# Creep behavior of sweetgum OSB: effect of load level and relative humidity

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**Abstract**

Flexural creep behavior of laboratory-fabricated sweetgum oriented strandboard (OSB), under constant (65% and 95%) and cyclic (65% ↔ 95% at a 96-hr. frequency) relative humidity (RH) conditions at 75°F (23.9°C) is presented. Two levels (4.5% and 6.5%) of resin content (RC) of phenol-formaldehyde were used in fabricating the test panels. Two load levels (20% and 40% of the modulus of rupture (MOR)) were chosen for the investigation. Load duration was 12 weeks followed by a 3-week recovery under constant 65 percent RH at 75°F. Constant high RH (95%) as well as the cyclic RH (65% ↔ 95%) showed a great influence on the creep resistance and relative creep. At constant low RH (65%), improvement of relative creep was observed when the RC was increased from 4.5 to 6.5 percent. The load-duration effect (creep-rupture) became evident when the load level was increased from 20 to 40 percent MOR under constant 95 percent or cyclic 65 ↔ 95 percent RH conditions.

The flexural creep behavior of structural hardwood flakeboards under constant load (20% modulus of rupture (MOR)) and constant relative humidities (RHs) (65% and 95%) or cyclic RH (65% ↔ 95%) was reported by Yeh et al. (7). Results indicated that the creep behavior of structural hardwood flakeboards was very sensitive to the constant high RH (95%), as well as the cyclic RH (65% ↔ 95%) to which boards were subjected during loading. Recently, in a sequential study, the creep behavior of southern pine oriented strandboards (OSBs) subjected to cyclic loading (20% ↔ 40% MOR) under constant 65 percent RH was studied and an 8-element mechanical model was developed for a better description of the creep behavior of OSB (6,8). It was concluded that a linear relationship between viscoelastic deformation and load existed in southern pine OSBs, at least up to a stress level equivalent to 40 percent MOR when they were loaded under constant 65 percent RH. Also, in a previous study (3), the creep performance of southern pine OSBs subjected to cyclic RH of 65 percent ↔ 95 percent under constant load was reported. Results indicated that the creep resistance of southern pine OSBs was affected by the RC and the load-duration effect showed at high load levels. More recently, the creep resistance performance of six commercial aspen and southern pine OSBs, subjected to constant low load under constant high RH (95%), at either 75°F or 95°F was investigated by Pu et al. (4,5). Results indicated that tertiary creep showed up in all products after 720 hours (30 days) of loading. Moreover, southern pine OSBs performed better in creep resistance than the aspen products even though they are given equivalent performance ratings. To further study the effect of load level (LL) and RH on the creep and creep-rupture behavior of wood composite panel products, the time-dependent load-deformation relationship of laboratory-fabricated sweetgum OSBs, subjected to constant low load (20% MOR) and constant high load (40% MOR) under constant 65 and 95 percent RH, and cyclic 65 percent ↔ 95 percent RH at 75°F (23.9°C) was examined.

## Materials and methods

Thirty-six sweetgum (*Liquidambar styraciflua* L.) logs were used to produce the 3-layer OSB materials. The average specific gravity (0.53) of sweetgum given

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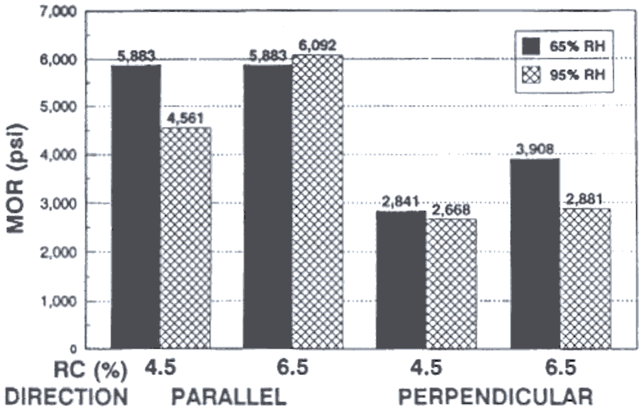


**Figure 1. — Effect of RC and RH levels on the bending MOR of sweetgum OSBs.**

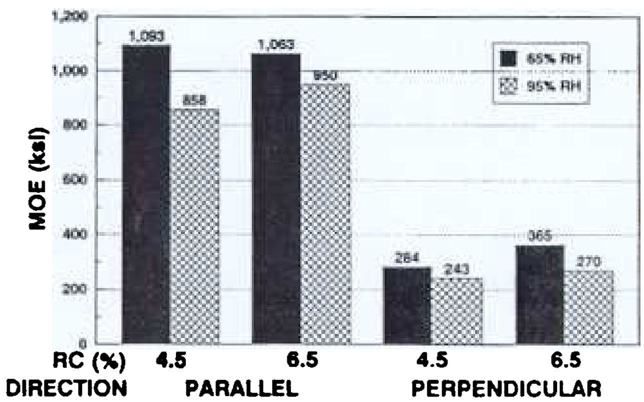


**Figure 2. — Effect of RC and RH levels on the bending MOE of sweetgum OSBs.**

in this paper was determined from five wood blocks randomly selected from the boards cut from the sweetgum logs and it was calculated based on the ovendry weight and volume under ambient condition. Veneer-type flakes, approximately 3 inches long by 1 inch wide by 0.02 inch thick (7.62 cm × 2.54 cm × 0.508 mm), were cut by using a laboratory model disk flaker. All flakes produced from the logs were considered to be homogeneous. The boards were fabricated with 4.5 or 6.5 percent RC of a commercial liquid phenol-formaldehyde resin (ovendry wood basis) at a nominal density of 39 pcf (0.625 $gr/cm^3$). The panel size was 42 by 40 inches with a nominal board thickness of 0.5 inch (1.27 cm). Sixteen panels for each RC group were laboratory fabricated. The panels were cut into 18- by 3-inch (45.72 by 7.62 cm) specimens for static and long-term bending tests. Other processing variables of the tested OSBs are identical to those of sweetgum flakeboards studied previously by Yeh et al. (7). Static bending tests were performed on both RC groups according to ASTM Standard D 1037 (1). The load levels employed in the long-term bending test were

**TABLE 1.** — *T-test to determine the significance of the effect of RH and RC on the short-term static mechanical properties of sweetgum OSB products.*[a]

| | t-values[b] | | | | |
|---|---|---|---|---|---|
| | Parallel | | Perpendicular | | |
| | MOR | MOE | MOR | MOE | IB |
| **RH** | | | **RC effect** (4.5% RC vs. 6.5% RC) | | |
| **65%** | 0.002[NS] (0.0) | 0.468[NS] (-2.7) | 2.236[*] (37.6) | 3.324[**] (28.5) | 5.136[**] (65.0) |
| **95%** | 3.120[**] (33.6) | 1.573[NS] (10.7) | 0.462[NS] (8.0) | 0.784[NS] (11.1) | 1.478[NS] (13.6) |
| **RC** | | | **RH effect** (65% RH vs. 95% RH) | | |
| **4.5%** | 2.521[*] (22.5) | 3.591[**] (21.5) | 0.391[NS] (6.1) | 1.803[NS] (14.1) | 0.128[NS] (1.7) |
| **6.5%** | 0.484[NS] (-3.6) | 1.946[NS] (10.6) | 2.076[*] (26.3) | 2.698[*] (26.0) | 4.178[**] (32.3) |

[a] There were 8 specimens for each bending testing group and 32 for each IB group. * = significant at the 95 percent level; ** = significant at the 99 percent level; NS = not significant at the 95 percent level.
[b] Numbers in parentheses represent the reductions based on the lower RH (65%) groups, or the improvement based on the groups of lower RC (4.5%).

based on the static bending MOR obtained at 65 percent RH and 75°F. Two LLs were chosen, i.e., constant low (20% MOR of each RC group) and constant high (40% MOR of each RC group). Eight specimens of each RC group were tested in static bending. Six specimens for the long-term bending test were designated to each LL, RC, and RH group and were preconditioned and equilibrated under constant 65 percent RH and 75°F.

Two computer-controlled walk-in environmental rooms provided the constant 65 or 95 percent RH and the cyclic conditions of 65 percent ↔ 95 percent RH for the creep tests. The specimens were subjected to the bending creep tests with a simple span of 16 inches (40.64 cm) and concentrated loads. The loads were removed at the end of a 12-week loading period (2,016 hr.) and the specimens were provided a 3-week recovery under a constant 65 percent RH at 75°F. The creep deflections were recorded daily using a displacement transducer (RDP DCT-1000) that was connected to a computer-controlled data-acquisition system. The set-up for the creep tests was identical to that used in the previous study of creep of commercial OSBs (4,5).

## Results and discussions

### Effect of RC and RH on static mechanical properties

The results of flatwise static bending MOR and MOE in the directions parallel to and perpendicular to face flakes of the sweetgum OSBs are illustrated in Figures 1 and 2, respectively. The statistical analysis on the significance of the effect of RH and RC on these properties is given in Table 1. The directional MOR was 5,883 psi (||) ad 2,841 psi (⊥) for 4.5 percent RC specimens and 5,883 psi (||) and 3,908 psi (⊥) for the 6.5 percent RC group under 65 percent RH and 75°F.

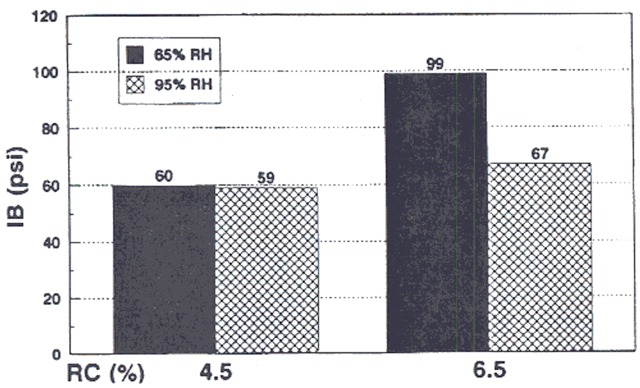


Figure 3. — Effect of RC and RH levels on the internal bond (IB) strength of sweetgum OSBs.

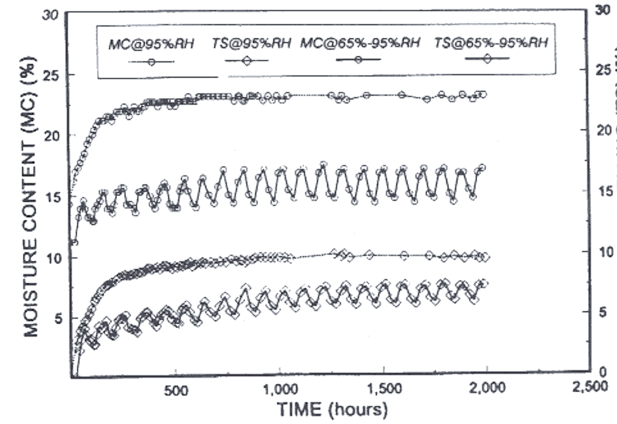


Figure 4. — Typical MC and TS histories of the sweetgum OSB under constant 95 percent RH and cyclic 65 ↔ 95 percent RH at 75°F.

Marked improvement (33.6%) in MOR for specimens loaded in the parallel direction under 95 percent RH was found when the RC increased from 4.5 to 6.5 percent. However, no improvement was found under 65 percent RH conditions. Also, no significant effect of RC on the parallel-direction MOE of the specimens tested was found.

When the specimens were loaded in the parallel direction and RH was raised from 65 to 95 percent, significant reductions in MOR (22.5%) and MOE (21.5%) resulted for the group fabricated with 4.5 percent RC. However, there was no significant RH effect on specimens fabricated with 6.5 percent RC. This indicates that better performance in static bending under humid environments may be achieved by increasing the RC.

The directional property ratio (DPR), defined as the ratio of bending MOR or MOE along the face flake alignment (| |) to that of cross face flake alignment (⊥), is a measure of the degree of the flake orientation in OSB products. Higher values in the DPR indicate better flake alignment. For the OSBs tested in this study, the overall average DPR was 3.45 for MOE but only 1.85 for MOR; RC and RH had no significant effect on these values.

The results of internal bond (IB) strength of sweetgum OSBs (32 specimens in each RC and RH group) as affected by the RC and RH are shown in Figure 3 and their statistical analysis is given in Table 1. As expected, under 65 percent RH, high IB (99 psi) showed in the group with a 6.5 percent RC, while the 4.5 percent RC group had only 60 psi IB. This suggests that, under a medium constant RH condition (65%), 65 percent improvement of IB (60 psi → 90 psi) in sweetgum OSBs can be achieved if the RC is increased from 4.5 to 6.5 percent. Note that only 26 percent improvement of IB (86 psi → 108 psi) was observed in southern pine OSBs with identical experimental design reported previously by Yeh (6). However, under a high constant RH condition (95%), RC effect on the IB of sweetgum OSBs was found to be non-significant (Table 1), but earlier a significant effect was reported by Yeh (6) for the southern pine OSBs. When the RH was increased from 65 to 95 percent at 75°F, the IB of the 6.5 percent RC group of sweetgum OSBs dropped 32.2 percent (99 psi → 67 psi) but almost no reduction (60 psi → 59 psi) was observed in the 4.5 percent RC groups. However, earlier Yeh (6) reported that the IB of southern pine OSB with a 6.5 percent RC dropped only 23 percent (108 psi → 83 psi) when the RH was changed from 65 to 95 percent.

## Moisture content and thickness swelling histories

All OSB specimens were preconditioned and equilibrated under constant 65 percent RH at 75°F, then they were moved to either constant 95 percent RH or cyclic 65 percent ↔ 95 percent RH for the creep test. The temperature was maintained at a constant 75°F during the test. Typical moisture content (MC) and thickness swelling (TS) histories of the OSBs tested are illustrated in Figure 4. The initial average MC of OSBs was 11.87 percent under 65 percent RH at 75°F. When they were placed in the environment of 95 percent RH at 75°F, adsorption occurred. As a result, the MC of the OSBs increased rapidly to 21 percent in the first 200 hours, and gradually approached the equilibrium MC of about 22.5 percent after 700 hours of adsorption. TS is based on the thickness measured in the preconditioning environment. TS increased quickly to 8 percent in the first 200 hours of adsorption under constant 95 percent RH at 75°F, following a pattern similar to that in the MC history, and leveled off at approximately 10 percent thereafter.

The testing environment of cyclic 65 percent ↔ 95 percent RH, with a duration of 46 hours at each level and a 2- hour ramp (96-hr. frequency) at a constant temperature of 75°F, was closely monitored in a computer-controlled walk-in environmental room. Typical oscillating patterns of MC and TS are shown in Figure 4. The MC varied between 14 to 17 percent while TS oscillated at 4.5 to 7.5 percent.

### Effect of LL and RH on creep

The creep deflections of the sweetgum OSB are summarized in Tables 2 and 3. The curves for creep deflection-time, creep recovery-time, and relative creep-time for each LL, RC, and RH group (unfailed specimens only) are plotted in Figures 5 to 8. Relative creep, which is commonly defined as the true creep normalized by the instantaneous deflection, is generally considered to be an index to assess the long-term engineering performance of structural wood composite members. The relative creep concept is also employed to compare the creep behavior between panels with different MOE values. At the low LL (20% MOR), improvement of creep resistance was not observed when RC was increased from 4.5 to 6.5 percent but

TABLE 2. — *Summary of deflections of the sweetgum OSB with 4.5 percent resin content.*

| Load level | Statistic ($n$=6) | Instant. deflection | Maximum deflection[a] | Instant. recovery | Permanent deflection[b] | Max. relative creep[c] |
|---|---|---|---|---|---|---|
| (%MOR) | | | | (in.) | | |
| Constant 65% RH at 75°F | | | | | | |
| 20 | Mean | 0.0915 | 0.1668 | 0.0952 | 0.0505 | 0.75 |
| | SD | 0.0116 | 0.0272 | 0.0162 | 0.0106 | 0.0709 |
| | COV (%) | 12.7 | 16.3 | 17.0 | 21.0 | 9.4 |
| 40 | Mean | 0.1858 | 0.3188 | 0.1975 | 0.0795 | 0.705 |
| | SD | 0.0142 | 0.0396 | 0.0142 | 0.0160 | 0.0837 |
| | COV (%) | 7.6 | 12.4 | 7.2 | 20.1 | 11.9 |
| Constant 95% RH at 75°F | | | | | | |
| 20 | Mean | 0.0927 | 0.4172 | 0.1098 | 0.2460 | 3.42 |
| | SD | 0.0088 | 0.0777 | 0.0143 | 0.0564 | 0.4641 |
| | COV (%) | 9.5 | 18.6 | 13.0 | 22.9 | 13.6 |
| 40 | Mean | 0.1842 | 0.7490[d] | 0.1830[d] | 0.4690[d] | 4.15 |
| | SD | 0.0413 | 0.0290 | 0.0030 | 0.0330 | 0.0307 |
| | COV (%) | 22.4 | 3.9 | 1.6 | 7.0 | 0.74 |
| Cyclic 65% ↔ 95% RH at 75°F | | | | | | |
| 20 | Mean | 0.0887 | 0.3636[e] | 0.0864[e] | 0.2176[e] | 3.376 |
| | SD | 0.0204 | 0.0733 | 0.0143 | 0.0500 | 0.345 |
| | COV (%) | 23.0 | 20.2 | 16.6 | 23.0 | 10.2 |
| 40 | Mean | 0.1737 | 1.0543[f] | 0.2293[f] | 0.6747[f] | 5.10 |
| | SD | 0.0096 | 0.2375 | 0.0291 | 0.1671 | 2.045 |
| | COV (%) | 5.5 | 22.5 | 12.7 | 24.8 | 40.1 |

[a] Measured right after being loaded for 12 weeks.
[b] Measured right after recovering for 3 weeks.
[c] Maximum relative creep = (maximum deflection/instantaneous deflection)-1
[d] Only two specimens survived.
[e] Only five specimens survived.
[f] Only three specimens survived.

TABLE 3. — *Summary of deflections of the sweetgum OSB with 6.5 percent resin content.*

| Load level | Statistic ($n$=6) | Instant. deflection | Maximum deflection[a] | Instant. recovery | Permanent deflection[b] | Max. relative creep[c] |
|---|---|---|---|---|---|---|
| (%MOR) | | | | | | |
| Constant 65% RH at 75°F | | | | | | |
| 20 | Mean | 0.0973 | 0.1428 | 0.0635 | 0.0255 | 0.451 |
| | SD | 0.0168 | 0.0237 | 0.0111 | 0.0095 | 0.1168 |
| | COV (%) | 17.3 | 16.6 | 17.5 | 37.3 | 25.9 |
| 40 | Mean | 0.2200 | 0.3343 | 0.2067 | 0.0675 | 0.497 |
| | SD | 0.0184 | 0.0395 | 0.0233 | 0.0168 | 0.0717 |
| | COV (%) | 8.4 | 11.8 | 11.3 | 24.9 | 14.4 |
| Constant 95% RH at 75°F | | | | | | |
| 20 | Mean | 0.1200 | 0.5762 | 0.1373 | 0.3433 | 3.761 |
| | SD | 0.0123 | 0.0889 | 0.0248 | 0.0463 | 0.2959 |
| | COV (%) | 10.3 | 15.4 | 18.1 | 13.5 | 7.9 |
| 40 | Mean | 0.2237 | 1.0840[d] | 0.2280[d] | 0.6670[d] | 4.781 |
| | SD | 0.0238 | | | | |
| | COV (%) | 10.6 | | | | |
| Cyclic 65% ↔ 95% RH at 75°F | | | | | | |
| 20 | Mean | 0.1028 | 0.5197 | 0.1377 | 0.3063 | 3.986 |
| | SD | 0.0045 | 0.0474 | 0.0079 | 0.0397 | 0.377 |
| | COV (%) | 4.4 | 9.1 | 5.7 | 13.0 | 9.5 |
| 40 | Mean | 0.1880 | 0.9110[d] | 0.2110[d] | 0.5920[d] | 4.55 |
| | SD | 0.0166 | - - | | | |
| | COV (%) | 8.8 | | | | |

[a] Measured right after being loaded for 12 weeks.
[b] Measured right after recovering for 3 weeks.
[c] Maximum relative creep = (maximum deflection/instantaneous deflection)-1
[d] Only one specimen survived.

relative creep did improve in the group exposed to 65 percent RH. In general, giving consideration to the time-dependent stiffness in the design of structural wood and wood composite systems, the value of relative creep, less than or equal to 2, is used as a design criterion (2) based on the rule of thumb. As shown in Figures 7 and 8, the values of relative creep under constant RH conditions, prior to unloading, were, respectively, 0.75 and 0.71 for low (20%) MOR and high (40%) MOR in the 4.5 percent RC groups, and 0.45 and 0.50 for the 6.5 percent RC groups with the corresponding load applications. This confirms the rule of thumb that accounted for the long-term loading for structural panels. As the loads doubled (40% MOR), significant increases in creep deflection resulted but significant RC effect was not observed.

The RH effect on the creep resistance and relative creep showed markedly in both RC groups when the RH level was increased from 65 to 95 percent. It is evident from Figures 7 and 8 that the application of the rule of thumb design criterion for long-term loading in structural wood composite panels should be done with caution when the panels are subjected to high RH (95%) conditions. The relative creep exceeded 2 within 100 hours after the load was applied in each application. Up to the time of unloading, the values of relative creep were equal to 3.76 and 4.78 for groups with 6.5 percent RC, in the low load (20% MOR) and high load (40% MOR) groups, respectively, while values of 3.42 and 4.15 were found for the groups with 4.5 percent RC. The effect of cyclic RH on the creep resistance, as well as on the relative creep, was about the same as that of high RH (95%).

### Load-duration effect

The load-duration effect (creep-rupture) showed up in the OSB specimens tested and a summary of the creep-rupture failures is given in Table 4. The load-duration effect showed up when OSBs were exposed to constant 95 percent RH and the LL was doubled.

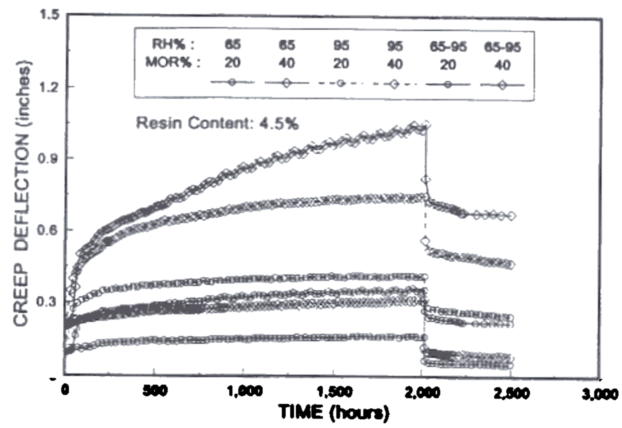


Figure 5. — Creep-recovery curves for the parallel-loaded sweetgum OSB under various RH conditions at 75°F (4.5% RC).

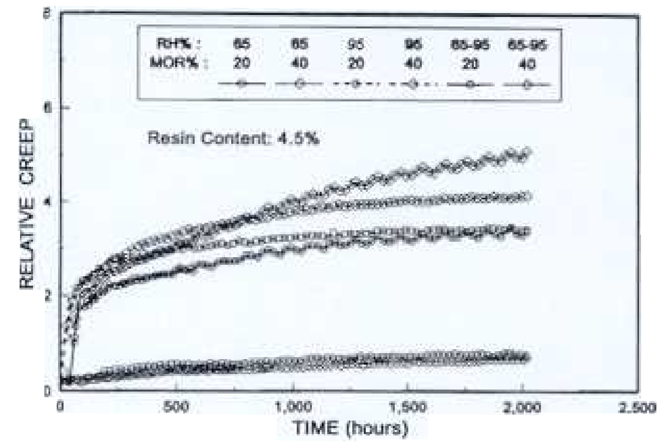


Figure 7. — Relative creep curves for the parallel-loaded sweetgum OSB under various RH conditions at 75°F (4.5% RC).

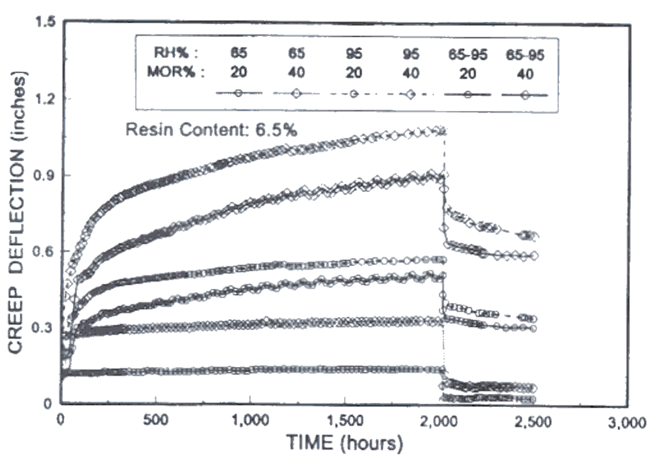


Figure 6. — Creep-recovery curves for the parallel-loaded sweetgum OSB under various RH conditions at 75°F (6.5% RC).

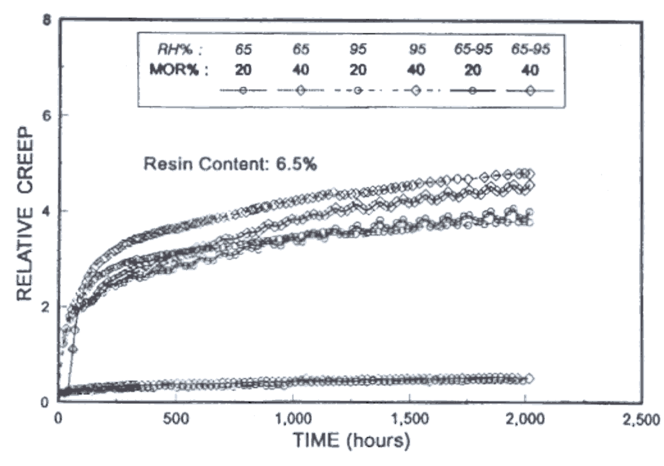


Figure 8. — Relative creep curves for the parallel-loaded sweetgum OSB under various RH conditions at 75°F (6.5% RC).

TABLE 4. — *Summary of creep-rupture failures.*[a]

| Testing environments | Mechanical load applications | Number of failures | |
|---|---|---|---|
| | | 4.5% RC | 6.5% RC |
| (%RH at 75°F) | (Directional %MOR) | | |
| Constant 65 | Constant 20 | 0 | 0 |
| Constant 65 | Constant 40 | 0 | 0 |
| Constant 95 | Constant 20 | 0 | 0 |
| Constant 95 | Constant 40 | 4 | 5 |
| Cyclic 65↔95 | Constant 20 | 1 | 0 |
| Cyclic 65↔95 | Constant 40 | 3 | 5 |

[a] $n$=18; each LL, RC, and RH group had 6 specimens.

Four out of six specimens fabricated with 4.5 percent RC and five out of six specimens fabricated with 6.5 percent RC failed before unloading. For the 4.5 percent RC group, the first failure was at 12 hours of loading, while the fourth failure was at 1,440 hours. For the 6.5 percent RC group, the first failure was at 21 hours, while the fifth failure was at 322 hours.

As expected, the load-duration effect also showed when OSBs were tested under cyclic RH of 65 percent ↔ 95 percent. One out of six 4.5 percent RC specimens failed before unloading but no specimens were broken in the 6.5 percent RC group when LL was at the 20 percent MOR. However, at the high LL (40% MOR), three out of six 4.5 percent RC specimens and five out of six 6.5 percent RC specimens were broken. The times-to-failure for the first specimen in the 4.5 and 6.5 percent RC groups were, respectively, 69 and 509 hours, while the last one in each RC group was 1,590 and 1,610 hours. Failures were not observed in both RC groups loaded at the level of 20 percent MOR when specimens were exposed to either constant 65 percent RH or 95 percent RH. This finding strongly suggests that if the panels are to be exposed to high constant RH environments (e.g., 95%) or cyclical RH (e.g., 65% ↔ 95%), excessive creep deflection may develop when the high load (40% MOR) is applied and the time-to-failure of the sweetgum OSB could be seriously shortened, which could cause such structural failure to happen during the service life of the OSB.

## Conclusions and remarks

1. The creep behavior of sweetgum OSBs was found to be very sensitive to high constant relative humidity (95%) and to cyclic relative humidity conditions (65% ↔ 95% at a 96-hr. frequency) at 75°F.

2. Under high RH or cyclic RH conditions, moderate improvement of creep resistance in OSB products can be achieved by increasing the resin level, i.e., if they are loaded at low stress levels.

3. Regardless of the load application used, sweetgum OSBs exhibit linear viscoelastic behavior when loaded under a constant 65 percent RH and 75°F environment.

4. Considerably high relative creep resulted in sweetgum OSBs when they were loaded under the constant 95 percent RH or cyclic 65 ↔ 95 percent RH. This information may be useful in the design of wood composite panels for structural applications.

5. Load-duration effect (creep-rupture behavior) in sweetgum OSBs was frequently apparent when the load applied was at the level of 40 percent MOR under either constant 95 percent RH or cyclic 65 percent ↔ 95 percent RH.

6. Additional research on evaluating the creep behavior of the OSB products, fabricated with different adhesives, loaded at high stress levels and/or cyclic stress, under hot-constant humidity and hot-cyclic humidity (dry to humid) environments is needed for the further understanding of long-term engineering performance of structural composite panels and for the improvement/development of their structural applications.

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