CREEP BEHAVIOR OF GLASS FIBER REINFORCED HARDBOARD[1]

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ABSTRACT

The flexural creep deflection of a dry-process hardboard matrix was significantly reduced by internal reinforcement with continuous glass fibers. The short-term flexural creep of glass fiber reinforced hardboard stressed within the elastic range at constant ambient conditions is well described by a 4-element linear viscoelastic model. Numerical estimates of creep model parameters are presented.

Keywords: Hardboard, reinforced wood composite, wood fiber, glass fiber, creep.

INTRODUCTION

Previously, the flexural properties of a dry-process hardboard matrix internally reinforced with continuous glass fibers were reported (Smulski and Ifju 1987). In the present paper the flexural creep behavior of the same glass fiber reinforced hardboard composite is examined.

The creep response of hardboard to various environmental and loading conditions has been established (Lundgren, 1957, 1969; Moslemi 1964a, b; Sauer and Haygreen 1968; Haygreen and Sauer 1969; Armstrong and Grossman 1972; Sutula and Moslemi 1973). These earlier studies showed that like solid wood and other wood-based composites, hardboard exhibits linear viscoelastic behavior at low-to-moderate levels of stress and moisture content. The magnitude and rate of creep deflection of hardboard under constant ambient relative humidity increase with increasing moisture content, stress, temperature, and time under stress. Under fluctuating relative humidity, creep rate and deflection are further increased, with the greatest change occurring during periods of desorption. A marked reduction of creep deflection when plywood and particleboard panels were surfaced with glass fiber reinforced polymer overlays (Boehme 1976) suggested that this technique may be effective in reducing hardboard creep deflection.

The objectives of this study were: 1) to examine the effect of reinforcement volume fraction on the flexural creep of glass fiber reinforced hardboard, and 2)

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to estimate the parameters of a 4-element linear viscoelastic model chosen to represent the composite's creep behavior. The results of this study will assist the selection of glass fiber reinforced hardboard composites for structural applications.

SYMBOLS

E_e	instantaneous modulus of elasticity (psi)
E_d	delayed modulus of elasticity (psi)
MOE	apparent modulus of elasticity (psi)
t	time (h)
V_f	glass fiber reinforcement volume fraction
ϵ	strain (in in.$^{-1}$)
η_d	delayed coefficient of viscosity (psi-h)
η_v	viscous coefficient of viscosity (psi-h)
σ	bending stress (psi)
τ	retardation time (h)

MATERIALS AND METHODS

Composite fabrication

Fabrication details for the wood fiber/glass fiber composite have been described previously (Smulski and Ifju 1987). Briefly, thermomechanical wood fiber, consisting of mixed hardwood fibers and phenolic resin and petrolatum additives, was used to produce ¼-inch-thick dry-process hardboard panels at a specific gravity of 0.95. In addition to nonreinforced controls, hardboard panels reinforced with 1, 2, or 3 plies of a woven glass fiber fabric at 0.01-inch intervals below each surface were produced. As reasoned in the previous work (Smulski and Ifju 1987), the effective reinforcement volume fraction for 1, 2, and 3 plies of glass fiber beneath each surface was 0.0073, 0.0158, and 0.0260, respectively. A powdered phenol-formaldehyde resin was used to bond the reinforcement to the matrix. Following conditioning to 4% moisture content, specimens were cut from the central portion of each panel with the continuous glass fibers oriented parallel to specimen length.

The midspan creep deflection of 3 composite beam replications at each effective reinforcement volume fraction was monitored for 4 hours under two load levels. The test apparatus accommodated a 2-inch by 10-inch specimen simply supported over an 8-inch span. The load was applied at two points 2 inches apart and symmetric about the specimen midspan. The loading head was supported on its underside by an overhead bracket that straddled the specimen. The bracket was manually lowered with a gear-and-rack mechanism, and descended from beneath the loading head once contact was made with the specimen. With this system, the specimen was loaded instantaneously in a smooth and highly controlled manner.

The beams were stressed within the elastic range at a nominal 650 or 1,110 psi at constant ambient conditions. The former value was calculated to be nominally 50% of the stress at proportional limit for the nonreinforced hardboard control; the latter was nominally 50% of the stress at proportional limit for hardboard reinforced with the greatest glass fiber volume fraction. Midspan deflection was measured to 0.0001 inch with a linear variable differential transducer interfaced

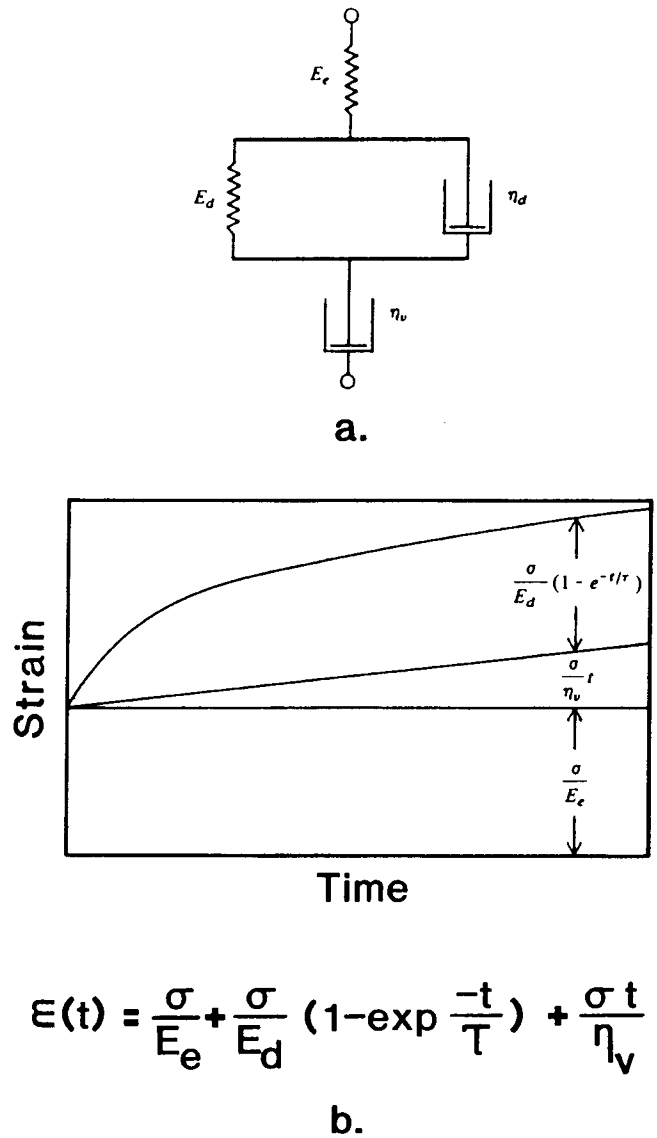

FIG. 1. (a) Four-element Burger model for creep of linear viscoelastic materials. (b) Flexural creep strain versus time as per the Burger model.

with a multimeter, calculator/controller, and printer that comprised an automated data acquisition system.

The instantaneous elastic deflection was measured with minimal error. A clock in the calculator/controller triggered execution of a program that recorded pre-stress data. Stress was then applied 1 second before the next scheduled reading, so that its application was concurrent with program execution. Creep deflection accrued rapidly during the first 20 minutes, and was measured every 15 seconds. By 20 minutes' time, the rate of creep had slowed considerably. Henceforth, deflection was measured every 5 minutes.

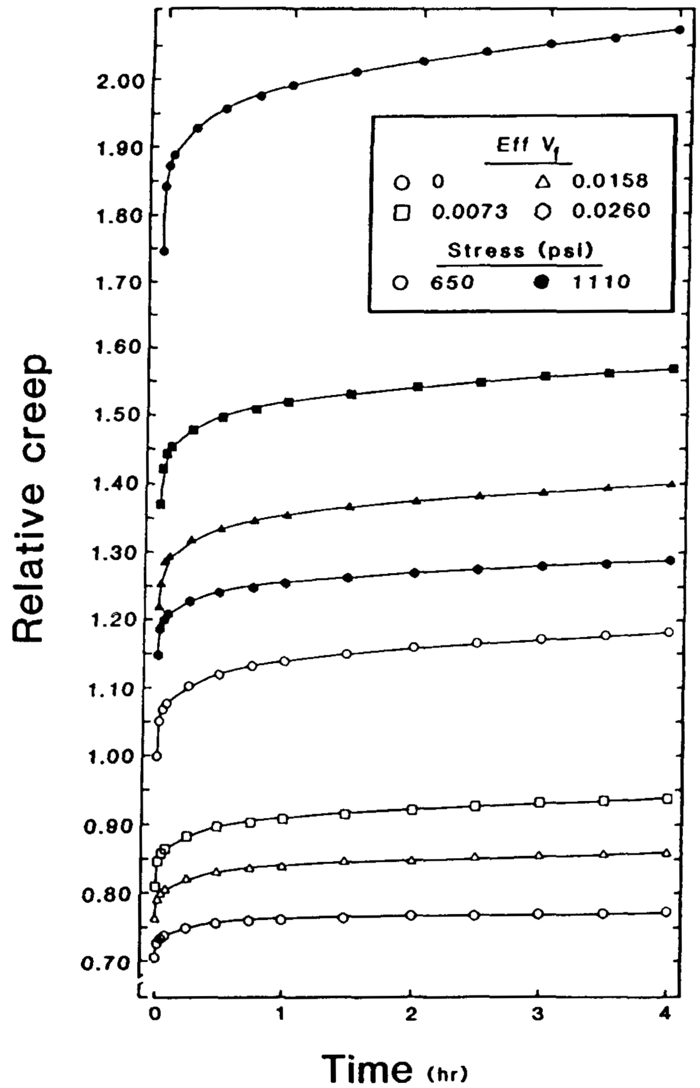

FIG. 2. Influence of effective reinforcement volume fraction (Eff V_f) and stress level on the relative creep of glass fiber reinforced hardboard with time.

Estimation of creep model parameters

A 4-element linear viscoelastic model was chosen to represent the creep behavior of glass fiber reinforced hardboard within the elastic range. The sufficiency of the model has been confirmed for solid wood (Senft and Suddarth 1971; Szabo and Ifju 1970), particleboard (Pierce and Dinwoodie 1977; Pierce et al. 1979, 1985), and wet-process hardboard (Moslemi 1964a).

A mechanistic representation of the Burger model is shown in Fig. 1a. The lone spring and dashpot represent, respectively, the instantaneous elastic and viscous responses to an applied stress; the spring and dashpot paired in parallel represent the delayed elastic, or viscoelastic response. Upon application of stress, the elastic

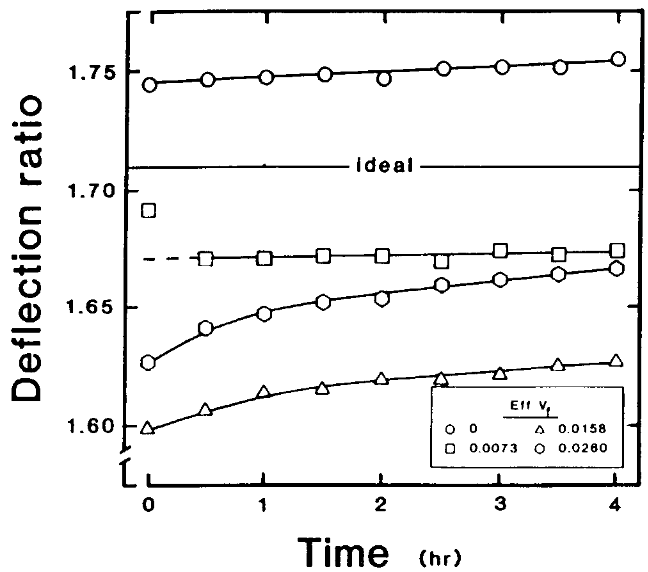

FIG. 3. Influence of effective reinforcement volume fraction (Eff V_f) on the creep deflection ratio of glass fiber reinforced hardboard with time. The deflection ratio is equal to the observed deflection under a stress of 1,110 psi divided by the deflection observed under a stress of 650 psi. A deflection ratio of 1,110/650 = 1.71 represents ideal linear viscoelastic behavior.

element deforms instantaneously. The viscoelastic and viscous elements gradually deform with time. Deformation in the elastic and viscoelastic elements is recoverable following stress removal, while that in the lone viscous element persists as an irrecoverable strain.

The mathematical analog of the Burger model expresses the total axial strain developed during flexure as the sum of the strains developed in its elastic, viscoelastic, and viscous components with respect to time under stress (Fig. 1b) (Flügge 1975):

$$\epsilon(t) = \frac{\sigma}{E_e} + \frac{\sigma}{E_d}\left(1 - \exp\frac{-t}{\tau}\right) + \frac{\sigma t}{\eta_v}$$

The retardation time, τ, is equal to η_d/E_d.

Creep deflection/time data were fitted to the Burger model using nonlinear least squares regression (Department of Biomathematics 1981). Since deflection, and not strain, was measured during testing, creep deflection was converted to creep strain through the observed instantaneous modulus of elasticity, E_e. Graphic estimates taken from high resolution creep strain/time plots served as initial estimates for the model parameters. With the computerized regression analysis, estimates of model parameters (E_e, E_d, η_v, and τ) were continuously adjusted within specified limits until the residual sum of squares attained a minimum value. Limits were defined as ± 10 percent of the initial estimates.

It was assumed that nonreinforced and glass fiber reinforced hardboard behaved as a linear viscoelastic material. Deflection due to shear was ignored, given the low load levels employed and the use of two-point loading. Estimates of the model

TABLE 1. *Estimated Burger model creep parameters for glass fiber reinforced hardboard under a stress of 650 psi.*

Effective V_f	E_e (psi)	E_d (psi)	η_d (psi-h)	τ (h)	η_v (psi-h)	R*
0	444,900	4,856,400	1,262,700	0.263	49,000,000	0.98
0.0073	538,100	6,521,800	1,826,100	0.281	75,667,000	0.98
0.0158	591,400	8,990,300	1,977,900	0.222	82,000,000	0.98
0.0260	643,800	11,473,300	2,179,900	0.189	113,500,000	0.98

* Multiple correlation coefficient.

parameters are valid only for short-term loading at stresses within the elastic range under conditions of constant moisture content, and ambient temperature and relative humidity.

RESULTS AND DISCUSSION

Effect of reinforcement volume fraction and stress level on composite flexural creep

At constant bending stress, the total flexural creep deflection and the rate of creep deflection of glass fiber reinforced hardboard decreased as effective reinforcement volume fraction increased. The result reflects the increase in the MOE of the composite and its greater resistance to bending that occurs with increasing effective reinforcement volume fraction. At constant effective reinforcement volume fraction, the total creep deflection and the rate of creep deflection increased as bending stress increased. The effects are illustrated in Fig. 2, where mean observed relative creep deflection is plotted versus time by effective reinforcement volume fraction and stress level. Relative creep is defined as the creep deflection at time t greater than zero divided by the deflection at t equal to zero.

Creep model parameter estimates

Use of the 4-element Burger model presupposes linear viscoelastic behavior. When subjected to stress σ, for example, the creep deflection of a simply supported beam at time t is y(t). If the stress is doubled to 2σ, and the test repeated, the creep deflection of a linear viscoelastic material will also be doubled to 2y(t), for the same elapsed time t. If upon doubling the stress, creep deflection differs significantly from 2y(t), then nonlinear behavior is indicated.

At all effective reinforcement volume fractions, glass fiber reinforced hardboard exhibited linear viscoelastic behavior. The ratio of creep deflection under a bending stress of 1,110 psi to that under 650 psi was essentially constant over the

TABLE 2. *Estimated Burger model creep parameters for glass fiber reinforced hardboard under a stress of 1,110 psi.*

Effective V_f	E_e (psi)	E_d (psi)	η_d (psi-h)	τ (h)	η_v (psi-h)	R*
0	439,300	5,141,000	1,131,000	0.223	35,000,000	0.98
0.0073	545,700	7,593,800	2,050,300	0.273	68,333,000	0.98
0.0158	630,200	8,679,200	2,690,500	0.311	83,333,000	0.98
0.0260	675,400	10,954,500	2,410,000	0.223	95,000,000	0.98

* Multiple correlation coefficient.

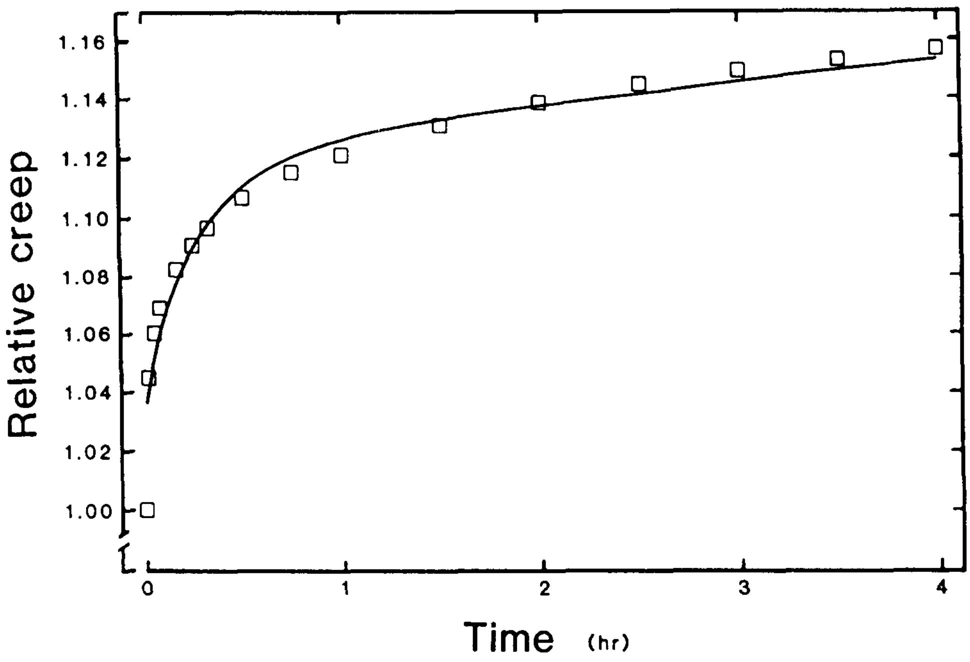

FIG. 4. Relative observed (□) and predicted (——) creep deflection of glass fiber reinforced hardboard at an effective reinforcement volume fraction of 0.0073 under a stress of 650 psi.

duration of the test, and approximated the ideal value of 1,110/650 or 1.71 (Fig. 3).

Nonlinear regression estimates of Burger model parameters are presented in Tables 1 and 2 for a bending stress of 650 and 1,110 psi, respectively. Excellent agreement existed between observed creep deflection and that calculated from parameter regression estimates at all effective reinforcement volume fractions for both levels of stress. The near-perfect correspondence is illustrated in Fig. 4, where mean values of relative observed and regression-calculated creep deflection are plotted versus time for the composite at an effective reinforcement volume fraction of 0.0073 under a bending stress of 650 psi. An equivalent coincidence between mean observed and regression-calculated creep deflection existed at all effective reinforcement volume fraction/stress level combinations.

Mean observed values for the MOE of the composite previously determined in static bending tests corroborate the mean regression estimates for the instantaneous modulus of elasticity, E_e (Table 3). A difference in loading arrangement and rate between the static bending and creep tests likely accounts for the slight departure.

Parameter estimates for the hardboard control confirm those reported by Moslemi (1964a). Estimates of 60 and 62 lb in.$^{-1}$ for the spring constant of the elastic element were made in the former and latter studies, respectively. (The spring constant is equal to the ratio of the applied load to the observed deflection within the elastic range.)

In the present investigation the retardation time for the hardboard control was estimated to be 0.26 and 0.22 hours, under a bending stress of 650 and 1,110

TABLE 3. *Comparison of modulus of elasticity of glass fiber reinforced hardboard determined in static bending and creep model regression estimates.*

Effective V_f	Static bending*	Creep regression estimate MOE (psi) 650**	1,110**
0	439,500	444,900	439,300
0.0073	524,900	538,100	545,700
0.0158	597,300	591,400	630,200
0.0260	664,800	643,800	675,400

* Smulski and Ifju 1987.
** Applied bending stress (psi).

psi, respectively. Moslemi (1964a) reported a value of 0.25 hours. The retardation time represents the time required for the delayed elastic strain to decay to 1/e times its value at removal of the applied stress. Like the true modulus of elasticity, E, and the modulus of rigidity, G, the retardation time is a material constant. It is invariant with specimen geometry and stress at levels below the stress at the proportional limit. With one anomaly, retardation time estimates are approximately equal under both levels of stress for each effective reinforcement volume fraction in support of the above (Tables 1 and 2). Although not fully substantiated by the experimental data, the retardation time appears to decrease with increasing effective reinforcement volume fraction. It is reasonable that a higher modulus material will recover from a deformed state more quickly than a material of lower modulus.

CONCLUSIONS

Significant reduction of the creep deflection of a dry-process hardboard matrix was achieved by internal reinforcement with continuous glass fibers. The total creep deflection and rate of creep deflection of glass fiber reinforced hardboard decreased with increasing effective reinforcement volume fraction at constant bending stress. Total creep deflection and rate increased with increasing bending stress at constant effective reinforcement volume fraction.

The short-term flexural creep of glass fiber reinforced hardboard stressed within the elastic range at constant ambient conditions was well described by a 4-element linear viscoelastic model. Creep deflections calculated from Burger model parameters estimated using nonlinear regression were in excellent agreement with observed values. Parameter estimates for the hardboard control confirmed prior published values.

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