BENDING CREEP BEHAVIOR OF MEDIUM DENSITY FIBERBOARD AND PARTICLEBOARD DURING CYCLIC MOISTURE CHANGES

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ABSTRACT

Bending creep behavior of four types of medium density fiberboard (MDF) and two types of particleboard during cyclic moisture changes was investigated in this study. Tests were made at 20°C with three cyclic relative humidity changes between 65% and 95% under the 10% short-term breaking stress. The effect of moisture content (MC) change on initial compliance and mechano-sorptive (MS) compliance was examined. The results indicated that relative deflection and total compliance of the samples increased over the history of cyclic moisture changes, and their magnitudes varied with board types. Melamine- and phenol-resin bonded boards had smaller relative deflection and total compliance than did urea-resin bonded boards. Both relative deflection and total compliance increased in adsorption and showed reduction in desorption. Initial compliance followed a linear relation with MC and had some influence on total compliance behavior under moisture cycles. MS compliance increased in adsorption while showing slight reduction or increase in desorption. The first adsorption led to the largest MS compliance, followed by subsequent adsorption. With increasing MC change, MS compliance increased linearly in the first adsorption, while it increased nonlinearly in the subsequent adsorption. The MS compliance coefficient K_M was product-dependent. Resin type appeared to be an important factor influencing the variations in K_M. In this study, urea-resin bonded boards had a greater K_M compared to melamine- and phenol-resin bonded boards.

Keywords: Mechano-sorptive effect, MDF, particleboard, cyclic moisture change, bending, resin type.

INTRODUCTION

Medium density fiberboard (MDF) and particleboard have been used widely for decades. In many situations where the boards are subjected to load for considerable lengths of time and variation in relative humidity (RH) of surrounding atmosphere, they show a notable deformation resulting from an interaction between applied stress and moisture content (MC) change (Armstrong and Grossman 1972; Halligan and Schniewind 1972). This deformation, known as mechano-sorptive (MS) ef-

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fect, has significant effects on the safety and serviceability of wood structures over their lifetime. This phenomenon is important not only for fundamental study but also for practical applications of wood composite panels.

Rheological equations to quantify the deformation of wood-based materials under combinations of mechanical stress and moisture change have been proposed (Leicester 1971; Ranta-Maunus 1975). The total deformation of wood composite panels under rapid MC change and short-term loading conditions contains mainly an initial deformation and an MS deformation. Total compliance can be expressed as:

$$D_T(t) = D_I(t) + D_M(t) \qquad (1)$$

where $D_T(t)$ = total compliance (MPa^{-1}), $D_I(t)$ = initial compliance (MPa^{-1}), $D_M(t)$ = MS compliance (MPa^{-1}), and t = time (hour). In order to compare experimental data from different sources, it is convenient to define relative deflection C_R as follows:

$$C_R = [\delta(t) - \delta_I(t)]/\delta_I(t) \qquad (2)$$

where $\delta_I(t)$ = initial deflection (mm), and $\delta(t)$ = deflection at time t (mm).

Moslemi (1964) studied creep deflection of hardboards as affected by MC. He found that the creep at high MC (16–17%) was apparently greater than at intermediate and low MCs (6–8% and 1–2%, respectively). Chow (1982) investigated creep deflection of veneered MDF at 20% stress level and 50, 64, 78, and 92% RH. The results indicated that the increase in RH from 50 to 64% had no significant effect on creep deflection, while the increase in RH from 64 to 78 or 92% had a significant effect on creep deflection. Dinwoodie et al. (1991) demonstrated that there was little increase in the effect of increasing RH on relative creep below 65% RH, but over the range of 65–90% RH, there was a very marked increase in relative creep at constant humidity for a range of boards including chipboard, waferboard, fiberboard, and plywood. Halligan and Schniewind (1972) studied the effect of moisture on physical and creep properties of laboratory-made particleboard. They found that relative creep under adsorption conditions varied between boards and was related to thickness swelling and MC increase during loading.

Armstrong and Grossman (1972) investigated MS creep behavior of particleboard and hardboard under 30% stress level during moisture cycling in the range 6 to 18% MC. They indicated that the largest increase in deflection occurred in the beams subjected to increasing MC during the first moisture change. In subsequent moisture changes, moisture desorption caused further appreciable increase in deflection, whereas adsorption caused successively smaller increases in deflection or even a slight decrease. Norimoto and Yamada (1966) and Bryan and Schniewind (1965) suggested that for particleboard, adsorption increased the deflection while desorption produced recovery. Gressel (1972a, b, c) conducted an extensive investigation of the effects of time, climate, loading on the bending properties of wood-based materials. The results showed that MS deflections under cyclic moisture conditions (25% to 95% RH) were about 2.5 to 4.5 times greater than creep deflections at a constant humidity of 65% RH. Haygreen et al. (1975) showed MS deflection of particleboard in a cyclic humidity environment (40% to 80% RH) to be 2 to 2.7 times greater than creep deflection at a constant 60% RH after 360 h under bending load. Pu et al. (1994) suggested that the flexural creep of oriented strandboard was very sensitive to high humidity (95% RH) and cyclic moisture conditions. There is little specific information, however, available on the relationship between MS compliance and MC change for commercial MDF and particleboard under cyclic moisture change conditions.

There seems to be a controversy over how resin type affects creep behavior. Halligan and Schniewind (1972) and Sekino and Suzuki (1984) demonstrated that urea-formaldehyde and phenol-formaldehyde bonded particleboard showed similar creep rate and relative creep at a particular elapsed time. However, Gressel (1972a, b, c) and Lyon and Barnes

(1978) found that there were differences in creep rate and relative creep between urea-formaldehyde and phenol-formaldehyde bonded particleboard. Dinwoodie et al. (1981) showed differences in the relative creep and creep modulus of urea-formaldehyde and melamine-formaldehyde boards. It appears that further work should be done to clarify the effect of resin type on bending creep behavior of boards under cyclic moisture change conditions.

The objectives of this study were: (1) to investigate the bending creep behavior of various types of commercial MDF and particleboard under cyclic moisture change conditions, (2) to examine the relationships of MC change to initial compliance and MS compliance, and (3) to evaluate the effect of resin type on creep behavior of the boards.

TABLE 1. *Properties of various boards used in the study.*

Board type[a]	Adhesive[b]	Thickness (mm)[c]	Specific gravity[d]	MOE (MPa)[e]	MOR (MPa)[e]
MDF					
MUH1	UF	12.1	0.59	3031	27.2
MUH2	UF	12.1	0.69	3641	32.7
MUS	UF	12.1	0.60	3869	37.4
MMH	MF	12.1	0.69	3640	32.7
Particleboard					
PBU	UF	12.0	0.68	2681	13.6
PBP	PF	12.0	0.71	3947	23.8

[a] MUH1 = urea-resin bonded MDF (with a specific gravity of 0.59) made of a hardwood; MUH2 = urea-resin bonded MDF (with a specific gravity of 0.69) made of a hardwood; MUS = urea-resin bonded mDF made of a softwood; MMH = melamine-resin bonded MDF made of a hardwood; PBU = urea-resin bonded particleboard made of mixed hardwoods; and PBP = phenol-resin bonded particleboard made of mixed hardwoods.

[b] UF: urea-formaldehyde; MF: melamine-formaldehyde; PF: phenol-formaldehyde.

[c] Thickness was measured at 20°C and 65% RH.

[d] Specific gravity was based on oven-dry weight and volume at 20°C and 65% RH.

[e] MOE and MOR were tested at 20°C and 65% RH.

MATERIALS AND METHODS

Specimen preparation

Four types of commercial MDF and two types of particleboard were obtained from manufacturers and used in this study. These included three urea-resin bonded MDFs (MUH1, MUH2, and MUS), one melamine-resin bonded MDF (MMH), and two particleboards (PBU and PBP) bonded with urea- and phenol-resin, respectively. The properties of test materials are summarized in Table 1. These boards were wrapped with plastic film during transport to protect against large MC changes. Before cutting, the panels were stored in a conditioning room maintained at 20°C and 65% RH. Fifteen specimens (320 mm × 30 mm × thickness) were cut from each type of board. Five specimens were prepared for testing modulus of elasticity (MOE) and rupture (MOR) in four-point bending with the span 300 mm. Four specimens were prepared for initial compliance test, and six specimens for creep test. All specimens were stored in a conditioning room maintained at 20°C and 65% RH prior to use.

Experimental setup and conditions

The MS creep test was performed in a chamber placed in the air-conditioned room at 20°C. The specimens for creep measurements were placed on a frame with the span 300 mm inside the chamber. Rounded supports were used, and radius of the rounded portion was greater than 1.5 times the thickness of the specimen. A load, corresponding to the 10% short-term breaking load, was applied on the specimen in the thickness direction to create four-point bending. The distance between two loading heads was 100 mm. In this study, the deflection at 1 min after load application was defined as the initial deflection. The deflection of the center of the specimen was measured by a dial gauge with an accuracy of 0.01 mm, which was attached to the testing frame. The dial gauge was in contact with the top of the specimen at the center. A load-free specimen for measuring thickness change due to moisture variation was also placed on the frame. The thickness change at the center of the specimen was continuously measured by another similar dial gauge. The weight change of the MC specimen was constantly monitored by a digital balance (accuracy up to 0.001 g), placed outside the conditioning chamber with an attached specimen hanger passing into the chamber.

After load application, saturated potassium sulfate solution was placed into the chamber, and the RH inside the chamber was changed from 65% to 95%. The air in the chamber was circulated by a small fan. A moisture adsorption was performed for 48 h. After adsorption, the potassium sulfate solution was removed from the chamber for moisture desorption, which also lasted 48 h. The above moisture change cycle (65%–95% RH) was then repeated two times. A total of three moisture change cycles were performed in one creep test. The test was replicated once for each type of board. After testing, all specimens were oven-dried, and their oven-dry weight was measured.

For each type of board, the weight and dimension of the four specimens for examining the MC effect on initial compliance were determined at 20°C and 65% RH. Their initial deflection under the same load as that in creep test was measured. Subsequently, the specimens were transferred to a conditioning chamber maintained at 20°C and 95% RH using saturated potassium sulfate solution. At measured time intervals, the specimens were removed from the conditioning chamber. Their weight, dimension, and initial deflection were measured immediately, and then the specimens were placed back into the conditioning chamber. The process was repeated until adsorption time reached 48 h. After adsorption, the saturated potassium sulfate solution was removed from the chamber and a desorption was then conducted. The testing was continued as in adsorption. The moisture cycle (adsorption-desorption) was repeated two times. A total of three cycles were conducted. The specimens were oven-dried after testing, and their oven-dry weight and dimension were measured.

Calculation and data analysis

A regression analysis on the initial compliance and MC data was used to examine the relationship between initial compliance and MC. In the creep tests, the deflection of the loaded specimen contained a thickness change due to MC variation, which was determined based on the measurement of the load-free specimen. In calculation for total compliance, the total deflection of the loaded specimens was calculated by adding the thickness swelling of the specimens to the measured deflection in adsorption and subtracting the thickness shrinkage of the specimens from the measured deflection in desorption. As in Eq. (1), MS compliance $D_M(t)$ was obtained by subtracting initial compliance $D_I(t)$ from total compliance $D_T(t)$. The MS compliance coefficient (K_M) was defined as a $D_M(t)$ change in unit MC change (ΔMC) within a given MC region (i.e., $D_M(t) \cdot \Delta MC^{-1}$).

RESULTS AND DISCUSSION

MC, relative deflection, and total compliance

Figure 1 shows the variations of MC, relative deflection, and total compliance of the specimens over the history of cyclic RH change between 65% and 95%. It can be seen that MC varied with boards used. Particleboards had greater MC than MDFs at a given condition, likely due to the high temperature treatment of the fibers in the pressurized refinders during MDF manufacturing (Suchsland 1972). As shown in Fig. 1, both relative deflection and total compliance showed increases over the history of cyclic moisture changes, and their values varied with boards. For the four types of MDF, the relative deflection of urea-resin bonded panels (MUH1, MUH2, and MUS) reached up to 6.56 to 10.01 compared with 3.32 for melamine-resin bonded MMH. Similarly, the total compliance of MUH1, MUH2, and MUS increased 698% to 1,055%, compared to 347% for MMH. For the two types of particleboard, the relative deflection of urea-resin bonded PBU reached up to 7.10, compared to 3.17 for phenol-resin bonded PBP. The total compliance of PBU increased 755% compared to 331% for PBP. In this study, resin type seems to be an important factor influencing relative deflection and total compliance of MDF and particleboard under cyclic moisture change conditions. The fact that phenol-formaldehyde and melamine-formaldehyde bonded boards had smaller relative deflection and total compliance was

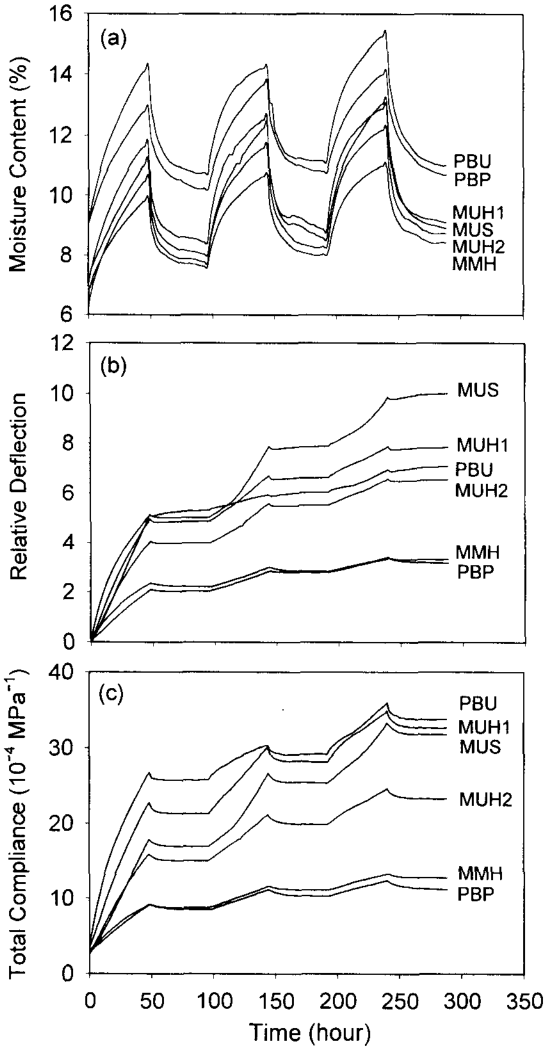

FIG. 1. Moisture content (a), relative deflection (b), and total compliance (c) as a function of sorption time for the boards used in the study.

thought to be due to the moisture-resistance properties of the two types of resins, MC and other parameters. It should be noted that for a given board, the values of MC, relative deflection, and total compliance as a function of time for narrow specimens may be greater than those for wide specimens. The creep behavior of wood composite boards may vary with resin content and wax content, which are known to have significant effect on the dimensional stability, especially the thickness swelling and MC in the boards under high RH and cyclic RH. The creep performance of wood composite boards is greatly influenced by the level of load applied, the level of RH, frequency of RH cycle, and the number of RH cycles imposed. Thus, the results of creep behavior of MDF and particleboard may vary with above-mentioned parameters.

As shown in Fig. 1, both relative deflection and total compliance appreciably increased in adsorption while showing slight reductions in desorption. These behaviors were consistent with observations made by Bryan and Schniewind (1965) and Norimoto and Yamada (1966) for creep deflection in commercial particleboard, but different from those by Armstrong and Grossman (1972) for relative creep deflection in commercial particleboard and hardboard, in which the creep deflection showed an increase during desorption. As explained by Armstrong and Grossman (1972), the different results may be due to the variations in construction and properties of materials and different test conditions. In addition, effect of thickness change on deflection value of the loaded specimen was not discussed in their studies, while the thickness change of wood composite panels is generally greater than that of solid wood during cyclic moisture changes.

The relative deflection and total compliance behavior of boards during cyclic moisture changes were different from those of solid wood (Hearmon and Paton 1964; Zhou et al. 1999, 2000a). The relative deflection and total compliance of the boards in this study increased in adsorption and showed slight decreases in desorption. For solid wood, however, desorption leads to an increase in deformation, while adsorption, except when it is the first moisture increase, causes only a small increase or even a reduction in deformation. The differences in creep behavior between wood composites and solid wood could be attributed to one or more of the following: (1) the uniform orientation of the fibers in wood in comparison with the random orientation of components, chips, or groups of fibers in wood composites; (2) the

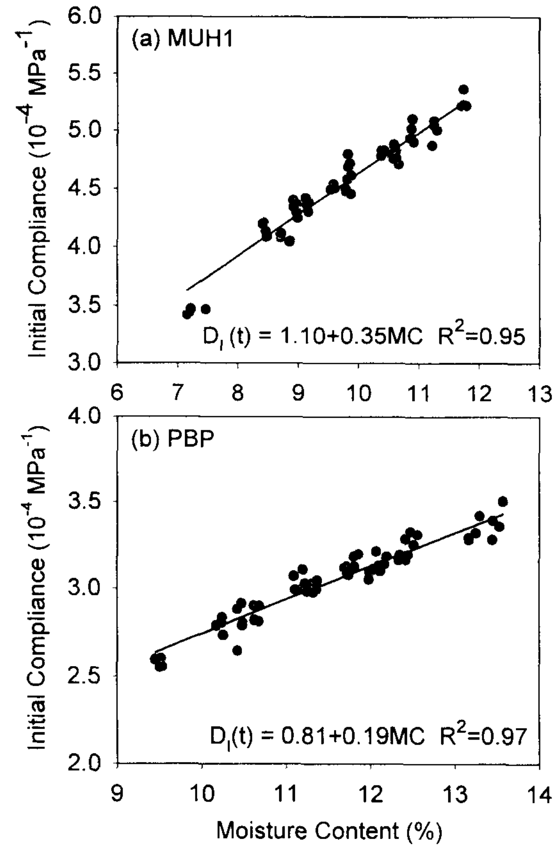

FIG. 2. Typical plots showing initial compliance as a function of moisture content. Lines show the linear fit of the data.

differences in the nature and/or degree of bonding between the fibers in wood and the components in wood composites; and (3) the mechanical weakening of the components in wood composites during processing (Armstrong and Grossman 1972).

Effect of MC on initial compliance and MS compliance

Typical plots of initial compliance as a function of MC for the boards are shown in Fig. 2. Initial compliance increased linearly with increasing MC during cyclic moisture changes. A linear regression was used to fit the data as the following equation

$$D_I(t) = K_I MC + D_{I0} \qquad (3)$$

where K_I = initial compliance coefficient (10^{-4} MPa^{-1}%ΔMC^{-1}), and D_{I0} = constant (10^{-4} MPa^{-1}). The results for K_I are summarized in Table 2. It can be seen that MMH and PBP had relatively small K_I compared with urea-bonded boards.

Typical plots of the relationship between MS compliance and MC change for the boards are shown in Fig. 3. In the first adsorption, MS compliance increased linearly with increasing MC change; whereas in the subsequent adsorption, for MC change-up to about 2% level, very little MS compliance developed, and as MC change increased further, MS compliance increased considerably. On the other hand, MS compliance showed slight reduction (except for MUS) as MC change increased in desorption.

TABLE 2. *Coefficients (K_I and K_M) (10^{-4} MPa^{-1} %ΔMC^{-1}) for various boards used in the study.*

		K_M					
		Adsorption			Desorption		
Board type	K_I	1	2	3	1	2	3
MDF							
MUH1	0.35	3.62	1.76	1.30	−0.05	−0.24	−0.23
MUH2	0.28	2.68	1.30	0.97	−0.04	−0.11	−0.18
MUS	0.46	3.12	1.73	1.22	0.21	0.16	0.17
MMH	0.17	1.84	0.76	0.58	−0.02	−0.08	−0.08
Particleboard							
PBU	0.32	4.21	0.99	1.39	0.03	−0.15	−0.29
PBP	0.19	1.39	0.56	0.45	−0.03	−0.14	−0.18

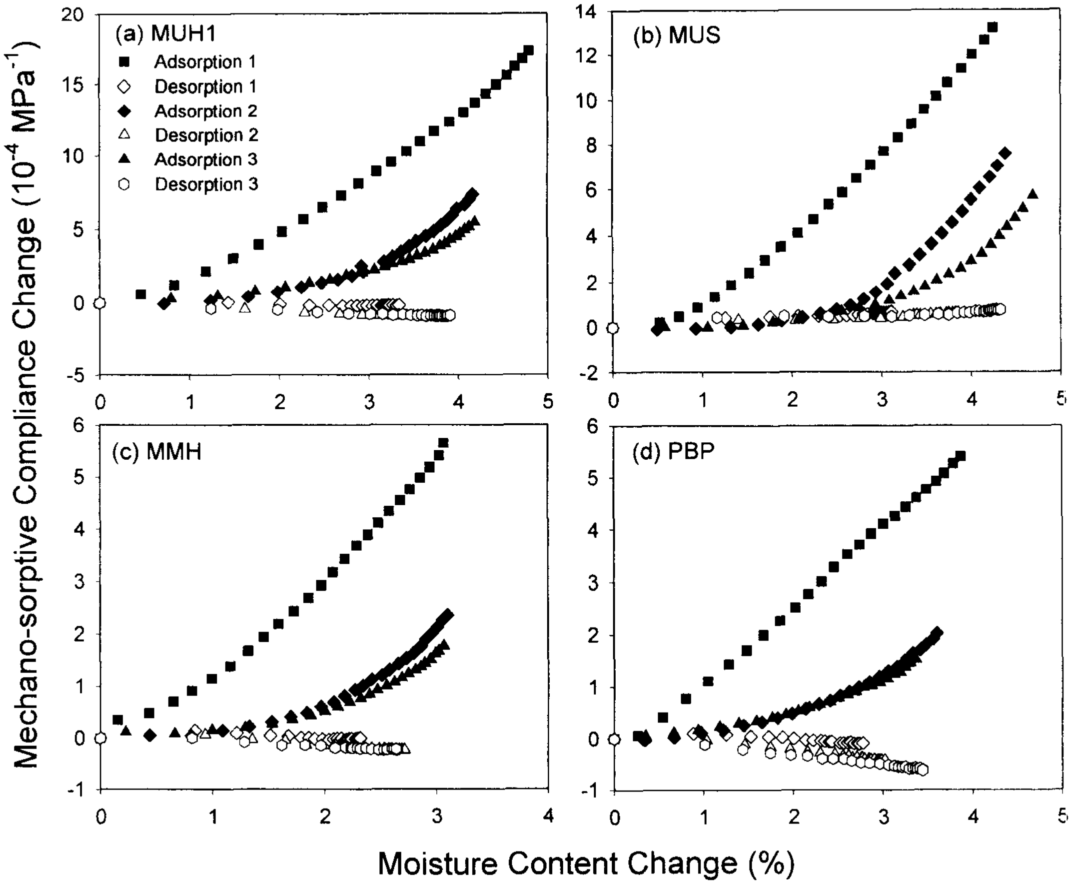

FIG. 3. Typical plots showing the relationship between mechano-sorptive (MS) compliance and moisture content change.

For all boards used in the study, the first adsorption led to the largest MS compliance, followed by subsequent adsorption.

Unlike solid wood studied previously (Zhou et al. 1999, 2000a), wood composites revealed a different relationship between MS compliance and MC change; namely, MS compliance showed considerable increase in adsorption and slight decrease in desorption. This implies that there seem to be different MS creep mechanisms between wood composites and solid wood. The main reason for MS creep in solid wood is the breaking of hydrogen bonds between hydroxyl groups of adjacent cellulose chains and water molecules in the wood. However, in fiberboard and particleboard used in this study, fibers and particles are bonded with adhesives. The dominant mechanism for MS creep in wood composites can be explained in terms of breaking of adhesive bonds in the boards. During moisture adsorption, increases in MC led to degradation of adhesive bonds. Under applied stresses, relative displacement between wood fibers or particles and between wood polymers occurred, which therefore resulted in a considerable deformation of the boards. On the other hand, the MC in the boards decreased in desorption, and little degradation of adhesive bonds occurred. Thus, little MS creep resulting from adhesive bond breaking happened in desorption. Since heat and pressure during board manufacturing may cause degradation of hemicellulose in wood and reduce the number of hydrogen bond sites