# COMPARISON OF THE CREEP BEHAVIOR OF A BASSWOOD WAFERBOARD TO THAT OF SOLID WOOD[1]

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ABSTRACT

Flexural creep at 50, 60, 70, and 80% RH for parallel- and perpendicular-to-grain solid wood was compared with a laboratory-produced particleboard of the same species. Accelerated flexural creep rates at high relative humidities did not follow trends of wood stressed in tension and compression perpendicular-to-grain. Creep in particleboard lies between that parallel- and perpendicular-to-grain.

*Keywords:* Creep, particleboard, relative humidity, flexure, parallel-to-grain, perpendicular-to-grain.

## INTRODUCTION

A family of structural wood-based panels is developing: waferboard, oriented flakeboards, and composite panels. Although the creep of conventional particleboard has been studied extensively from a descriptive point of view, little is known about the mechanism of time-dependent behavior. Even less is known about the mechanism of viscoelastic behavior in these new structural products. The purpose of this study was to determine if the creep characteristics of a waferboard are related to the parallel-to-grain and perpendicular-to-grain creep properties of solid wood.

Creep is time-dependent deformation caused by an imposed constant load. It is influenced by change in moisture content and temperature. Relative creep is defined as the ratio of creep deformation to elastic deformation and relative recovery as the ratio of time-dependent recovery to elastic recovery. Nonrecoverable relative creep is the difference at any time between the relative creep curve and relative recovery curve. It is this component of creep that is most serious in design considerations.

The effect of moisture content (MC) on the creep behavior of wood is well described in the literature. Gibson (1965) suggested that the additional deformation in a creep test under changing moisture conditions was due to the continual making and breaking of hydrogen bonds in reaching a new equilibrium moisture content (EMC). Gardner et al. (1967) verified this experimentally. Bryan and Schniewind (1965) tested urea formaldehyde and phenol formaldehyde bonded particleboard to investigate the flexural creep under constant and cyclically changing moisture conditions. They found that moisture content and sorption effects were more pronounced in particleboard than in whole wood.

Lundgren (1969) examined the long-term deformational behavior of plywood, particleboard, and different types of hardboard at different moisture conditions and stress levels. He found that the increases in total strain at higher relative humidities are very pronounced. Haygreen et al. (1976) found in a shavings/res-

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idue type particleboard that flexural creep accelerated if relative humidity (RH) exceeded 75%. Lehmann et al. (1975) studied the creep characteristics of structural particleboards produced from large flakes, particularly panel types of high strength and stiffness. They found that panels with high stiffness yielded high creep resistance.

Comparatively little research has been done on creep behavior of wood under transverse tensile and compressive stress. Ellwood (1954) in his study of American beech noted that transverse tensile and compressive creep increased with increasing moisture content and temperature. He also found that during drying of wood, creep was greater in compression than in tension perpendicular-to-grain. Youngs (1957) studied the perpendicular-to-grain mechanical properties of red oak. He also observed that creep and recovery for tension and compression perpendicular-to-grain increased with increasing moisture content and temperature.

The objectives of this study were: 1. To explain the performance of a waferboard panel by studying the effect of grain orientation on creep behavior. 2. To understand the nonlinear creep behavior of particleboard that occurs at high humidity conditions by studying the development of creep in solid wood under compression and tension perpendicular-to-the-grain. The research will be described in two parts designed to meet these objectives.

## FLEXURAL CREEP BEHAVIOR OF SOLID WOOD AND WAFERBOARD

### *Experimental procedure*

To study the effect of grain orientation on the flexural creep behavior, it seemed logical to use three types of material: 1. wood stressed parallel-to-grain (WA), 2. particleboard (waferboard) of random grain orientation (PB), and 3. wood stressed perpendicular-to-grain (WB).

Keeping in mind the importance of moisture in creep deformation, it was decided to use four different humidity levels (50, 60, 70, and 80% RH) to evaluate the development of creep. The dry bulb temperature used throughout was 72 F. The lower humidity level was chosen because it is widely used for testing panel products. The upper level was chosen so that the different board types could be exposed to a condition where accelerated creep was known from earlier research (Lehmann et al. 1975) to occur. The stress level used in this study was set at 12% of the stress at failure for each board type as determined in a standard static bending test. This value was chosen because it is within the elastic limit of the boards and also it is a realistic allowable working stress.

The experimental material for all material types in both phases of this study came from a basswood (*Tilia americana*) tree grown in northern Wisconsin. This species was selected because of its straight grain and low variability in strength properties. A low density species was selected because of its suitability for waferboard. The moisture content of this green basswood was 102% and density was 25.8 pounds per cubic foot at 9% MC. The logs were sawn into cants, the ends of the cants were coated, sealed with aluminum foil and air-dried.

For WA, cants were ripped into strips (a total of 36) and dressed to 18 × 2 × ½ inch. For WB, strips were edge-glued with resorcinol formaldehyde resin into a panel approximately 20 × 24 inches. Four such panels were made, sanded to

½ inch, and subsequently cut into strips of 18 × 2 inch with the grain direction transverse to the length.

For PB, cants were cut into blocks that were reduced in a disk flaker to wafers averaging 1.7 × 2.4 × 0.035 inch. The wafers were dried, and to reduce knife checks in the wafers that would be weak spots, the wafers were passed through a hammermill. This reduced wafer width but still retained the wafer nature of the furnish. To reduce fines, the screen in the hammermill was removed. The furnish from the hammermill was passed over ¼-inch screen and what was retained was used in the board manufacture. A liquid phenol formaldehyde particleboard resin was sprayed in a rotary drum blender to give 6% solid resin by weight. Mats were hand-formed using a 20- × 22-inch forming box, and then pressed at 350 F for 15 min with a closure to stops of 55 sec. Four such panels were produced. Panels coming out of the press were kept in an oven at 215 F for 6 h to simulate hot stacking. The panel density was 39.7 pounds per cubic foot at 7.6% MC (50% RH). The compression ratio was 1.54. These panels were sanded and then cut into 18- × 2- × ½-inch strips, the size of all the bending specimens. The objective was not to produce a board that would be typical of commercial waferboards but to reduce the within-board variability to the lowest level possible. The narrower wafers helped in this regard.

For board type WA, nine samples were randomly assigned for each humidity level. Nine samples from each panel of board types WB and PB were randomly assigned such that there were at least two samples for each humidity level. This resulted in a total of nine samples for each humidity level.

The bending stress to be imposed in the flexural creep test was determined from a static bending test. From each board type, four samples were selected randomly out of nine allotted to each humidity level, and the remaining five were used in creep test. The samples were equilibrated to their respective humidity conditions prior to testing. The modulus of rupture (MOR) was determined using a span of 12 inches and a crosshead speed of 0.2 inch per minute. These conform to ASTM testing procedures for wood-based panel products (ASTM 1974).

For statistical analysis the board types and humidity levels were considered as two main factors. Three board types and four humidity levels constituted a 3 × 4 factorial design with five replicates for each of 12 treatment combinations. Although for WB and PB the samples were really balanced with respect to the four panels, this was ignored in the analysis and the 20 samples from each board type were treated as random samples from a homogeneous material. The analysis consisted of a test of significance for each main treatment effect and their interaction by means of an "F-test" in the analysis of variance.

The testing apparatus consisted of a supporting frame, applied loads, and a dial gauge with an accuracy of 0.001 inch for measuring deflection. The test was conducted with a two point loading arrangement so that creep deflection could be determined under pure bending over the center span, which was four inches. The overhang on each end was seven inches. The loads were applied one inch from the ends. The MOR and total load imposed to produce the 12% stress level for each board type at the different humidity levels are shown in Table 1.

The test was run for 300 h under load and another 300 h after unloading for recovery. Elastic deflection was considered to be the deformation at 5 sec. Frequent readings were taken in the first 8 h and then readings were taken daily.

TABLE 1. *MOR (psi), EMC (percent) and Load (pounds) imposed to produce the 12% stress level. MOR is averaged over four samples.*

| Relative humidity (percent) | Material type | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | WA | | | WB | | | PB | | |
| | MOR | Load | EMC | MOR | Load | EMC | MOR | Load | EMC |
| 50 | 11550.4 | 34.75 | 8.85 | 602.5 | 2.04 | 9.18 | 3855.1 | 11.52 | 7.63 |
| 60 | 10286.3 | 30.74 | 9.48 | 552.9 | 1.90 | 9.62 | 3600.3 | 11.16 | 8.72 |
| 70 | 9178.6 | 29.76 | 10.20 | 470.6 | 1.62 | 10.22 | 3442.1 | 11.55 | 9.52 |
| 80 | 8013.6 | 24.75 | 11.26 | 391.1 | 1.35 | 11.20 | 2950.9 | 10.16 | 10.73 |

After unloading, elastic recovery was recorded at 5 sec. Frequent readings were taken in the first 12 h and then daily for the rest of the unloaded period.

## *Results of flexural creep*

The experimental data are summarized in Table 2. Analysis of variance was used to evaluate the treatment effects. Both main factors and their interaction were highly significant ($P = 0.01$). Because of the significant interaction, the ef-

TABLE 2. *Bending deflection, creep, recovery data for the three material types at different humidity levels. Relative creep, and relative recovery data in parentheses, are dimensionless. Figures are average of five samples.*

| Material type | Time, hours | Deflection, $\times 10^{-4}$ inch RH (%) 50 | 60 | 70 | 80 | Creep, recovery, $\times 10^{-4}$ inch RH (%) 50 | 60 | 70 | 80 |
|---|---|---|---|---|---|---|---|---|---|
| WA | Elas. defln. | 68 | 56 | 56 | 49 | 0 (0.000) | 0 (0.000) | 0 (0.000) | 0 (0.000) |
| | 300 | 81 | 71 | 72 | 65 | 13 (0.191) | 15 (0.268) | 16 (0.286) | 16 (0.327) |
| | Elas. recov. | 13 | 14 | 14 | 19 | 0 (0.000) | 0 (0.000) | 0 (0.000) | 0 (0.000) |
| | 300 | 7 | 6 | 8 | 10 | 6 (0.088) | 8 (0.140) | 6 (0.103) | 9 (0.196) |
| PB | Elas. defln. | 47 | 59 | 51 | 50 | 0 (0.000) | 0 (0.000) | 0 (0.000) | 0 (0.000) |
| | 300 | 66 | 88 | 84 | 111 | 19 (0.404) | 29 (0.492) | 33 (0.647) | 61 (1.220) |
| | Elas. recov. | 20 | 30 | 32 | 63 | 0 (0.000) | 0 (0.000) | 0 (0.000) | 0 (0.000) |
| | 300 | 7 | 12 | 15 | 38 | 13 (0.283) | 18 (0.310) | 17 (0.327) | 25 (0.521) |
| WB | Elas. defln. | 122 | 190 | 143 | 130 | 0 (0.000) | 0 (0.000) | 0 (0.000) | 0 (0.000) |
| | 300 | 201 | 352 | 335 | 404 | 79 (0.648) | 162 (0.853) | 192 (1.343) | 274 (2.108) |
| | Elas. recov. | 75 | 162 | 174 | 232 | 0 (0.000) | 0 (0.000) | 0 (0.000) | 0 (0.000) |
| | 300 | 35 | 81 | 87 | 189 | 40 (0.317) | 81 (0.426) | 87 (0.540) | 91 (0.734) |

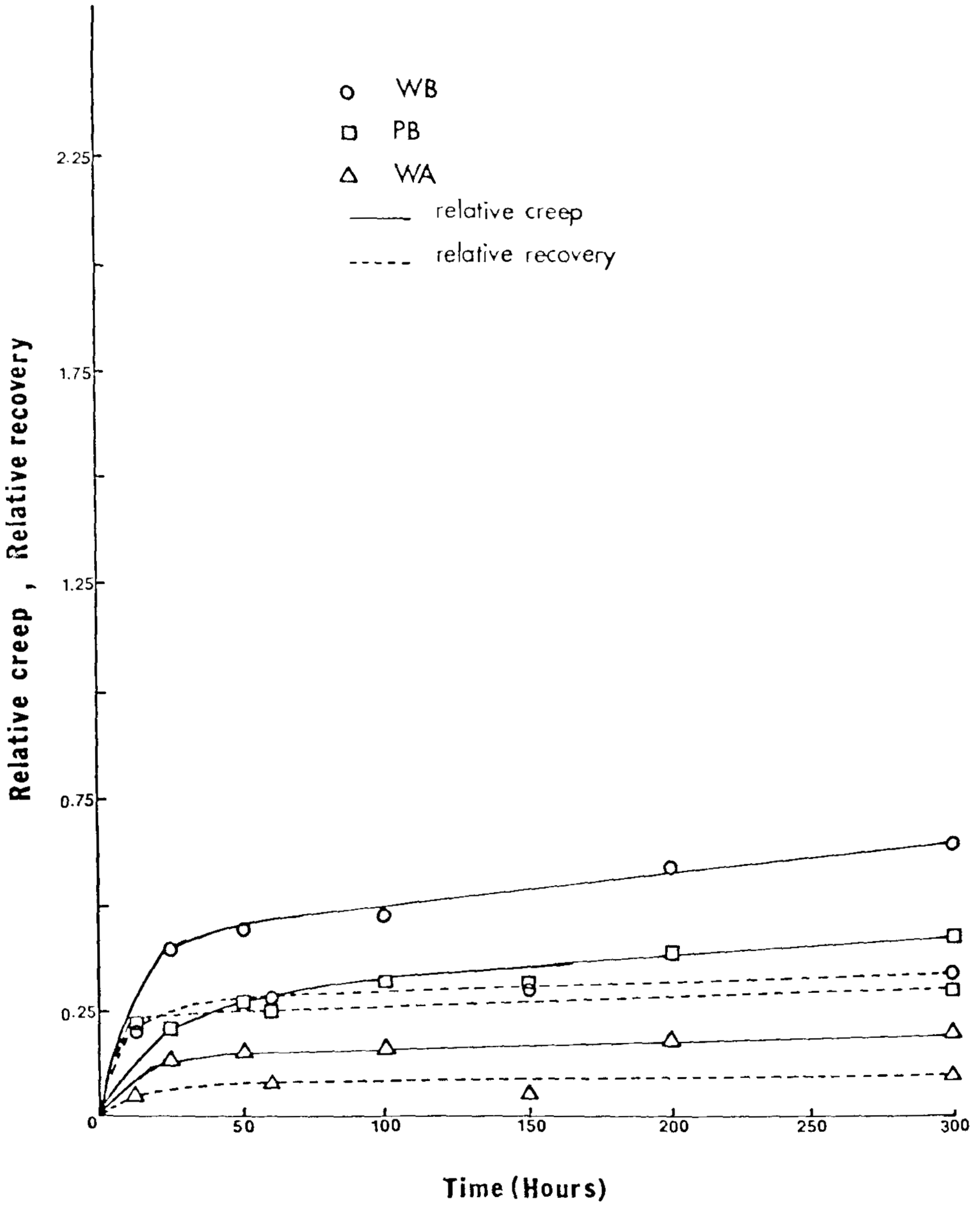



FIG. 1. Relative creep, relative recovery as a function of time for the three board types at 50% RH.

fect of humidity averaged across board types and the effect of board types averaged over humidity levels were of more interest than the main effects. The Bonferroni significant difference method was used in comparing the data means to find the effect of humidity levels over different board type combinations and the effect of board types under different humidity level combinations. The effect of different humidity levels on the relative creep behavior of different material

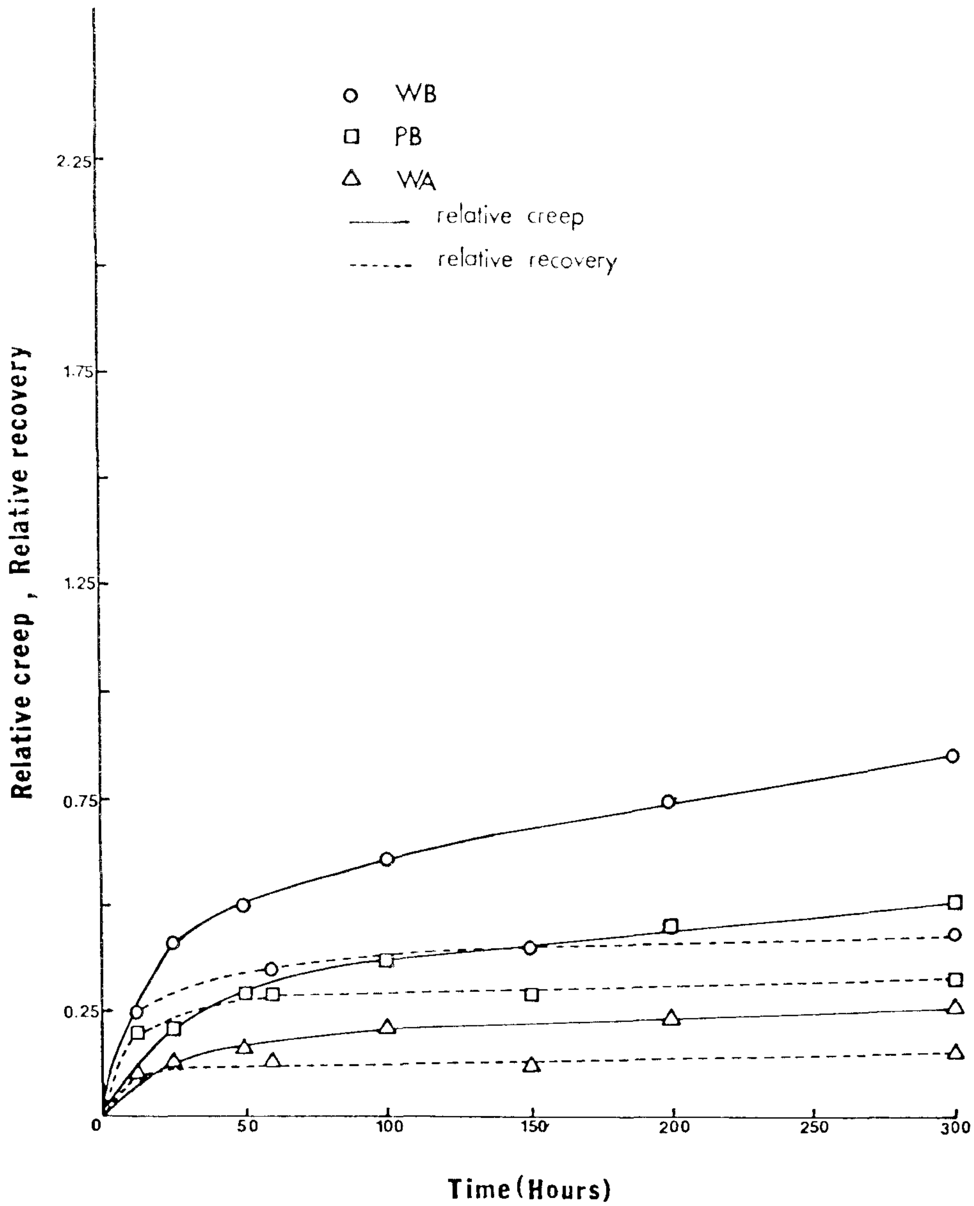



FIG. 2. Relative creep, relative recovery as a function of time for the three board types at 60% RH.

types is plotted in Figs. 1 through 4. Each point in a curve is an average of five samples.

Different humidity levels when averaged across board types did not have any effect on the elastic deflection. This is understandable because each sample was stressed to 12% of its MOR at that moisture content. The similarity of deflections

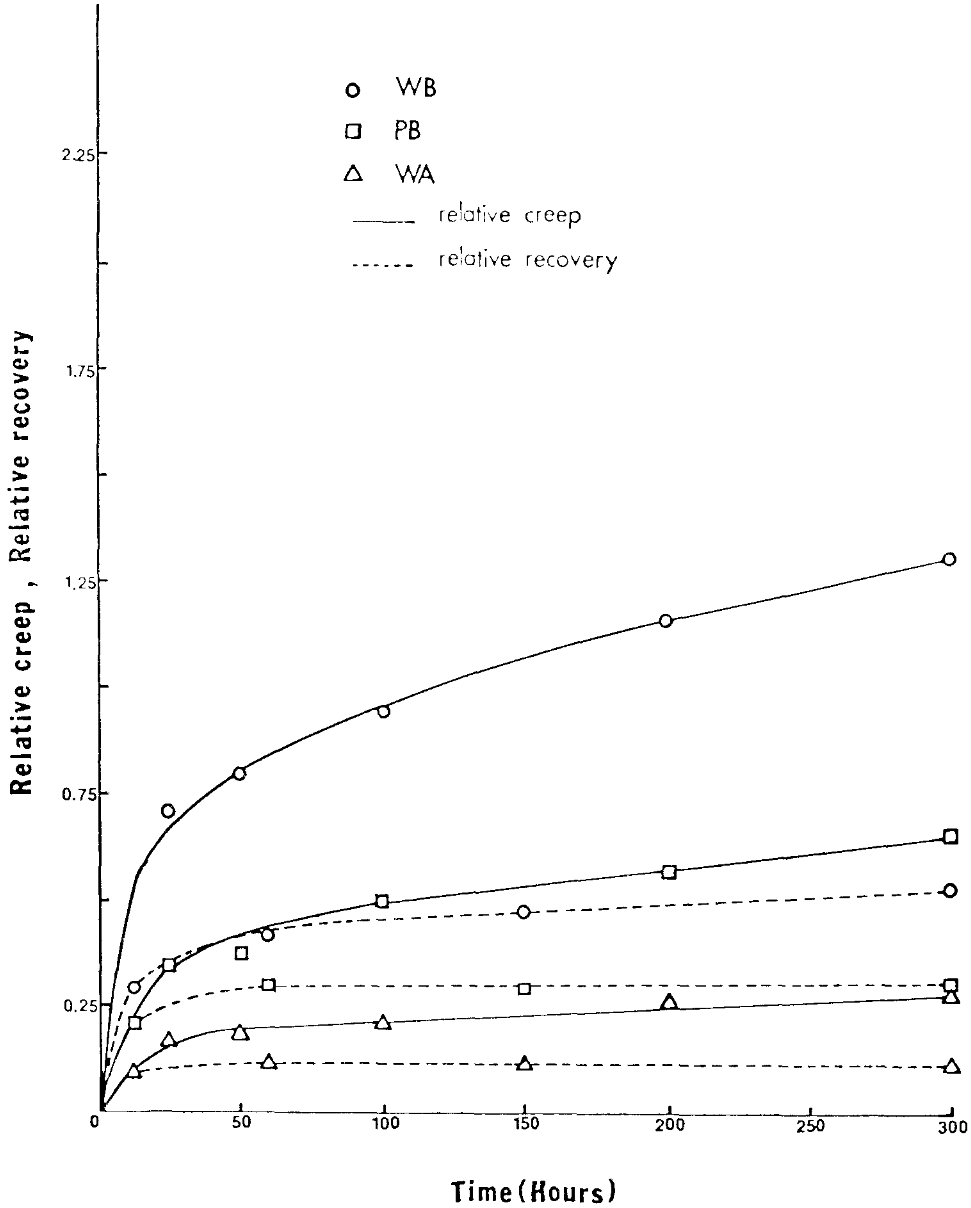



FIG. 3. Relative creep, relative recovery as a function of time for the three board types at 70% RH.

at all relative humidities within a board type verifies that the goal of testing at equivalent elastic properties was attained.

The effect of humidity on relative creep when averaged across board types was significant. Wood stressed parallel-to-the-grain (WA) did not exhibit significantly different creep ($P = 0.05$) between the humidity levels. For particleboard, relative

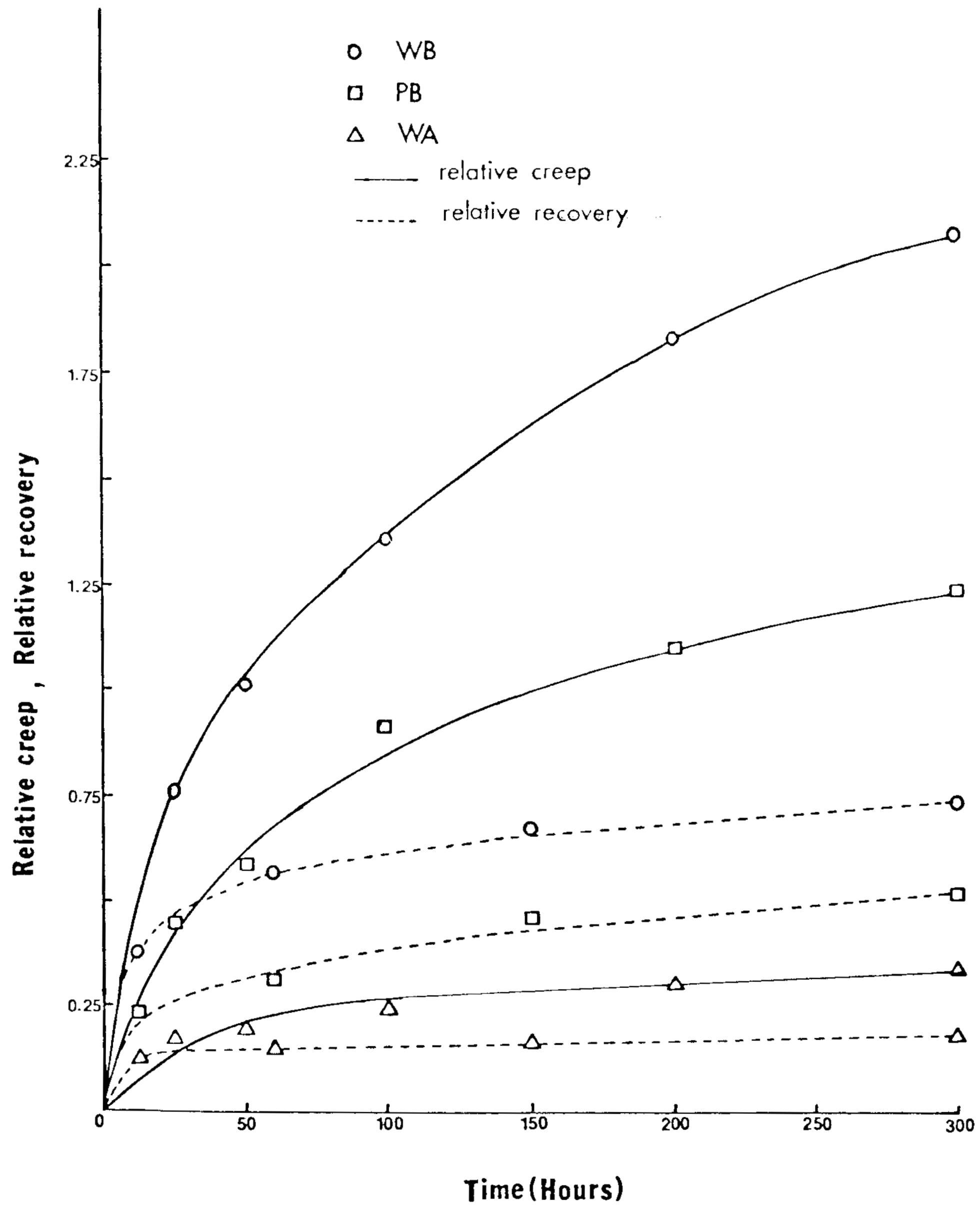



FIG. 4. Relative creep, relative recovery as a function of time for the three board types at 80% RH.

creep at 80% RH was significantly more ($P = 0.05$) than relative creep at other humidity levels. This agrees with the findings of Haygreen et al. (1976) and others that the flexural creep of particleboard is accelerated when the relative humidity exceeds about 75%. For wood stressed perpendicular-to-the-grain (WB), relative creep at 50% RH was not significantly different ($P = 0.05$) from relative creep at 60% RH. There was a significant difference, however, between creep at all other humidity level combinations.

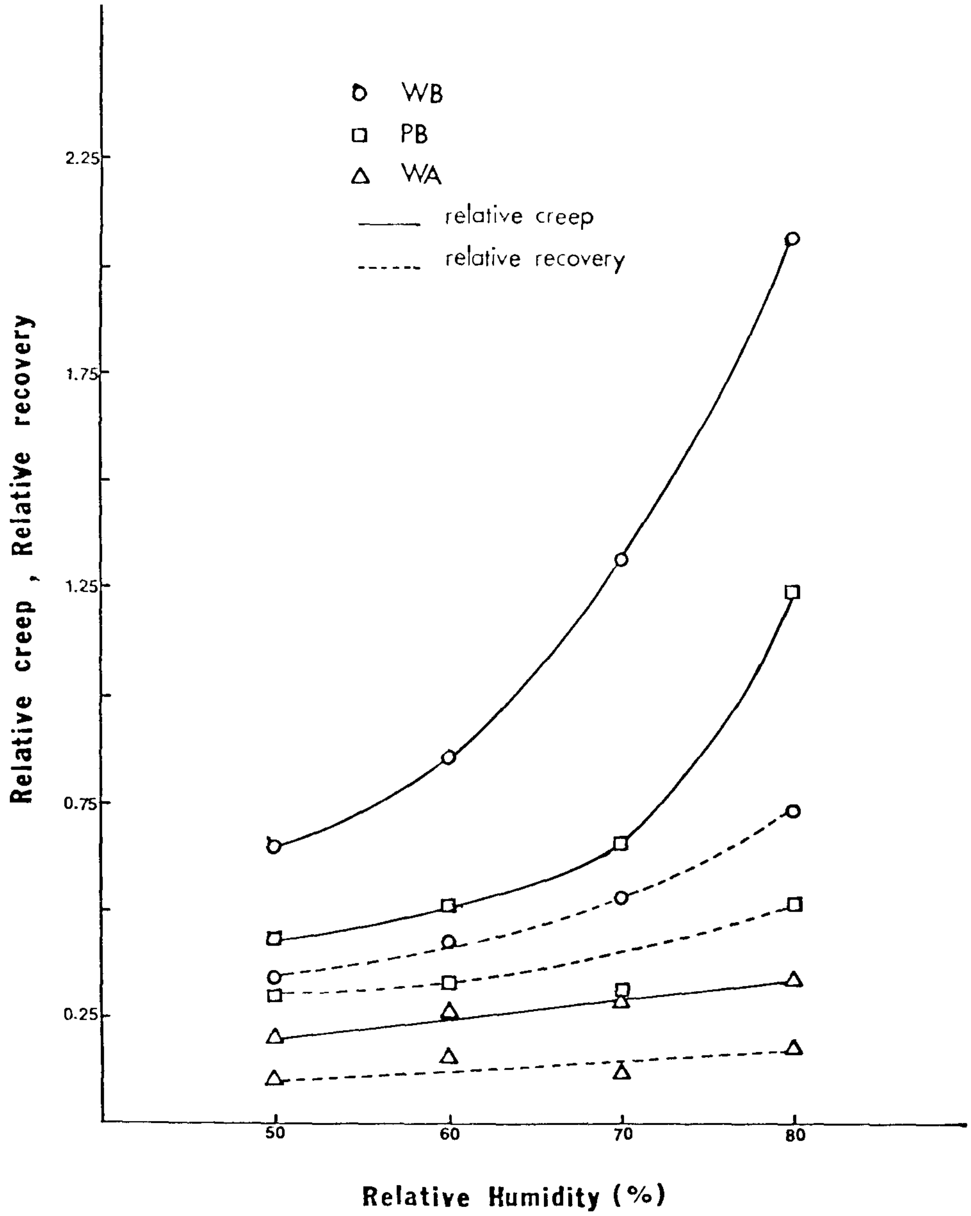
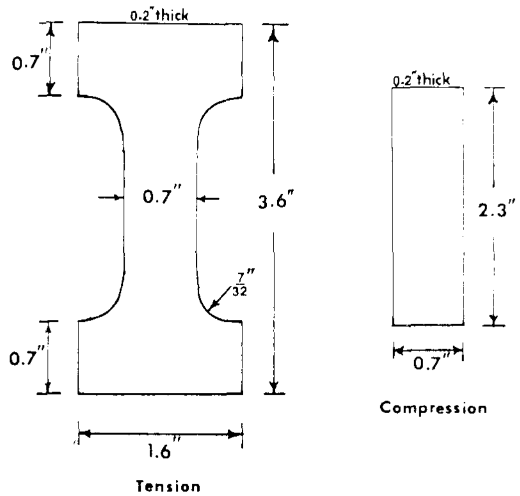



FIG. 5. Relative creep at 300 h and relative recovery at the conclusion of test as a function of relative humidity for the three board types.

The overall humidity effect on relative recovery was highly significant ($P$ = 0.01). The trend observed in the analysis of relative creep data was also seen with relative recovery, that is, PB falls between WA and WB (Fig. 5). One can see from Figs. 1 through 4 that the relative creep rate and the relative recovery rate are very much similar for WA. For PB and WB, the relative recovery is much lower than the relative creep rate.



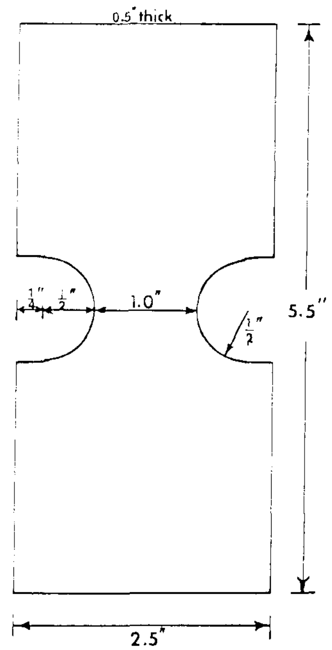




FIG. 6. Tension and compression perpendicular to grain creep test samples.

FIG. 7. Static tension perpendicular to grain test sample.

Humidity when averaged across board types had a highly significant effect ($P = 0.01$) on the nonrecoverable component of relative creep. As the relative humidity increases, it is the viscous portion of the deformation that increases the most; the time-dependent elastic components are not affected to the same extent.

The relative creep behavior of different board types is significantly different at $P = 0.01$. Board type WB was significantly poorer than WA and PB at all humidity levels tested. For any type, it was observed that the higher the relative creep, the higher the nonrecoverable relative creep.

Summarizing the results on a relative basis, when averaged over humidity levels, grain orientation had more influence on performance than did moisture. The performance of particleboard with random grain orientation fell between solid wood parallel- and perpendicular-to-grain. Particleboard was significantly poorer (showed more creep) than wood parallel-to-grain at higher humidity levels. The creep rate of PB and WB accelerated above 70% RH. WB was significantly poorer than WA and PB under all humidity levels tested.

## TENSILE AND COMPRESSIVE CREEP PERPENDICULAR-TO-GRAIN IN SOLID WOOD

### *Experimental procedure*

The results of the first portion of this study suggest the importance that perpendicular-to-grain wood properties have on the behavior of a randomly oriented particleboard. One question that remains is the extent to which tensile and/or compressive strains are responsible for particleboards increasing creep rate at

TABLE 3. *Analysis of variance of flexural creep data.*

| Source of variation | DF | F Elastic deflection | Relative creep at 300 hours | Relative recovery at the conclusion of test | Nonrecoverable relative creep at the conclusion of test |
|---|---|---|---|---|---|
| Humidity (H) | 3 | 1.60 | 112.40** | 54.96** | 55.61** |
| Material type (M) | 2 | 44.93** | 279.40** | 263.00** | 100.50** |
| H × M Interaction | 6 | 1.23 | 25.77** | 10.02** | 14.05** |
| Error | 48 | | | | |

** Significant at $P = 0.01$.

high moisture levels. To obtain insights here, the creep in tension and compression in solid wood perpendicular-to-grain were studied.

The same source of basswood was used for this second experiment. Thin boards were sawn and dried from randomly chosen cants. The thickness of these boards was sanded to 0.20 inches in a drum sander. The boards were randomly assigned to four different humidity levels (50, 60, 70, and 80% RH). Shapes and dimensions of compression and tension perpendicular-to-grain samples are shown in Fig. 6. Twelve samples each of tension and compression were made and three samples were randomly assigned to each humidity level.

It is not possible to obtain the ultimate compressive strength perpendicular-to-grain since wood will be densified and not fail completely. Therefore, to determine the stress level for the creep tests, it was decided to conduct tension perpendicular-to-grain tests and use 12% of that ultimate strength value for testing in both tension and compression. The dimensions of the static test specimen are shown in Fig. 7. Four samples were tested at each humidity level. The samples were equilibrated to their respective humidity conditions prior to testing.

A simple completely randomized factorial design similar to that in flexural creep test was used. Two stress types (tension and compression perpendicular-to-grain) and four humidity levels (50, 60, 70, and 80% RH) were used. These two main treatment effects constituted a completely randomized 2 × 4 factorial design with three replicates for each of eight treatment combinations.

The initial tensile and compressive tests were conducted in a small counterflow temperature and humidity cabinet. Individual testing jigs for tension and compression tests were housed in a specially designed inner chamber.

In the flexural creep tests it was observed that approximately 75% of total creep occurred in the first 100 h of the 300-h test. It was decided to conduct the tensile and compressive creep tests for only 100 h. The same relative stress level as in the flexural creep test, 12% of ultimate strength, was used. Elastic deformation was recorded at 5 sec after loading. Frequent readings were taken in the first 4 h and then were taken daily. Recovery measurements were not taken.

### *Results of tensile and compressive creep on solid wood*

The effect of different humidity levels on tensile and compressive creep behavior is plotted in Figs. 8 and 9. Each point in a curve is an average of three replicates. Results are tabulated in Tables 4 and 5.

Humidity had a highly significant effect ($P = 0.01$) on creep behavior. Ellwood

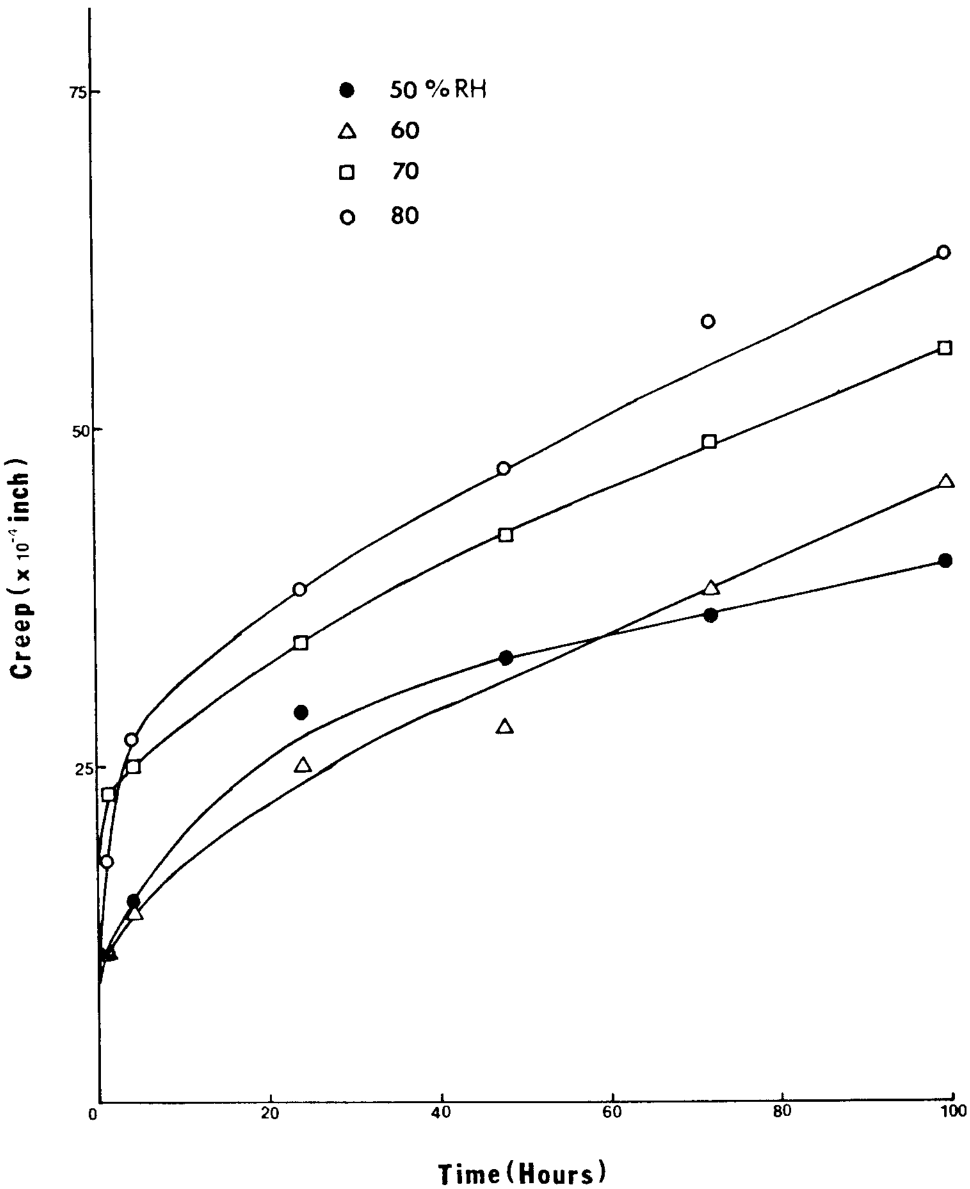



FIG. 8. Tensile creep as a function of time at four different humidity levels.

(1954) testing American beech for creep in tension and compression perpendicular to grain at 90% of ultimate tensile stress for two hours, found that green compression samples exhibited creep nearly two and a half times that at 6% MC. In this present study for both tension and compression, the ratio between the creep at 80% RH and 50% RH in 100 h was 1.58. One should keep in mind that the stress level used in this study was only 12%, which should be well within the elastic limit. Youngs (1957) found that creep in tension and compression perpendicular-

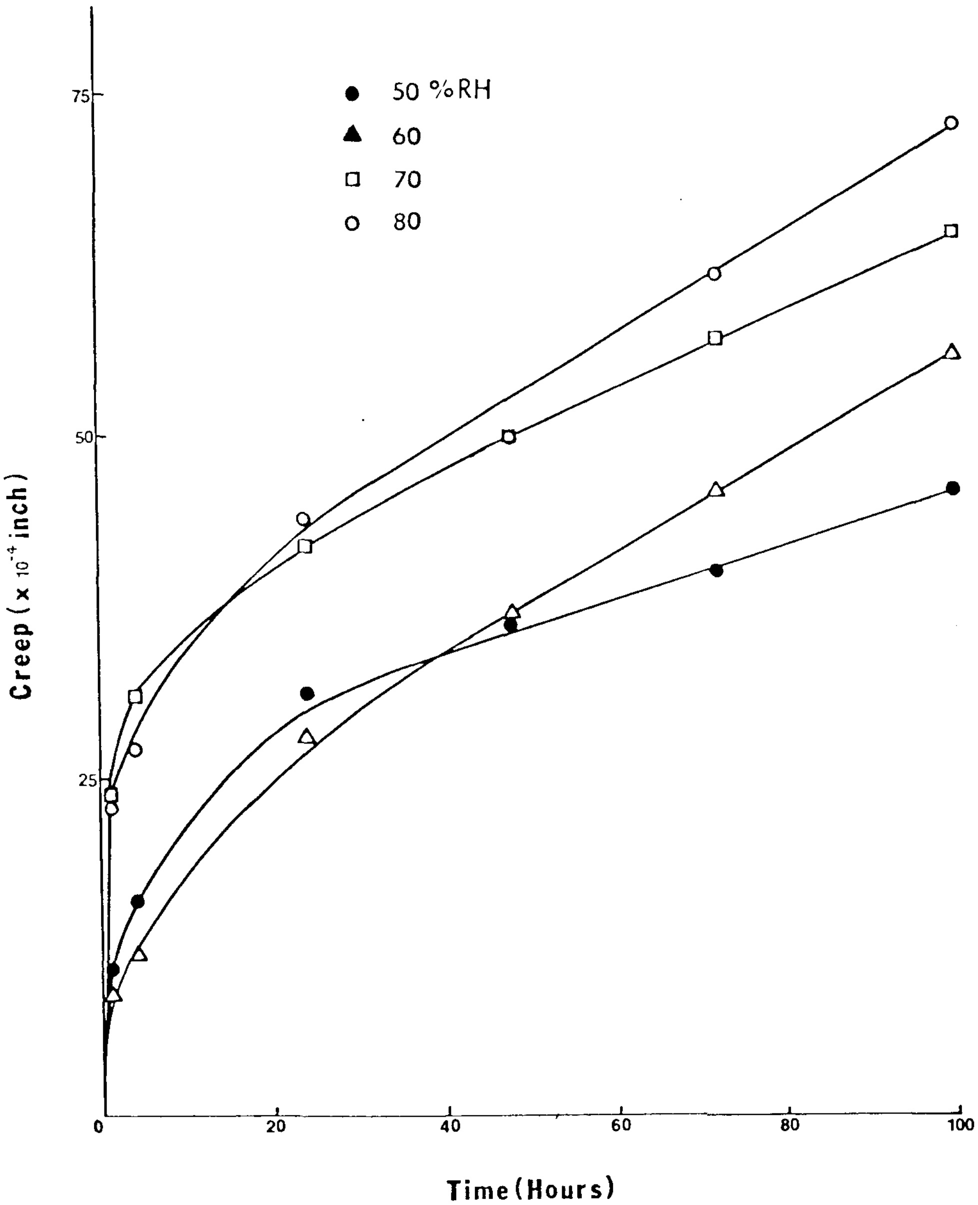



FIG. 9. Compressive creep as a function of time at four different humidity levels.

to-grain increased with moisture content. In Youngs' data at 80 F and 40 % of maximum tensile stress for 70 h, the ratio between the total creep strain for green samples and at 12% MC was 1.40 for compression perpendicular-to-grain, and 1.56 for tension perpendicular-to-grain. This same trend was observed in this study.

The tension and compression tests did not show any significant difference in creep between 70 and 80% RH as was observed in the flexural creep behavior of

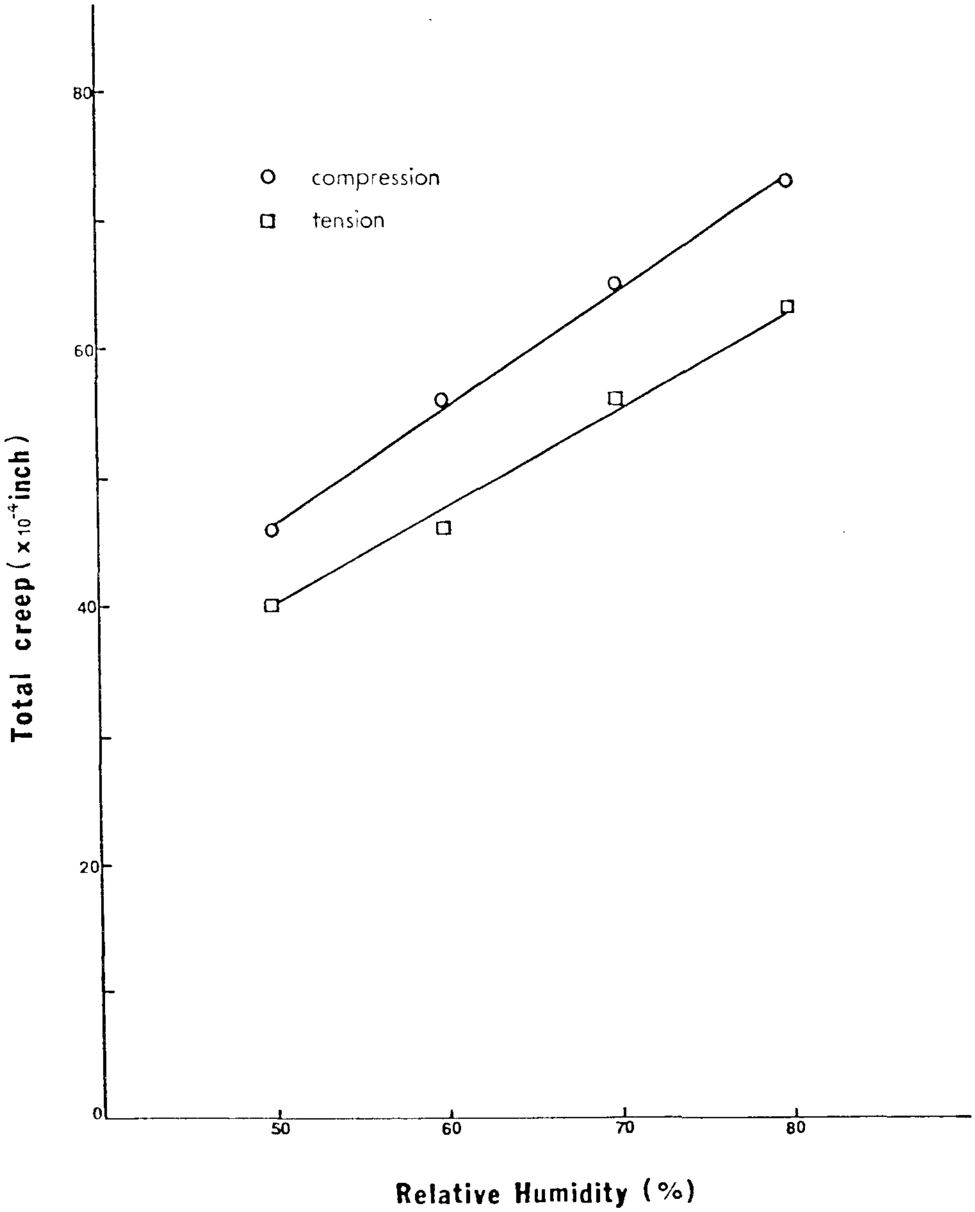



FIG. 10. Tensile, compressive creep at 100 h as a function of relative humidity.

PB and WB. Compressive creep was more than tensile creep (Fig. 10) at all four humidity levels tested, but it was significantly more ($P = 0.05$) only at 60 and 80% RH. One can conclude that moisture affects tensile and compressive creep in a similar way but to a slightly different magnitude. It does not appear that the acceleration of creep in particleboard at 75% RH can be attributed to either tensile or compressive creep behavior, at least with the materials used in this study.

TABLE 4. *Perpendicular-to-grain creep data for solid basswood. Total creep at 100 h. Figures are average of three samples.*

| | Creep, $\times 10^{-4}$ inch | | | |
|---|---|---|---|---|
| | RH (%) | | | |
| Stress type | 50 | 60 | 70 | 80 |
| Compression | 46 | 56 | 65 | 73 |
| Tension | 40 | 46 | 56 | 63 |

## DISCUSSION

This study does confirm the importance of not exposing particleboard under load to conditions above 70% RH for long periods. When so exposed, the nonrecoverable component of creep becomes serious.

Particleboard creep properties, presumably because of random orientation of particles, fall between the properties of wood in the longitudinal and transverse directions. Therefore, one approach that is likely to reduce creep in particleboard is to eliminate the cross-grain components, that is, to align the particles. Observing the importance of grain orientation in flexural creep, the orientation of particles becomes critical to improved mechanical behavior in particleboard.

The flexural creep test had a four point loading arrangement so that creep deflection could be determined under pure bending stress. This eliminated the influence or interference of shear strain in creep deflection. The first phase of the study showed that the bending stress parallel-to-grain is not a major factor in the acceleration of flexural creep behavior of particleboard at higher humidity levels. The second phase of the study showed that tensile and compressive creep perpendicular-to-grain increased linearly with relative humidity. This appears to rule out tensile and/or compressive creep perpendicular-to-grain as being the cause of accelerated flexural creep of particleboard at higher humidities.

Then why does creep in particleboard increase dramatically above 70% RH? A reasonable explanation is proposed here. Libby and Haygreen (1967) found that the transverse tensile stress induced an increase in moisture content of Douglas-fir. They also found that moisture content was affected only to a small degree by stress level. Bello (1968) found that transverse compressive stress decreased equilibrium moisture content of wood and noted that differences tended to increase with relative humidity level. In his study of five North American hardwoods, average change in equilibrium moisture content at 77 F and 87% RH was 1.44%. Simpson (1971), studying the effect of transverse tensile and compressive

TABLE 5. *Analysis of variance of transverse creep data.*

| Source of variation | DF | F |
|---|---|---|
| Humidity (H) | 3 | 43.93** |
| Board type (B) | 1 | 28.88** |
| H × B Interaction | 3 | 0.37 |
| Error | 16 | |

** Significant at $P = 0.01$.

stresses on red oak, found that tensile stress increased moisture content, while compressive stresses decreased moisture content. He also noted that the size of the stress-induced change in moisture content approached 1% at high stress levels and high initial moisture contents. Moisture change increased in an approximately exponential way with initial moisture content. The change was distinctly noticed above 85% RH.

From these studies one can hypothesize how moisture content changes induced by transverse stresses could play an important role in the mechanism of creep. The flexural creep test in this study with a two point loading arrangement has the upper half of the test specimen stressed in tension and the lower half stressed in compression. Because of an increase in moisture content with transverse compressive stress, a moisture gradient is presumably developed across the thickness of the specimen. From the data in the literature, one could assume a change of up to 0.5% in equilibrium moisture content at the higher humidity level (80% RH) in this study. The deformation (apparent deflection) in a bending test induced by such a moisture gradient, that is, by the swelling on the tension side and the shrinkage on the compression side, would be nearly 40% of the total creep deformation which was measured.

Moisture flux is also known to accelerate the creep rate. Bryan and Schniewind (1965) found that sorption increased the creep rate and that the sorption effect was more pronounced in particleboard than in whole wood. These two factors, development of a moisture gradient resulting in shrinkage/swelling on opposite faces, and moisture flux, may explain the nonlinear creep behavior of particleboard and board type WB at higher humidity levels (Fig. 5).

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