant 65% RH for relaxation period), C5 (creep under constant 65% RH but at the load level of one-half of the static MOR), and C1 (creep under constant 65% RH).

Summary

1. The boards conditioned under constant 95 percent RH may lose, respectively, 49 percent, 48 percent, and 51 percent of their MOR, MOE, and IB measured at the constant 65 percent RH condition.

2. The plate shear modulus and E_{sw} were substantially reduced after the boards were treated with a first cycle of 65/95/65 percent RH; further reductions were not observed after the second RH cycle. The average reductions of plate shear modulus and E_{sw} evaluated at the end of a second RH cycle were 39 and 23 percent, respectively.

3. Boards fabricated with red oak and sweetgum flakes performed much better in mechanical properties than the white oak groups, under both constant 65 and 95 percent RH conditions. For white oak boards, the improvement of mechanical properties can be achieved by increasing the RC.

4. Substantial differences in bending MOE and MOR were not observed between the boards with and without loading histories, when exposed to either constant 65 or 95 percent RH conditions. Furthermore, improvement of residual mechanical properties may not be achieved even if RC is increased from 5 to 7 percent.

5. After being subjected to load application and relaxation, higher reductions of the residual mechanical properties will occur if the boards are treated with either a fast cycle of 65 to 95 percent RH condition or a constant 95 percent RH condition. However, boards treated with a slow cycle of 65 to 95 percent RH will show moderate reduction.

6. The effect of loading levels on the reduction of residual mechanical properties in flakeboards is less pronounced than the hygroscopic treatments, and such influence can be easily minimized by increasing the RC. However, higher reductions can result from the combined hygroscopic treatment and loading history.

Information reported in this study may be useful in improving the engineering design of wood composite materials and their structural applications. However, for further understanding of the durability and serviceability of wood composite panel products, additional studies on the performance of the composite products bonded with different adhesives and treated under service conditions are highly recommended.

Literature cited

1. Alexopoulos, J. 1983. Performance of waferboards: resistance to decay and effect of load on creep properties. Eastern Lab., Forintek Canada Corp., Canadian Forest Serv. Rept. No. 9.
2. American Society for Testing and Materials. 1988. Annual book of ASTM Standards. Vol. 04.09. Wood.
3. Back, E. and E. Sandstrom. 1982. Critical aspects on accelerated methods for predicting weathering resistance of wood based panels. Holz als Roh-und Werkstoff 40:61-75.
4. Bryan, E.L. and A.P. Schniewind. 1965. Strength and rheological properties of particleboard as affected by moisture content and sorption. Forest Prod. J. 15(4):143-148.
5. Chow, P. and J.J. Janowiak. 1984. Durability evaluation on hardwood veneered flakeboard composites. Proc. of a workshop on the durability of structural panels. Gen. Tech. Rept. SO-53. USDA Forest Serv., So. Forest Expt. Sta. pp. 119-126.
6. Countryman, D.R. 1979. Investigation of composite panels under exposure conditions. Proc. 13th WSU Inter. Part. Symp., Pullman, Wash. T. M. Maloney, ed. No. 13. pp. 3-23.
7. Deppe, H. 1981. Long-term comparative tests between natural and accelerated weathering exposure of coated and uncoated wood-based material. Proc. 15th WSU Inter. Part. Symp., Pullman, Wash. T.M. Maloney, ed. No. 15. pp. 79-100.
8. Dinwoodie, J.M. 1981. Characterizing the performance of chipboard in the United Kingdom. Proc. 15th WSU Inter. Part. Symp., Pullman, Wash. T.M. Maloney, ed. No. 15. pp. 59-78.
9. Geimer, R.L. 1982. Dimensional stability of flakeboards as affected by board specific gravity and flake alignment. Forest Prod. J. 32(8):44-52.
10. ________, W.F. Lehmann, and J.D. McNatt. 1974. Engineering properties of structural particleboards from forest residues. Proc. 8th WSU Inter. Part. Symp., Pullman, Wash. T.M. Maloney, ed. No. 8. pp. 119-143.
11. Generalla, N.C., E.J. Biblis, and H.F. Carino. 1989. Effect of two resin levels on the properties of commercial southern OSB. Forest Prod. J. 39(6):64-68.
12. Gerhards, C.C. and L.H. Floeter. 1982. Nondestructive evaluation of mechanical properties of a structural flakeboard made from forest residues. Res. Pap. FPL 414. USDA Forest Serv., Forest Prod. Lab. pp. 16.
13. Gillespie, R.H. 1984. Accelerated aging of wood-based panel products: A review and commentary. Proc. of a workshop on the durability of structural panels. Gen. Tech. Rept. SO-53. USDA Forest Serv., So. Forest Expt. Sta. pp. 11-26.
14. Halligan, A.F. and A.P. Schniewind. 1974. Prediction of particleboard mechanical properties at various moisture contents. Wood Sci. and Techn. 8:68-78.
15. Hse, C.Y. and Mon-lin Kuo. 1988. Influence of extractives on wood gluing and finishing — a review. Forest Prod. J. 38(1):52-56.
16. Kelly, M.W. and E.W. Price. 1984. Durability of structural flakeboard from southern hardwoods species. Proc. of a workshop on the durability of structural panels. Gen. Tech. Rept. SO-53. USDA Forest Serv., So. Forest Expt. Sta. pp. 85-96.
17. ________. 1985. Effect of species and panel density on durability of structural flakeboard. Forest Prod. J. 35(2):39-44.
18. Knudson, R.M. and G.N. Rosenberg. 1984. Predicting ASTM D-1037 6-cycle accelerated aging of waferboard in 27 hours. Proc. of a workshop on the durability of structural panels. Gen. Tech. Rept. SO-53. USDA Forest Serv., So. Forest Expt. Sta. pp. 77-84.
19. Lee, A.W.C. and E.J. Biblis. 1976. Effect of high and low relative humidity cycle on properties of southern pine particleboards. Forest Prod. J. 26(6):32-35.
20. ________ and C.B. Stephens. 1988. Comparative shear strength of seven types of wood composite panels at high and medium relative humidity conditions. Forest Prod. J. 38(3):49-52.
21. Lehmann, W.F. 1972. Moisture-stability relationships in wood-base composition boards. Forest Prod. J. 22(7):53-59.
22. ________. 1977. Durability of composite board products. Proc. 11th WSU Inter. Part. Symp. Pullman, Wash. T.M. Maloney, ed. No.11. pp. 351-368.
23. ________. 1978. Cyclic moisture conditions and their effects on strength and stability of structural flakeboard. Forest Prod. J. 28(6):23-31.
24. McNatt, J.D. 1984. How cyclic humidity affects static bending and dimensional properties of some wood-base panel products. Proc. of a workshop on the durability of structural panels. Gen. Tech. Rept. SO-53. USDA Forest Serv., So. Forest Expt. Sta. pp. 67-76.
25. ________ and M.O. Hunt. 1982. Creep of thick structural flakeboards in constant and cyclic humidity. Forest Prod. J. 32(5):49-82.
26. Price, E.W. 1985. Creep behavior of flakeboards made with a mixture of southern species. Wood and Fiber Sci. 17(1):58-74.
27. River, B.H., R.H. Gillespie, and A.J. Baker. 1981. Accelerated aging of phenolic-bonded hardboards and flakeboards. Res. Pap. FPL 393. USDA Forest Serv., Forest Prod. Lab., Madison, Wis. 28 pp.
28. Ross, R.J. and R.F. Pellerin. 1985. NDE of wood-based composites with longitudinal stress waves. Forest Prod. J. 38(5):39-45.
29. Smulski, S.J. and G. Ifju. 1987. Flexural behavior of glass fiber reinforced hardboard. Wood and Fiber Sci. 19(3):313-327.
30. Srpcic, J. and R.C. Moody. 1988. Creep of small glulam beams under changing relative humidity conditions. Proc. of the 1988 Inter. Conf. on Timber Engineering. Vol. 1. Forest Prod. Res. Soc. pp. 523-530.
31. Suchsland, O. 1972. Linear hygroscopic expansion of selected commercial particleboards. Forest Prod. J. 22(11): 28-32.
32. ________. 1973. Hygroscopic thickness swelling and related properties of selected commercial particleboards. Forest Prod. J. 23(7):26-30.
33. Tang, R.C., C.Y. Hse, and Z.J. Zhou. 1984. Effect of flake-cutting patterns and resin contents on dimensional changes of flakeboard under cyclic hygroscopic treatment. Proc. of a workshop on the durability of structural panels. Gen. Tech. Rept. SO-53. USDA Forest Serv., So. Forest Expt. Sta. pp. 43-52.
34. Vital, B.R., J.B. Wilson, and P.H. Kanarek. 1980. Parameters affecting dimensional stability of flakeboard and particleboard. Forest Prod. J. 30(12):23-29.
35. ________ and J.B. Wilson 1980. Water adsorption of particleboard and flakeboard. Wood and Fiber 12(4):264-271.
36. Yeh, M.C., R.C. Tang, C.Y. Hse, and T.Y. Chen. 1988. Effect of relative humidity on the creep behavior of flakeboards I: Constant stress level. Proc. of the 1988 Inter. Conf. on Timber Engineering. Seattle, Wash. Vol(1):538-546.
37. ________, ________, ________, and ________. 1990. Flexural creep of structural flakeboards under cyclic humidity. Forest Prod. J. 40(10):51-57.