STUDIES OF FLEXURAL CREEP BEHAVIOR IN PARTICLEBOARD UNDER CHANGING HUMIDITY CONDITIONS[1]

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ABSTRACT

The effect of changing relative humidity, to cause simple adsorption or cyclic adsorption-desorption, on the creep behavior of particleboard, oriented particleboard, and plywood was studied. For the particular boards studied, creep response was sensitive to the highest humidity to which the boards were subjected. Behavior of both urea and phenolic resin-bonded particleboards was similar. When stressed below approximately 20% of maximum static bending strength, flexural creep was linear with stress level. An increased rate of adsorption had a smaller overall effect than the greatest humidity level to which the board was subjected. A shavings/residue-type particleboard demonstrated accelerated creep behavior above about 75% RH. Although plywood and oriented particleboard had increased creep at the higher humidity levels, there did not appear to be as definite a point where creep rate accelerated. Flexural creep behavior under a single concentrated load was qualitatively similar to that under simple flexural stress.

Additional keywords: Particleboard, oriented particleboard, plywood, moisture content, creep, cyclic testing, relative humidity, mechanical properties, stress level.

INTRODUCTION

The rheological properties of wood-based panels are being recognized for their important implications in developing working stresses and design procedures for a new generation of wood building materials. Traditionally, plywood and lumber have been used for the structural and nonstructural skins of residences. No great concern has arisen over their creep behavior because these materials exhibit relatively elastic behavior if kept dry. As new shavings-flake-wafer-veneer composite sheets are developed, however, questions of rheological behavior become more important.

A substantial amount of research has been reported concerning the rheological properties of solid wood, but much less information is available for particleboard and other composite products. One aspect of creep behavior in composite products that appears to be very significant is the effect of a changing environment. The early work of Armstrong and Christensen (1961), Armstrong and Kingston (1960, 1962), and Hearman and Paton (1964) with solid wood is well known. 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 under some conditions moisture content and sorption effects are more pronounced in particleboard than in whole wood and that sorption generally increases relative creep in particleboard. They also concluded that fluctuating relative humidity considerably increased relative creep over that under constant relative humidity.

Halligan and Schniewind (1972) found that under adsorption conditions particleboard that had a high incidence of thickness swelling also exhibited accelerated creep. They concluded that particleboard would perform more satisfactorily in structural use if precautions were taken to reduce thickness swelling. Haygreen and Sauer (1969) and Sauer and Haygreen

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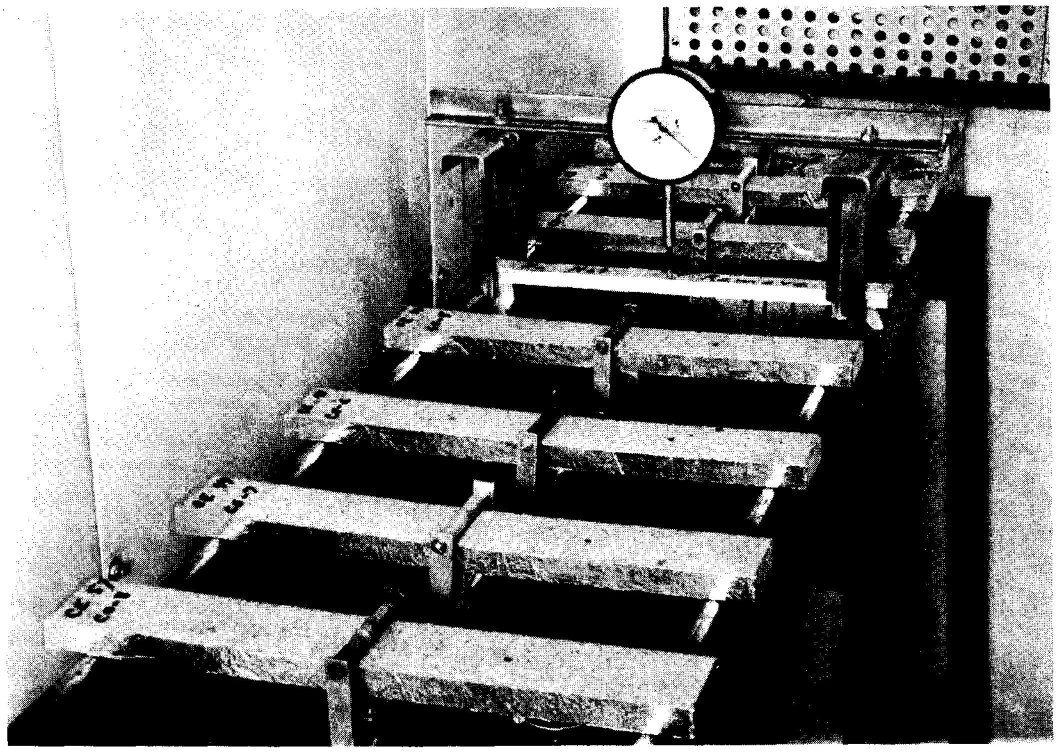

FIG. 1. Method of loading and measuring flexural creep. Note that the edges of samples are covered to force sorption through faces only.

(1968) studied the effect of sorption on the flexural behavior of hardboard and found that both adsorption and desorption increase the rate of creep deformation.

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 high RH are very pronounced. Norimoto and Yamada (1966) tested wood-based materials and found much greater creep in particleboard than in blockboard. Perkitny and Perkitny (1966) examined the relative creep of wood-based materials. They found that the creep of whole wood, particleboard, and hardboard is in the approximate ratio of 1:4:5.

OBJECTIVES

Several aspects of creep in particleboard were studied in three separate experiments summarized in Table 1. The object of these experiments was to evaluate the effect of cyclic humidity on creep, both under situations of simple flexural stress and under concentrated load on a simulated floor system. It has been observed (Nielsen 1972) that creep may be a particular problem once some moderately high "critical" relative humidity level is reached. Therefore, one experiment was directed toward establishing the relative humidity at which creep is accelerated in several commercially produced sheet materials.

In experiment A, both urea- and phenolic-bonded commercial particleboard were subjected to constant and cyclic humidity changes. The stress levels were set at approximately 10% and 20% of the short-term static strength. It was felt that in use structural boards will generally not be subjected to stresses above this level. The cyclic humidity changes were established such

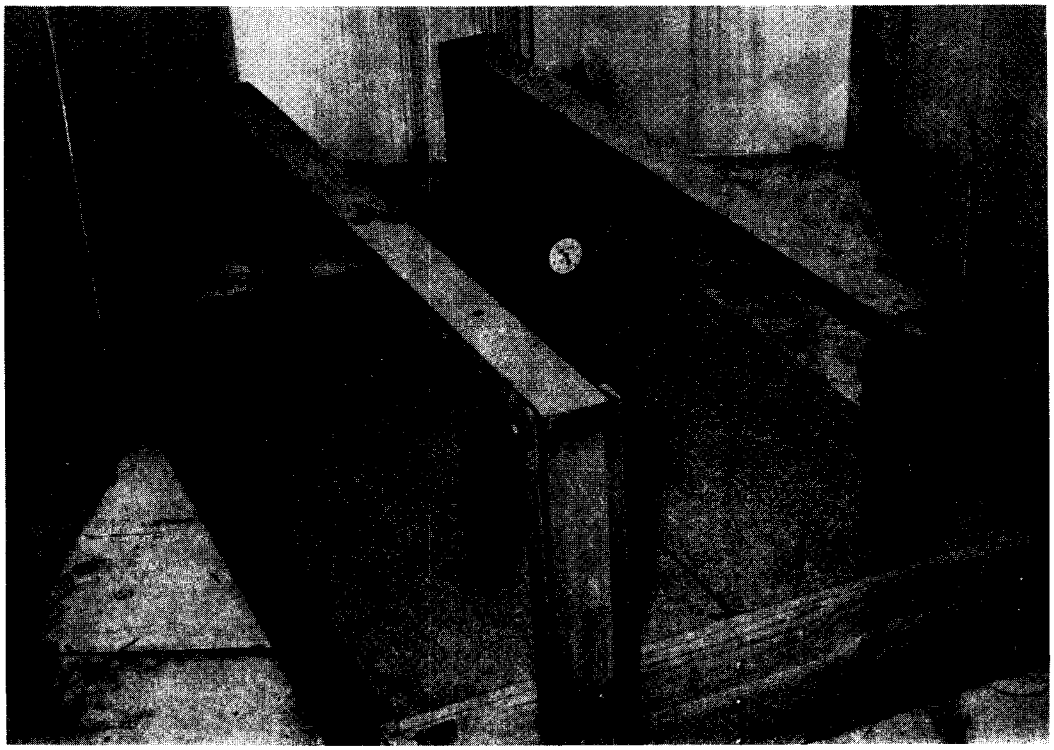

FIG. 2. Method of loading and measuring creep under concentrated load on the 32-inch by 48-inch simulated floor systems.

TABLE 1. *Summary of the three experiments*

	A	B	C
Type of boards	(1) Particleboard--1B2, 5/8" (2) Particleboard--2B2, 5/8"	(1) Particleboard--2B2, 5/8" (2) Oriented Particleboard--5/8" (3) Plywood--Group I, Underlayment Grade, 5/8" Southern pine, 5-ply	(1) Particleboard--2B2, 5/8" (2) Plywood--Group I, Underlayment Grade, 5/8" Douglas-fir, 5-ply
Conditions of test	Temperature--80°F Humidity--(1) Constant--60% RH Cyclically changing, (48-hr cycles) (2) 55 ↔ 65% RH (3) 50 ↔ 70% RH (4) 40 ↔ 80% RH	Temperature--72°F Humidity--(1) Constant--65% RH (2) Constant--70% RH (3) Constant--75% RH (4) Constant--80% RH	Temperature--72°F Humidity--(1) Constant--50% RH (2) Constant--85% RH Cyclically changing, (48-hr cycles) (3) 50 ↔ 70% RH (4) 50 ↔ 85% RH
	Boards conditioned before tests to 60% RH	Boards conditioned before tests to 50% RH	Boards conditioned before tests to 50% RH
Type of loading	Simple flexure--center-loaded, 12" span	Simple flexure--center-loaded, 12" span	Concentrated load on 32" x 48" floor with joists 16" o.c. Loaded midway between joists and 12" from band joist.
Stress level	(1) 550 psi (2) 275 psi	550 psi	200-lb load imposed by 2" dia. rod
Number of replications	8 replications of each board type/condition combination	8 replications of each board type/condition combination	2 replications of each board type/condition combination

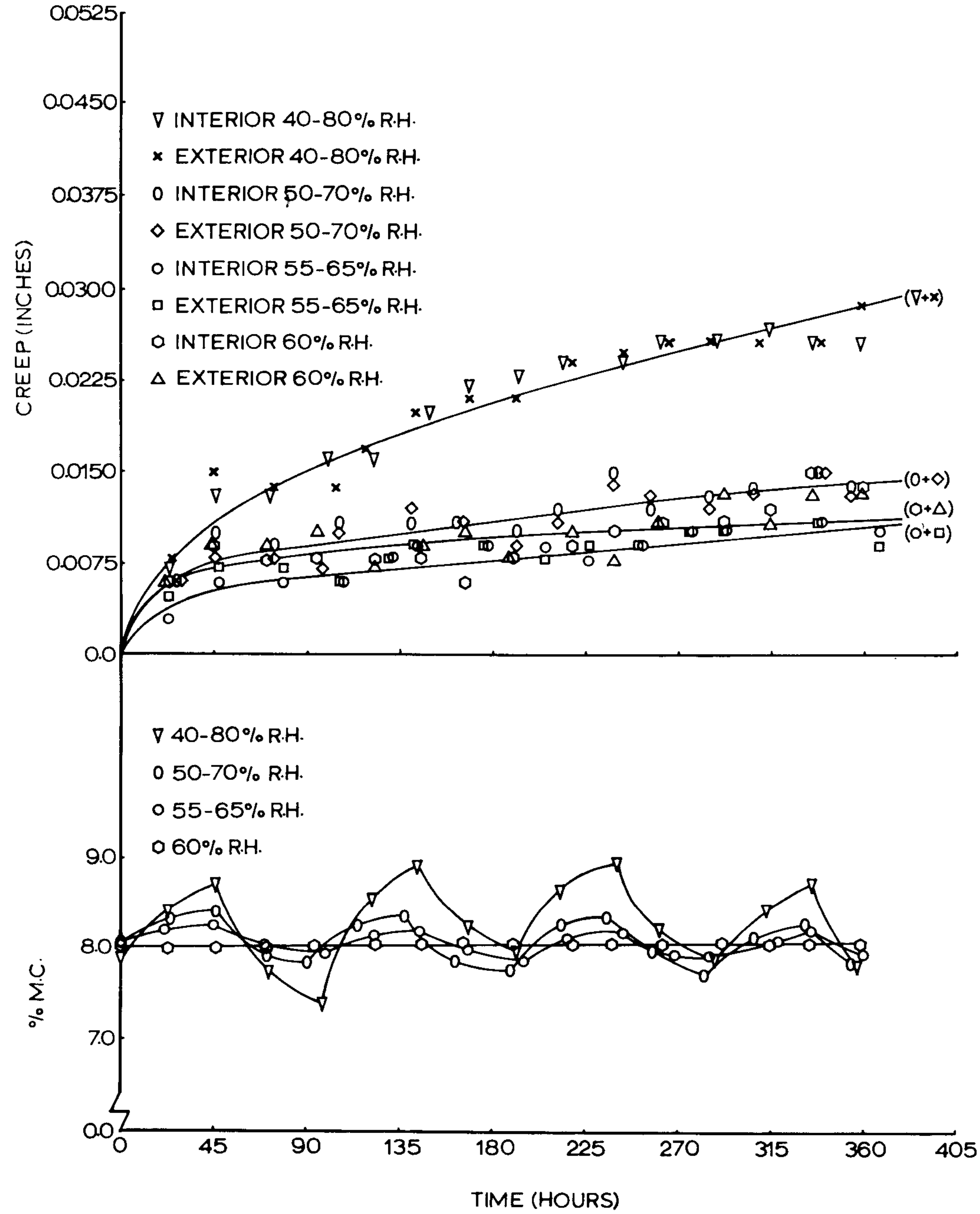

FIG. 3. Creep and moisture content of particleboards in experiment A loaded at the 275 psi flexural stress level. "Interior" and "exterior" refers to boards bonded with urea and phenolic resins, respectively.

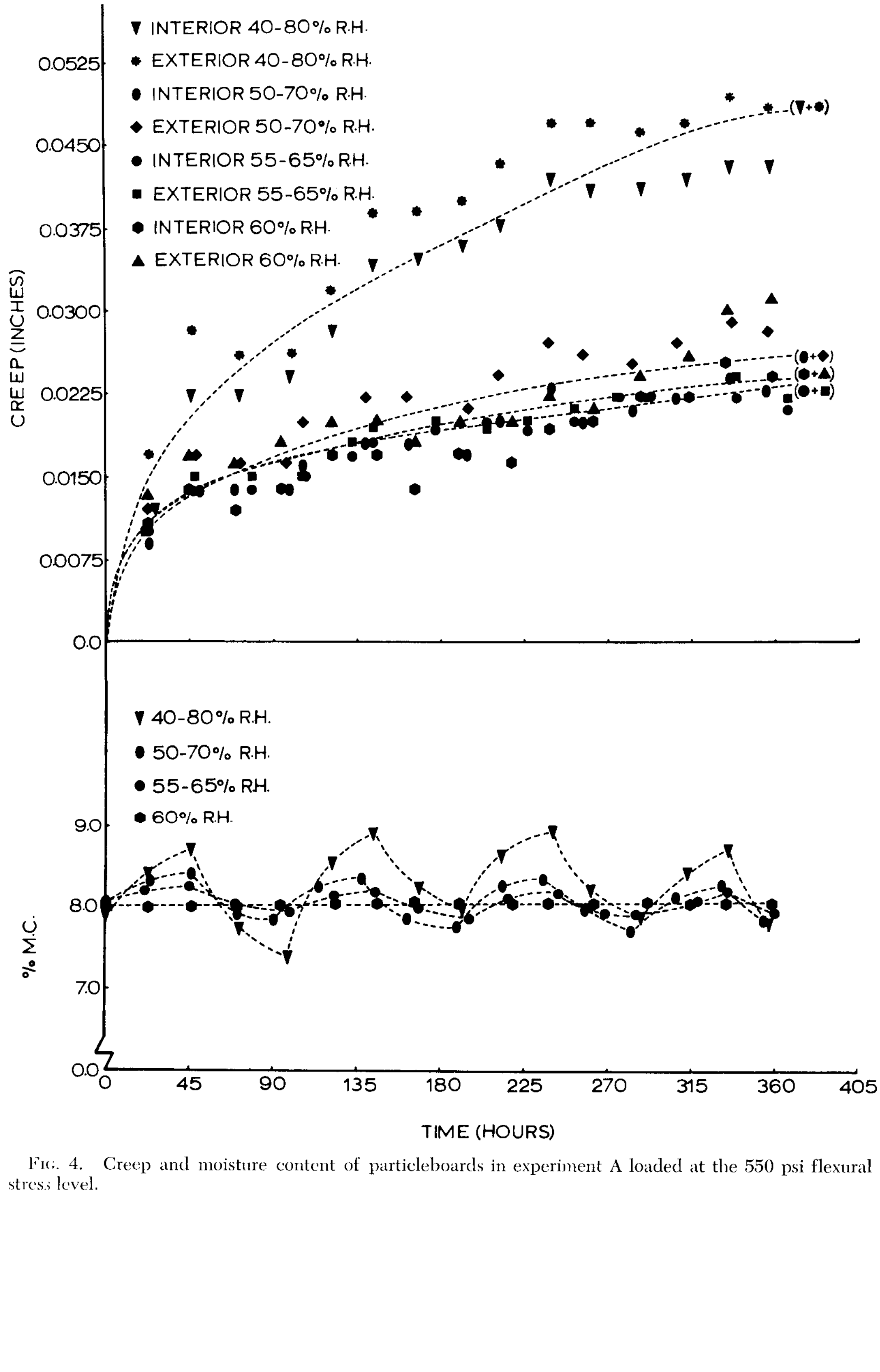

FIG. 4. Creep and moisture content of particleboards in experiment A loaded at the 550 psi flexural stress level.

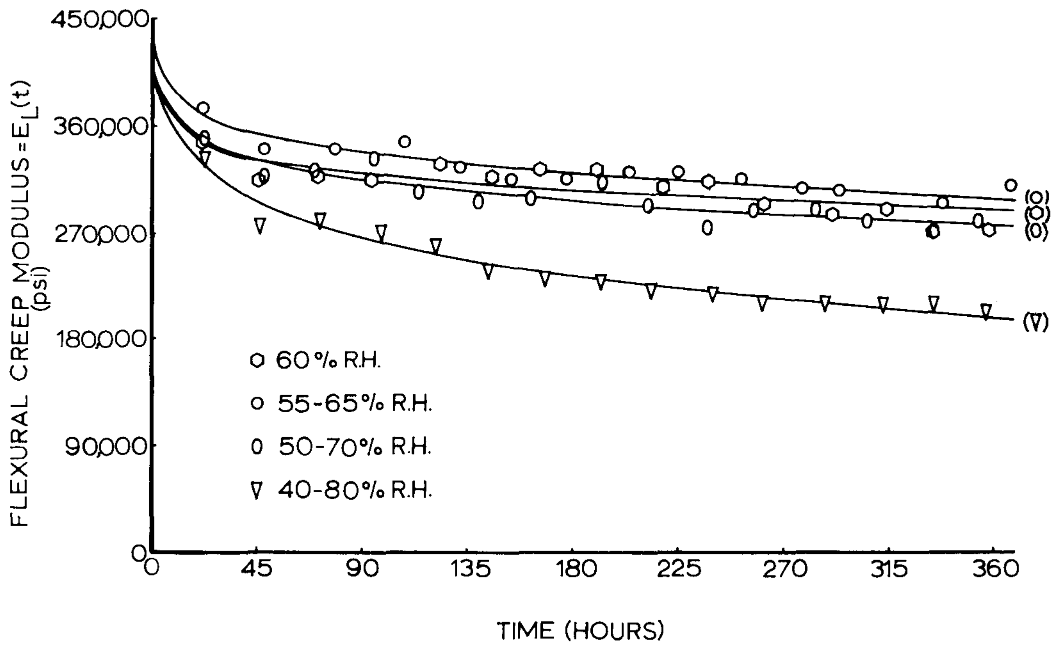

FIG. 5. Flexural creep modulus of particleboards in experiment A loaded at 275 psi.

that the moisture content of the board fluctuated around the same average under all conditions. Therefore, the main effect of the different cycles was in the rate of moisture sorption and not in the average amount of moisture present. The cycles were of short duration to maximize the rate of sorption. It was intended that under the 48-h cycle the boards would not approach equilibrium at the various humidity conditions.

In experiment B the objective was to de-

TABLE 2. *Physical properties of materials used in the three experiments*

Experiment	Product	Type of Board	Resin	Density Mean (PCF)	Density C.V.[a]	Nominal Thickness (inches)	Actual Thickness (inches)	MOR Mean (psi)	MOR C.V.	MOE Mean (10^6 psi)	MOE C.V.
A	Particleboard	1B2[b]	Urea	45.6	2.8	5/8	0.63	2630	6.6	0.404	3.1
A	Particleboard	2B2[c]	Phenolic	45.5	1.7	5/8	0.64	2750	8.8	0.471	7.3
B	Particleboard	2B2[c]	Phenolic	47.6	4.4	5/8	0.62	2624	18.1	0.48	13.1
B	3-layer oriented particleboard	special	Phenolic	38.7	1.3	5/8	0.67	4311	13.5	0.75	12.1
B	Plywood	Group I Underlayment Grade	Phenolic	39.8	2.2	5/8	0.60	9764	6.0	1.05	10.6
C	Particleboard	2B2[c]	Phenolic	48.7	2.0	5/8	0.63	2356	9.2	0.487	8.3
C	Plywood	Group I Underlayment Grade	Phenolic	34.1	1.7	5/8	0.61	6129	15.2	1.15	16.3

[a]C.V. is standard deviation as percentage of mean

[b]Produced for mobile home deck

[c]Produced for manufactured house deck

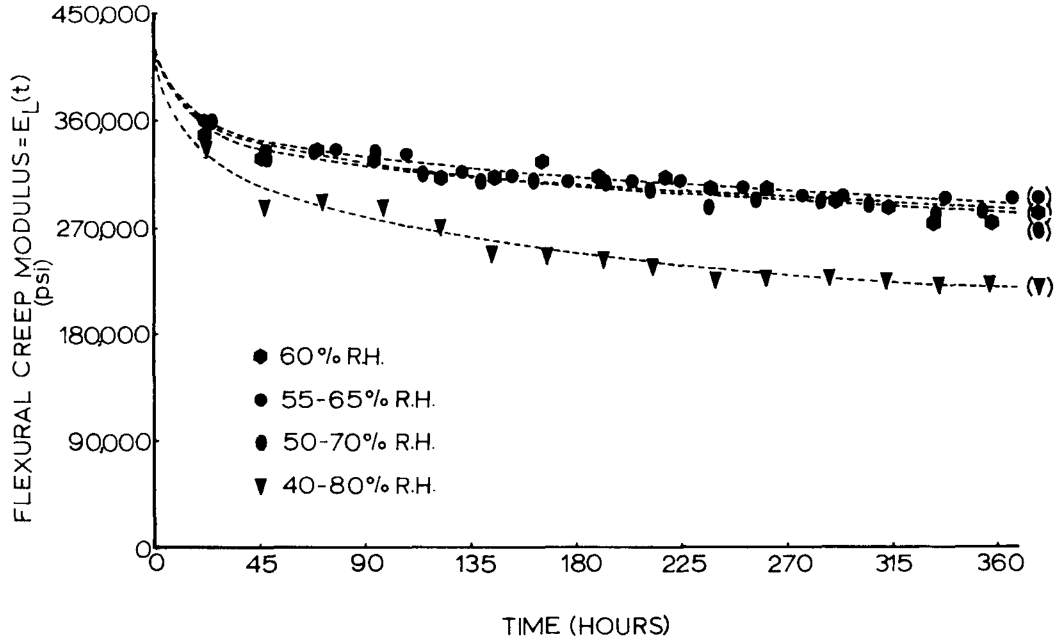

FIG. 6. Flexural creep modulus of particleboards in experiment A loaded at 550 psi.

termine the humidity level at which the creep rate is accelerated. Preliminary work indicated that this effect appears somewhere in the 65% to 80% RH range; therefore four levels of humidity in this range were evaluated. The boards in this study were conditioned to 50% RH and 72 F, then loaded and subjected to the various levels of humidity. Therefore, these creep curves represent behavior during sorption to increasing moisture content conditions. Plywood was included to allow a comparison of particleboard behavior to that of a wood product with complete grain orientation. Also, a particleboard with oriented flakes and three-layer laminated construction was used to evaluate the effect of aligning particles with the principal stress axis. It can be hypothesized that creep development may be highly influenced by the proportion of the furnish in which stresses develop in a cross-grain direction within particles.

Experiment C was designed to evaluate creep under a situation of concentrated load rather than the simple flexural stress as used in experiments A and B. Such loading results, of course, in complex stress development and simulates a type of long-term loading to which floor systems are actually subjected. The load level of 200 pounds was selected because it is used in some building standards as the basis for floor deflection criteria. In only a few situations do concentrated loads in residences exceed this level. Particleboard manufactured housing deck and plywood were used, both of a grade intended for single layer combined subfloor/underlayment floor systems. Creep was measured under a constant high and a constant normal relative humidity level as well as under a moderate and a severe humidity cycle. The 50% to 70% RH cycle was below the relative humidity level where creep was found to be accelerated in experiment B while the 50% to 85% RH cycle exceeded that critical relative humidity.

EXPERIMENTAL PROCEDURE

In both the simple flexural and concentrated load creep experiments, instantaneous deflection was measured as the load was applied. Deflection at approximately 5 seconds was termed elastic deflection (Δ_0) and the modulus computed from Δ_0 in the

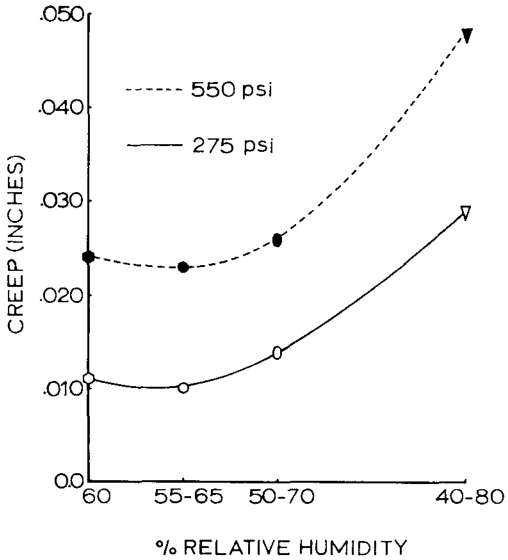

FIG. 7. Creep at 360 h in experiment A shown as a function of the highest humidity attained during the cycles. The 60% RH point shows creep at constant humidity.

simple flexural tests was termed the elastic modulus (E_o). Deflection occurring after initial loading (5 seconds) was termed creep deflection (Δ_o). Relative creep (R_c) is then:

$$R_c = \frac{\Delta_c}{\Delta_o} \qquad (1)$$

The use of a creep modulus E_l is sometimes convenient for engineering purposes since deflections can be calculated using conventional elastic deflection theory. Nielsen (1972) discusses applications of the creep modulus. The creep modulus is defined as:

$$E_l = \frac{E_o}{1 + R_c} \text{ or } \frac{E_o}{1 + \frac{\Delta_c}{\Delta_o}} \qquad (2)$$

The general procedures for flexural and concentrated load tests were as follows. In the flexural tests 2- × 14-inch specimens were simply supported on steel rails with a 12-inch span (Fig. 1). Loading was provided by weights hung from the midspan. Deflection measurements were made with a

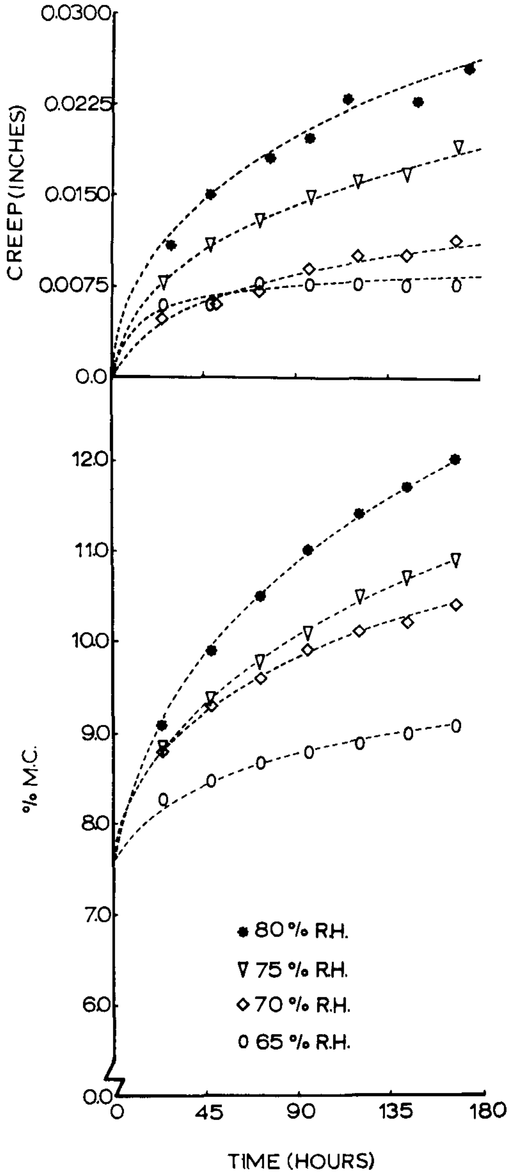

FIG. 8. The creep and moisture content of plywood in experiment B when adsorbing at four RH levels.

dial gauge on a movable frame. Graphite was placed on the rails and lower surface of the test strips to lower friction at the supports although some lateral forces still may have developed. The deflection measurement device in experiments A and B was such that increases in thickness of the speci-

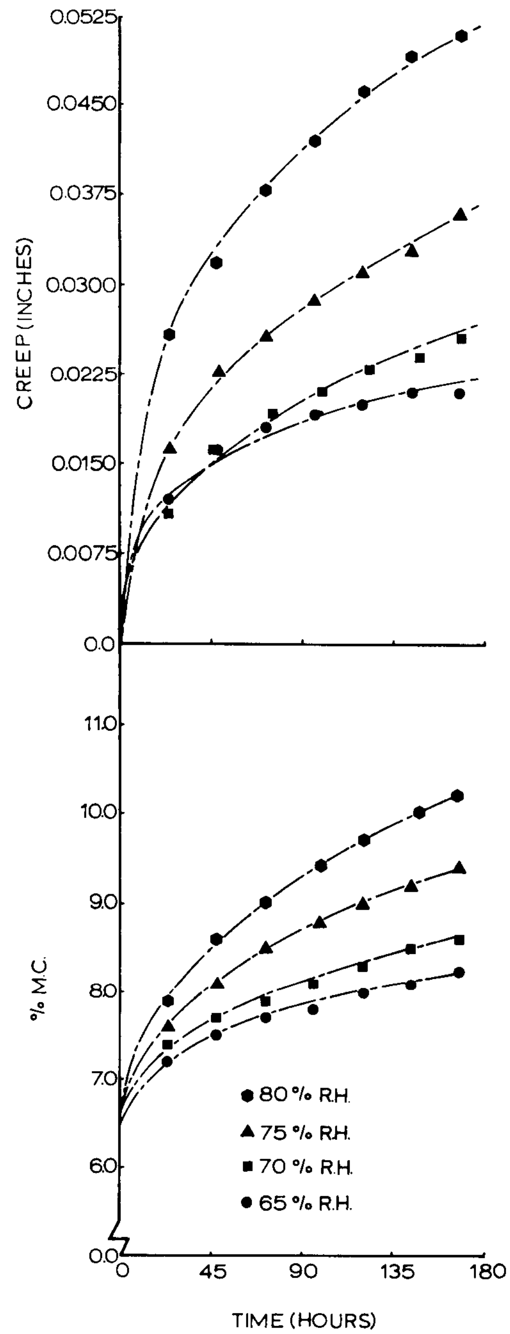

FIG. 9. The creep and moisture content of oriented particleboard in experiment B when adsorbing at four RH levels.

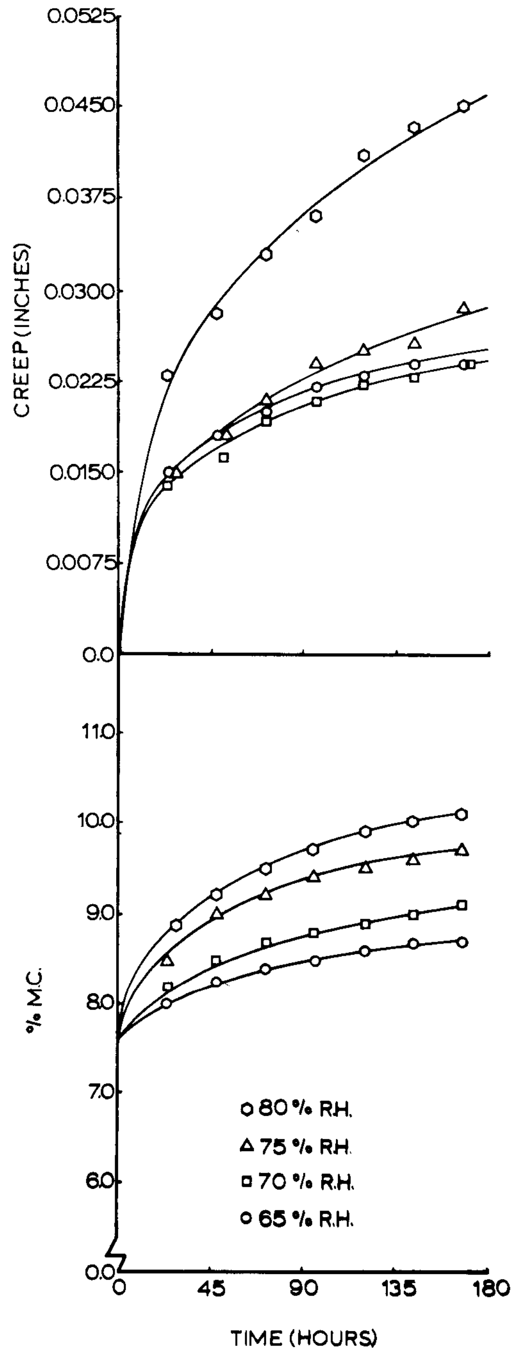

FIG. 10. The creep and moisture content of residue/shavings particleboard in experiment B when adsorbing at four RH levels.

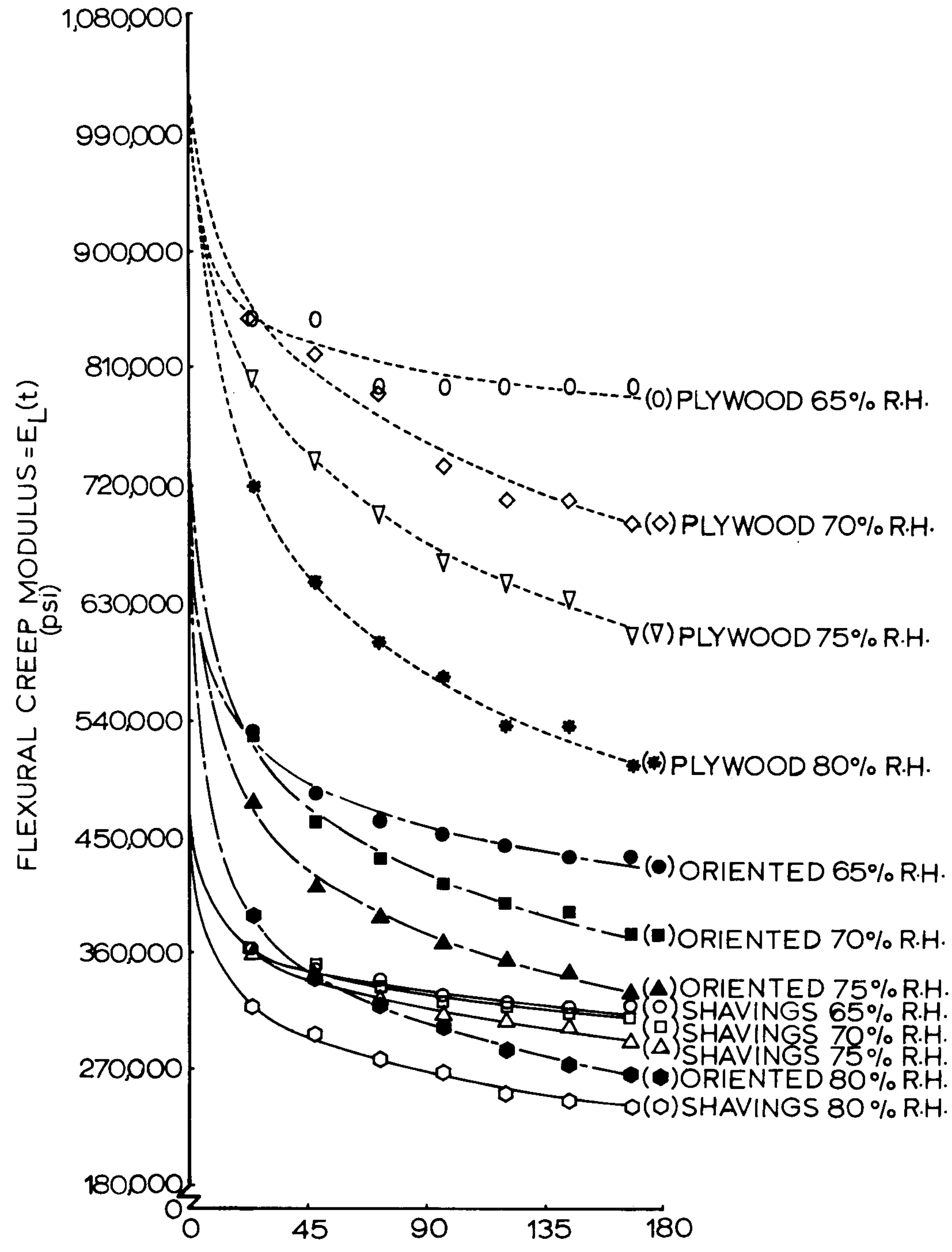

FIG. 11. Flexural creep modulus in experiment B for three board products during adsorption for 168 h.

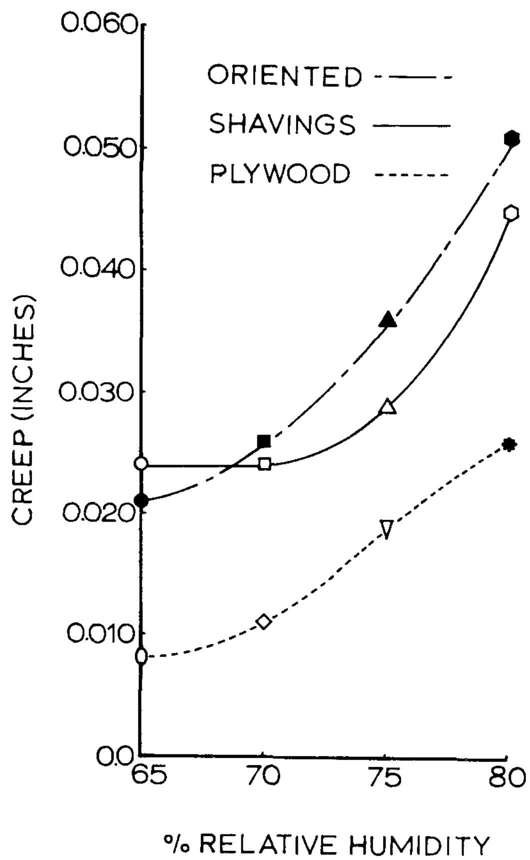

FIG. 12. Creep at 168 h in experiment B as a function of RH.

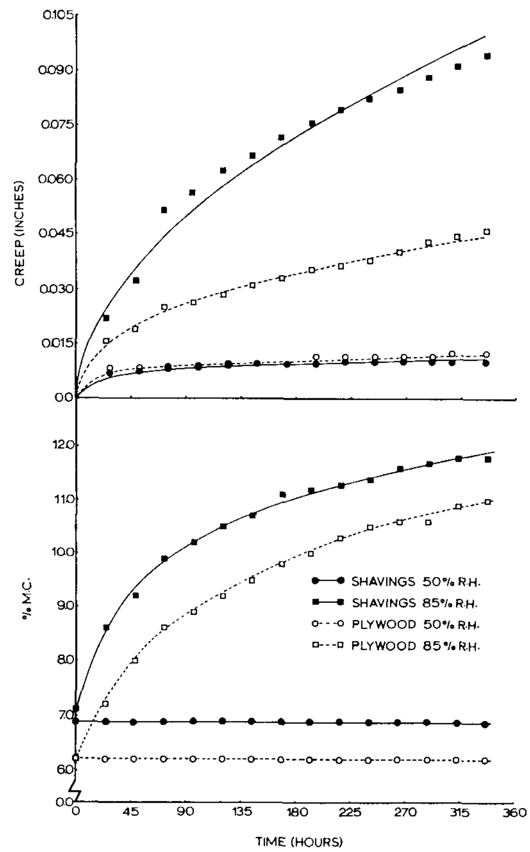

FIG. 13. Creep and moisture content in experiment C under constant 50% RH and adsorbing under constant 85% RH. "Shavings" refers to the shavings/residue type of particleboard.

mens during the course of the experiment reduced the recorded deflection by an equivalent amount. This problem was not realized immediately; therefore, correction of the data was accomplished from swelling information collected from identical sorption experiments. In most cases these corrections were minor, involving less than a 5% adjustment.

Concentrated load tests were conducted on 32- × 48-inch panels nailed to wood frames consisting of three joists 16 inches-on-center running the 48-inch length. On each wood frame two loading devices were fixed and the load on the 2-inch-diameter ram was adjusted to 200 pounds. The loading points on each panel were separated by the center joist as shown in Fig. 2. Preliminary work indicated that the load at one point on the panel did not affect the elastic deflection at the other load point. Because of limited environment-room space, only two replications could be completed. A movable dial gauge was used to measure the deflection of the panels.

In all tests moisture content changes were determined by periodically weighing dummy samples that were not under load. In experiments A and B the edges of all samples were covered with foil so that sorption occurred through faces only. This is important in small creep tests under sorption conditions if these tests are to be used to understand behavior of large-size sheets. Moisture sorption on the surface has a much different effect than in the core.

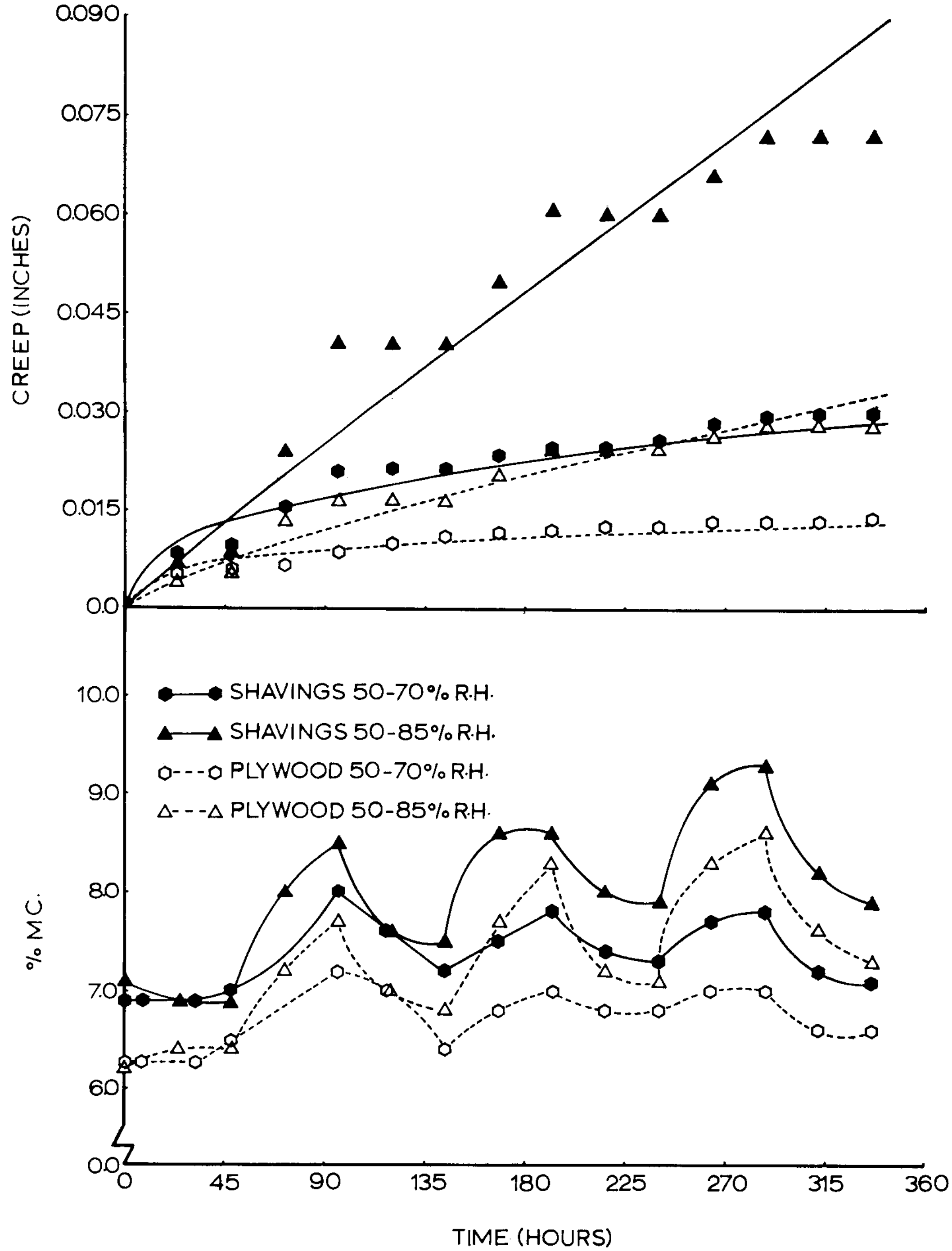

FIG. 14. Creep and moisture content in experiment C under cyclic RH conditions.

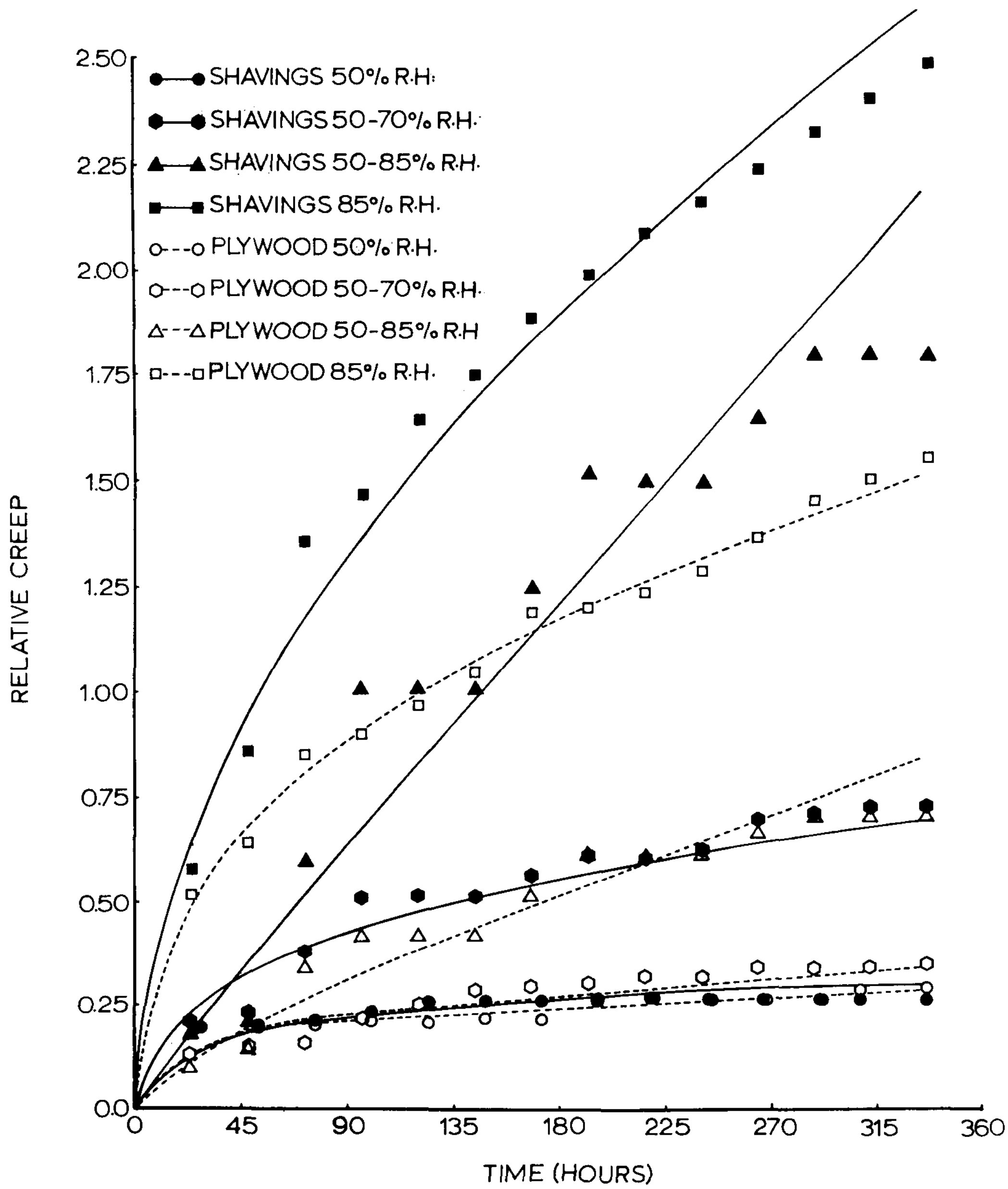

FIG. 15. Relative creep under concentrated loads in experiment C.

The panels used in all tests were commercially produced. A description and some properties of the boards used are shown in Table 2. The phenolic- and urea-bonded particleboards in experiment A were produced by the same manufacturer from the same type of furnish and at approximately the same density. All particleboards used, except the oriented flakeboard in experiment B, were planer-shavings/residue type boards.

Among the many empirical creep-time functions used in studies of rheological behavior, the power function is perhaps the

TABLE 3. *Simple flexural creep data for experiment A*

Stress Level	Board Type	Symbol	R.H. Level ( )	Creep Power Function: Creep equation[a]	Creep Power Function: R^2	Elastic Deflection (inches)	Predicted Relative Creep at 360 hours (interior & exterior ave.)
low = 275 psi	interior	⬡	60	$0.00306(t)^{0.223}$	0.512	0.024	0.48
	exterior	△	60			0.022	
	interior	○	55 ↔ 65	$0.00158(t)^{0.321}$	0.813	0.025	0.42
	exterior	□	55 ↔ 65			0.022	
	interior	⬯	50 ↔ 70	$0.00247(t)^{0.294}$	0.792	0.027	0.57
	exterior	◇	50 ↔ 70			0.022	
	interior	▽	40 ↔ 80	$0.00206(t)^{0.448}$	0.947	0.027	1.18
	exterior	×	40 ↔ 80			0.022	
high = 550 psi	interior	⬢	60	$0.00493(t)^{0.266}$	0.686	0.048	0.53
	exterior	▲	60			0.043	
	interior	●	55 ↔ 65	$0.00442(t)^{0.279}$	0.942	0.050	0.49
	exterior	■	55 ↔ 65			0.043	
	interior	⬮	50 ↔ 70	$0.00405(t)^{0.314}$	0.805	0.053	0.54
	exterior	◆	50 ↔ 70			0.043	
	interior	▼	40 ↔ 80	$0.00427(t)^{0.413}$	0.897	0.054	1.00
	exterior	✱	40 ↔ 80			0.042	

[a] t in hours

most common. It was used throughout these experiments in various forms to investigate creep modulus and relative creep. A simple linear flexural stress distribution was assumed such that the form used in uniaxial stress studies can also be used in flexure, as follows:

$$\Delta_c = a \cdot t^b \tag{3}$$

Tables 3, 4, and 5 show the power functions that fit the various experiments, along with the elastic deflections and the final relative creep.

The relationship between creep modulus and time was determined from:

$$E_\ell = \frac{E_0}{1 + \frac{a t^b}{\Delta_0}} \tag{4}$$

where a and b were established from the power equation of the experimental creep curves using these values from Tables 3 and 4. To illustrate this relationship, experimental results from experiments A and B are shown in Figs. 5, 6 and 11.

Experiment A (simple flexural creep under cyclic relative humidity)

In this experiment the tests were run for 360 h. During that time creep appeared to be linear at the stress levels used, i.e., creep at 550 psi was approximately double that at 275 psi. Creep in urea-bonded and phenolic-bonded board was not statistically different even under severe humidity conditions; therefore data for interior and exterior boards were combined in Figs. 3 to 7. Figures 3 to 6 illustrate creep and creep modulus as functions of time. Figure 3 shows creep behavior under the low stress and Fig. 4 under the high stress level. Creep modulus curves shown in Figs. 5 and 6 were computed using equation (4); the data points represent calculations based upon recorded deflections at the corresponding time. In these figures the designation "interior" refers to urea-bonded boards, while "exterior" refers to phenolic boards.

TABLE 4. *Simple flexural creep data for experiment B*

Stress Level	Board Type	Symbol	R.H. Level (%)	Creep Power Function: Creep equation[a]	Creep Power Function: R^2	Elastic Deflection (inches)	Relative Creep at 168 hours
high = 550 psi	shavings	○	65	$0.00691(t)^{0.254}$	0.990	0.047	0.51
	oriented	●	65	$0.00506(t)^{0.287}$	0.966	0.029	0.72
	plywood	O	65	$0.00337(t)^{0.178}$	0.755	0.025	0.32
	shavings	□	70	$0.00546(t)^{0.290}$	0.986	0.043	0.56
	oriented	■	70	$0.00292(t)^{0.430}$	0.990	0.026	1.00
	plywood	◇	70	$0.00121(t)^{0.429}$	0.964	0.021	0.52
	shavings	△	75	$0.00509(t)^{0.334}$	0.988	0.044	0.66
	oriented	▲	75	$0.00470(t)^{0.397}$	0.989	0.028	1.28
	plywood	▽	75	$0.00205(t)^{0.432}$	0.996	0.026	0.73
	shavings	⬡	80	$0.00724(t)^{0.356}$	0.992	0.045	1.00
	oriented	⬢	80	$0.00874(t)^{0.346}$	0.998	0.028	1.82
	plywood	✱	80	$0.00280(t)^{0.433}$	0.993	0.024	1.08

[a] t in hours

Note that boards subjected to the 55–65 RH cycles exhibited about the same creep as boards at a constant 60% relative humidity. The 50–70% RH cycles produced only slightly greater creep. Boards subjected to 40–80% RH cycles, however, developed much more creep.

The swelling and mechanical behavior of particleboard are known to be sensitive to high moisture conditions. Here creep was greatly accelerated when subjected to a relative humidity in excess of 70%, i.e., 80%. Continual adsorption-desorption cycles about 60% RH did not result in appreciably greater creep than at a constant 60% unless an RH above 70% was encountered. This suggests that the maximum humidity level to which a board is subjected has greater influence on creep development than does the rate of sorption on the surfaces under high flexural stress. Figure 7 is an attempt to illustrate this relationship in another way. The data are shown with the highest RH encountered during the cycle plotted on the x axis.

Experiment B (simple flexural test)

Analysis of variance of this 3 × 4 factorial experiment indicated that relative humidity and type of board both exhibited significantly different creep development. Figures 8, 9, and 10 show the creep of plywood, oriented particleboard and particleboard under different moisture regimes. As in experiment A, the creep curves shown are from equation (3) with a and b determined from data. Moisture content during the tests is also shown. Creep tests for the three board types at each relative humidity level were carried out together. Thus differences in moisture sorption between board types are not a result of varying experimental control of the RH.

The absolute creep rates for the two particleboards, Figs. 9 and 10, are significantly higher than for the plywood, Fig. 8, under all relative humidity conditions. However, a different impression of relative behavior is obtained if the creep modulus-time relationship shown in Fig. 11 is examined. The loss of flexural modulus with time is quite similar for the two particleboards and plywood, the primary difference being that the initial modulus for plywood is much greater.

The main difference between the two types of particleboard is that in the oriented board there is fairly uniform increase in creep as relative humidity is increased, while in the shavings/residue type board there was a sharp increase in creep after 75% RH was exceeded. Figure 12 illustrates

TABLE 5. *Concentrated load creep data for experiment C*

Board Type	Symbol	R.H. Level (%)	Creep Power Function: Creep equation[a]	Creep Power Function: R^2	Elastic Deflection	Relative Creep at 336 hours
shavings	●	50	$0.00233(t)^{0.267}$	0.953	0.0365	0.27
plywood	○	50	$0.00331(t)^{0.222}$	0.967	0.043	0.29
shavings	■	85	$0.00452(t)^{0.533}$	0.969	0.038	2.49
plywood	□	85	$0.00402(t)^{0.414}$	0.992	0.0295	1.56
shavings	⬢	50 - 70	$0.00296(t)^{0.392}$	0.942	0.041	0.73
plywood	⬡	50 - 70	$0.00231(t)^{0.299}$	0.932	0.0395	0.35
shavings	▲	50 - 85	$0.00036(t)^{0.945}$[b]	0.923	0.040	1.80
plywood	△	50 - 85	$0.00040(t)^{0.757}$	0.932	0.0395	0.71

[a] t in hours

[b] See Fig. 14. If the 24- and 48-hour data points are omitted, a better prediction is obtained by $0.00169(t)^{0.658}$

creep after 180 h as a function of relative humidity. Note here the similarity between plywood and oriented particleboard. Creep in plywood in this experiment appears as sensitive to RH as in oriented particleboard. Creep in shavings/residue board is less sensitive to RH changes between 60 and 75% RH but more sensitive above 75% RH.

Experiment C (concentrated load test)

It is evident from experiments A and B that the maximum level which the relative humidity periodically reaches is a very important environmental factor determining the magnitude of creep. Both plywood and particleboard decking exhibited an increased rate of creep under absorption to increasing RH levels. Under the concentrated loading of experiment C, these relationships were found to be essentially the same. In Fig. 13 the greatly increased creep during adsorption to constant 85% RH is very pronounced for both particleboard and plywood as compared to the relatively stable deflection at a constant 50% RH. After two weeks of loading, absorption creep to 85% RH was four times greater in plywood than that under constant 50% RH, while creep in particleboard was eight times greater.

The effects of cyclic humidity are presented in Fig. 14. Little or no creep develops under the desorption portion of the cycle as can be noted from the uneven nature of the data points. Therefore, the samples subjected to continual sorption to 85% RH in Fig. 13 exhibited greater creep than those subjected to cyclic conditions where creep occurs only on the adsorption cycle.

Under concentrated load, particleboard decking was more sensitive to high moisture or relative humidity conditions than was plywood. These results are consistent with those of the simple flexural tests in experiment B. The 50% RH test did not produce much difference in creep between these two types of panels. However, under 85% RH the creep in particleboard was twice as great as that of plywood. Under the 50–70% RH and 50–80% RH cycles, the creep of particleboard was two and three times that of plywood.

Because of complexities of establishing a flexural modulus under concentrated load situations, the relative creep shown in Fig. 15 was used as a means of comparison rather than the E_l as in experiments A and B. Relative creep during 315 h varied from about 0.25 for a stable 50% RH environment to 1.5 and 2.5 for plywood and particleboard respectively at a stable 85% RH.

It is not possible from these experiments to make a quantitative comparison between creep under concentrated loading and that under simple flexural stress. However, in a qualitative way it can be seen that the general response to environment changes is similar. At 50% RH particleboard compares more favorably with plywood in concentrated load tests than it does in simple bending tests where the flexural stresses imposed act only in one direction. This may be because of its similar flexural properties in all directions in the plane of the board.

CONCLUSIONS

This report summarizes the results of three experiments dealing with the effects of changing relative humidity on creep behavior in particleboard. Because these experiments were conducted on different boards under different conditions and with two types of loading, caution must be used in making comparisons between experiments. The reader should also be aware that creep behavior varies widely between types and groups of plywood and also between particleboard produced from varying furnishes with different processes. Keeping these limitations in the scope of this study in mind, it does seem possible to propose some conclusions that complement what is presently known about rheological behavior of particleboard.

1. Flexural creep is linear, i.e., proportional to stress below approximately 20% of the maximum static bending strength.

2. The creep behavior of a urea-bonded board is not significantly different from a phenolic-bonded product.

3. The amount of creep that develops is very sensitive to the highest RH to which the board is subjected. Increasing the rate of sorption at the surfaces of the boards has only a small effect on creep rate as long as high humidity levels are not encountered.

4. In a shavings/residue type-particleboard, flexural creep is accelerated if the relative humidity exceeds about 75%. In plywood and oriented particleboard, creep increases as RH is increased, but there does not appear to be as definite a point where acceleration of creep rate occurs.

5. Flexural creep behavior under concentrated load is qualitatively similar to that under simple flexural stress. There appears to be no reason that simple flexural stress studies cannot be used to evaluate environmental or product differences for the actual concentrated load situations that typically occur in floor constructions.

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