CREEP FUNCTIONS FOR WOOD COMPOSITE MATERIALS

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ABSTRACT

Two related functions used to describe the creep of non-wood materials were fitted to data for wood composite materials. The first function, which is linear in its constants, was unsatisfactory for representing the creep of plywood, oriented strandboard, laminated timber, and dry-process hardboard under the given loading and environmental conditions. The second function is nonlinear in its constants. Creep of plywood and oriented strandboard were moderately well represented by this function, while creep of laminated timber and hardboard were exceptionally well represented. Experimental creep data and estimates of empirical constants are presented.

Keywords: Creep, plywood, oriented strandboard, laminated timber, dry-process hardboard.

INTRODUCTION

Selection of an appropriate function to represent the creep behavior of wood and wood composite materials is often made on a previous-experience or trial-and-error basis. Creep functions are typically exponential in form and comprise multiple terms and constants whose evaluation requires nonlinear or iterative techniques (Schniewind 1968; Szabo and Ifju 1970; Senft and Suddarth 1971; Pierce and Dinwoodie 1977; Gerhards 1985; Hoyle et al. 1986; Smulski and Ifju 1987). Nine of those most commonly used have been excerpted from the comprehensive work of Conway (1967) and summarized by Bodig and Jayne (1982). Of the nine, only two can be rearranged into a linear form that facilitates evaluation of empirical constants. In this paper, a third linearizable function, and a related nonlinear expression are assessed for their adequacy in describing the creep of wood composite materials.

METHOD

Linearizable function

The creep behavior of polymeric materials (Peleg 1979a) and various foodstuffs (Peleg 1979b, 1980) has been accurately represented by the function:

$$y = \frac{t}{a + bt} \qquad [1]$$

When (t, y) point pairs are replotted as (t, t/y), a straight line is obtained (Fig. 1):

$$t/y = a + bt \qquad [2]$$

The intercept, a, and slope, b, are estimated by performing simple linear regression on the (t, t/y) point pairs. A smooth curve can be fitted to experimental data by inserting the estimates for a and b and sequential values of t into Eq. [1].

When applied to creep curves, t represents the time elapsed since load appli-

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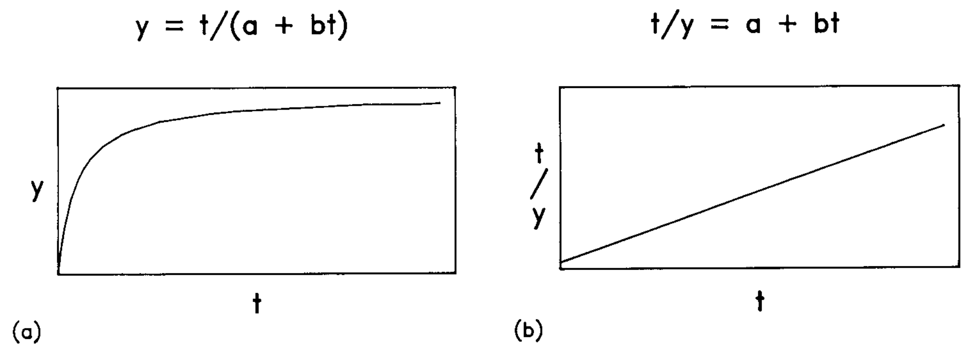

FIG. 1. (a) Idealized plot of creep deflection or strain vs. time. (b) Linear representation.

cation, and y the observed creep deflection or strain. Creep only is considered; instantaneous elastic deflection or strain must be deducted from subsequent observations. The reciprocal intercept, 1/a, indicates the initial rate of creep. The reciprocal slope, 1/b, is the terminal value to which creep rises over the duration of the experiment. The time required for creep to accrue to one-half of its terminal value, or ½b, is a/b.

Nonlinear function

Equation [1] is a special case (m = 1) of the function recommended by the American Concrete Institute (ACI 1988) for predicting the creep of concrete:

$$y = \frac{t^m}{a + bt^m} \qquad [3]$$

With this function, the advantage of using simple linear regression is lost; nonlinear methods are required to evaluate a, b, and m. Peculiar to nonlinear regression is the need for good initial estimates of constants to avoid local minima of the residual sum of squares. The values for a and b obtained by linear regression from Eq. [2] are valuable in this regard. By inspection, $0 < m < 1$. Because of the nature of the function, constants a, b, and m have no physical significance.

For this study, flexural creep data for plywood, oriented strandboard (OSB),

TABLE 1. *Regression-estimated constants for Peleg (1979a) creep equation (Eq. [1]).*

	Fig.	a (hr in.$^{-1}$)	b (in^{-1})	*r* coef. corr.	1/a (in hr^{-1})	1/b (in)
Plywood	2	354.477	8.939	0.993	0.0028	0.112
OSB	3	102.901	4.336	0.996	0.0097	0.231
Laminated timber*	4	124.332	3.870	0.998	0.0080	0.258
Hardboard						
0–5 hr	5, 6	18.027	74.552	0.998	0.0555	0.0134
0–4 hr	6	15.867	77.134	0.998	0.0630	0.0130
0–3 hr	6	13.626	80.495	0.998	0.0734	0.0124
0–2 hr	6	11.674	84.368	0.998	0.0857	0.0119
0–1 hr	6	8.696	94.463	0.996	0.1150	0.0106

* Constants dimensionless as data were expressed as relative creep.

TABLE 2. *Observed and regression creep values for plywood. Data of Laufenberg (1987) and O'Halloran (1987).*

		Eq. [1]		Eq. [3]	
t (hr)	y_{obs} (in)	y_{reg} (in)	% diff.*	y_{reg} (in)	% diff.*
0.00	0.000	0.0000	—	0.003	—
0.17	0.015	0.0005	−96.7	0.016	+6.7
0.5	0.018	0.001	−94.4	0.020	+11.1
2	0.029	0.005	−82.8	0.026	−10.3
6	0.037	0.015	−59.5	0.033	−10.8
24	0.045	0.042	−6.7	0.044	−2.2
72	0.051	0.072	+41.2	0.056	+9.8
168	0.064	0.091	+42.2	0.068	+6.3
336	0.081	0.100	+23.5	0.081	0.0
504	0.093	0.104	+11.8	0.090	−3.2
672	0.100	0.106	+6.0	0.096	−4.0
840	0.101	0.107	+5.9	0.102	+1.0
1008	0.104	0.108	+3.8	0.108	+3.8
1176	0.119	0.108	−9.2	0.112	−5.9
1344	0.112	0.109	−2.7	0.117	+4.5

* % diff. = $\frac{y_{reg} - y_{obs}}{y_{obs}} \times 100\%$

laminated timber, and dry-process hardboard were obtained from external sources. The data described creep at constant ambient conditions under stress representing, respectively, 25, 25, 20, and 33% of the materials' ultimate flexural strength. Equations [1] and [3] were fitted to these data. The adequacy of each function for describing creep was judged on the percent difference between observed and regression values, using the observed values as a base.

TABLE 3. *Observed and regression creep values for OSB. Data of Laufenberg (1987) and O'Halloran (1987).*

		Eq. [1]		Eq. [3]	
t (hr)	y_{obs} (in)	y_{reg} (in)	% diff.*	y_{reg} (in)	% diff.*
0.00	0.000	0.000	—	0.001	—
0.17	0.028	0.002	−92.9	0.030	+7.1
0.5	0.033	0.005	−84.8	0.042	+27.3
2	0.054	0.018	−66.7	0.063	+16.7
6	0.102	0.047	−53.9	0.084	−17.6
24	0.129	0.116	−10.1	0.118	−8.5
72	0.141	0.173	+22.7	0.148	+5.0
168	0.166	0.202	+21.7	0.172	+3.6
336	0.197	0.215	+9.1	0.192	−2.5
672	0.200	0.223	+11.5	0.211	+5.5
840	0.207	0.224	+8.2	0.217	+4.8
1008	0.222	0.225	+1.4	0.222	0.0
1176	0.229	0.226	−1.3	0.226	−1.3
1344	0.244	0.227	−7.0	0.229	−6.1

* % diff. = $\frac{y_{reg} - y_{obs}}{y_{obs}} \times 100\%$

TABLE 4. *Observed and regression relative creep values for laminated timber. Data of Anderson (1985) and Hoyle (1987).*

		Eq. [1]		Eq. [3]	
t (hr)	y_{obs} (in)	y_{reg} (in)	% diff.*	y_{reg} (in)	% diff.*
0.0	0.000	0.000	—	0.000	—
1.0	0.080	0.008	−90.0	0.074	−7.5
2.5	0.088	0.019	−78.4	0.090	+2.3
6.5	0.110	0.043	−60.9	0.108	−1.8
10.7	0.118	0.064	−45.8	0.119	+0.9
25.6	0.137	0.115	−16.0	0.141	+2.9
35.5	0.146	0.136	−6.8	0.150	+2.7
51.6	0.156	0.159	+1.9	0.160	+2.6
59.6	0.165	0.168	+1.8	0.165	0.0
79.2	0.172	0.184	+7.0	0.173	+0.6
99.5	0.180	0.195	+8.3	0.180	0.0
151.2	0.196	0.213	+18.9	0.194	−1.0
197.6	0.203	0.222	+9.4	0.203	0.0
251.3	0.211	0.229	+8.5	0.211	0.0
299.9	0.220	0.233	+4.1	0.217	−1.4
360.5	0.229	0.237	+3.5	0.224	−2.2
390.8	0.229	0.239	+4.4	0.227	−0.9
447.4	0.234	0.241	+3.0	0.232	−0.9
514.0	0.241	0.243	+0.8	0.237	−1.7
656.5	0.246	0.246	0.0	0.247	+0.4
826.8	0.251	0.249	−0.8	0.256	+2.0
996.8	0.259	0.250	−3.5	0.263	+1.5

$$* \ \% \text{ diff.} = \frac{y_{reg} - y_{obs}}{y_{obs}} \times 100\%$$

RESULTS

Linearizable function

A wide departure between observed and regression values indicated that under the present loading and environmental conditions, creep of the wood composites considered is unsatisfactorily represented by Eq. [1]. Regression values derived from the constants of Table 1 grossly underestimated observed values during the initial exponential rise of the creep curve. The trend shifted to moderate overestimation as the observed curve began to flatten, and reverted to underestimation in the latter near-linear region. The pattern was consistently manifest for plywood (Table 2), OSB (Table 3), laminated timber (Table 4), and hardboard (Table 5).

Peleg's (1980) observation that the function works best in cases where loading and environmental factors favor virtual stabilization of creep is corroborated by the present results. The regression curves for plywood (Fig. 2) and OSB (Fig. 3) are poorly fitted to empirical data. In both cases, observed creep continually accrued without stabilizing. As a result, the shape of the creep curve for these materials deviated significantly from the ideal.

Considerably less discrepancy existed between observed and estimated values for both laminated timber (Fig. 4) and hardboard (Fig. 5). Creep tended towards stabilization in these materials, with the curve shape approaching the ideal. Although inappropriate for representing the immediate creep response, the function

TABLE 5. *Observed and regression creep values for dry-process hardboard. Data of Smulski and Ifju (1987).*

		Eq. [1]		Eq. [3]	
t (hr)	y_{obs} (in)	y_{reg} (in)	% diff.*	y_{reg} (in)	% diff.*
0.000	0.0000	0.0000	—	0.0000	—
0.017	0.0036	0.0009	−75.0	0.0035	−2.8
0.050	0.0048	0.0023	−52.1	0.0048	0.0
0.083	0.0055	0.0034	−38.2	0.0055	0.0
0.167	0.0066	0.0055	−16.7	0.0067	+1.5
0.250	0.0073	0.0068	−6.8	0.0074	+1.4
0.333	0.0079	0.0078	−1.3	0.0079	0.0
0.417	0.0083	0.0085	+2.4	0.0083	0.0
0.500	0.0086	0.0090	+4.7	0.0087	+1.2
0.583	0.0090	0.0095	+5.6	0.0089	−1.1
0.667	0.0092	0.0098	+6.5	0.0092	0.0
0.750	0.0095	0.0101	+6.3	0.0094	−1.1
0.833	0.0097	0.0104	+7.2	0.0096	−1.0
0.917	0.0099	0.0106	+7.1	0.0098	−1.0
1.000	0.0100	0.0108	+8.0	0.0100	0.0
1.333	0.0106	0.0114	+7.5	0.0106	0.0
1.667	0.0110	0.0117	+6.4	0.0110	0.0
2.000	0.0114	0.0120	+5.3	0.0114	0.0
2.333	0.0117	0.0122	+4.3	0.0117	0.0
2.667	0.0120	0.0123	+2.5	0.0120	0.0
3.000	0.0122	0.0124	+1.6	0.0122	0.0
3.333	0.0124	0.0125	+0.8	0.0124	0.0
3.667	0.0126	0.0126	0.0	0.0126	0.0
4.000	0.0128	0.0127	−0.8	0.0127	−0.8
4.333	0.0130	0.0127	−2.3	0.0130	0.0
4.667	0.0131	0.0127	−3.1	0.0131	0.0
5.000	0.0132	0.0128	−3.0	0.0132	0.0

* % diff. = $\frac{y_{reg} - y_{obs}}{y_{obs}} \times 100\%$

may be useful for describing the mid-to-long term deformation of laminated timber or hardboard. Estimates for hardboard creep, for example, differed from experimental values by −6.8 to +8.0% over the interval from 0.25 to 5 hours.

Creep of wood and wood-based materials is a function of stress, time, temperature, and relative humidity. Factors thought to favor virtual stabilization include low levels of stress and constant ambient conditions. Although Eq. [1] is inadequate under the present loading and environmental conditions, it may be appropriate for creep of wood-based materials under other conditions.

The function was found to lack predictive power. Five regression curves were generated from the same hardboard creep data when analyzed as subsets that began at t = 0 and extended to t = 1, 2, 3, 4, or 5 hours. A poor fit to subsequent observations resulted when a regression curve derived from a shorter interval was extrapolated over the complete interval covered by available data (Fig. 6). Using a modified *t*-test, estimates for both a and b were statistically different at $\alpha = 0.01$ for all five least-square curves (Table 1).

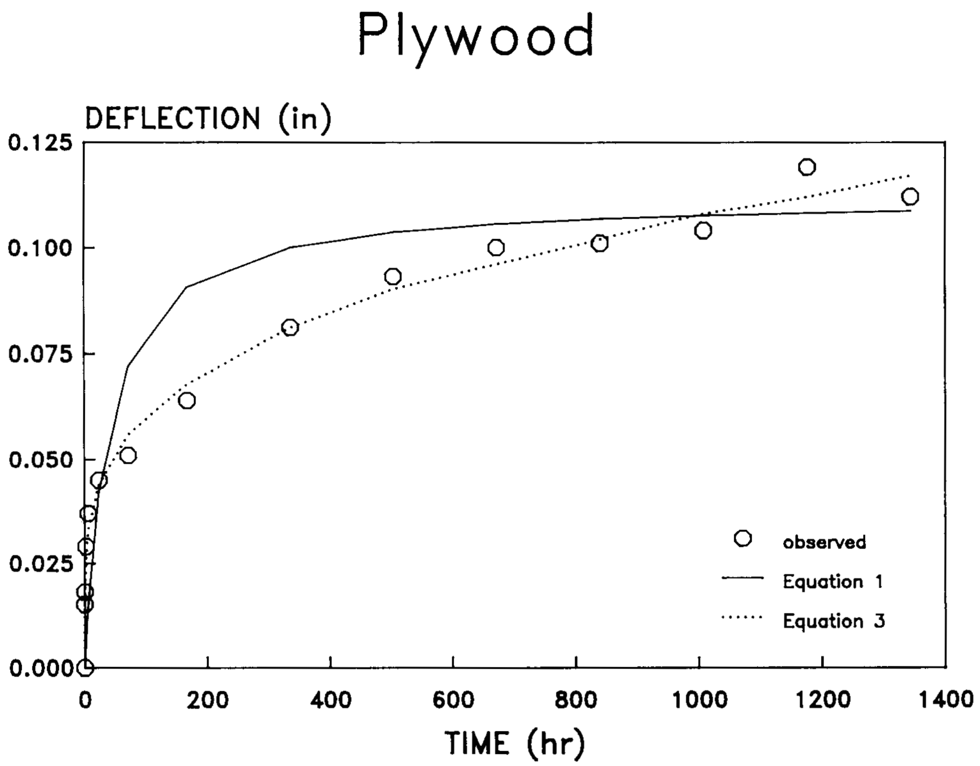

FIG. 2. Observed and regression-calculated creep deflection vs. time for plywood (Laufenberg 1987; O'Halloran 1987).

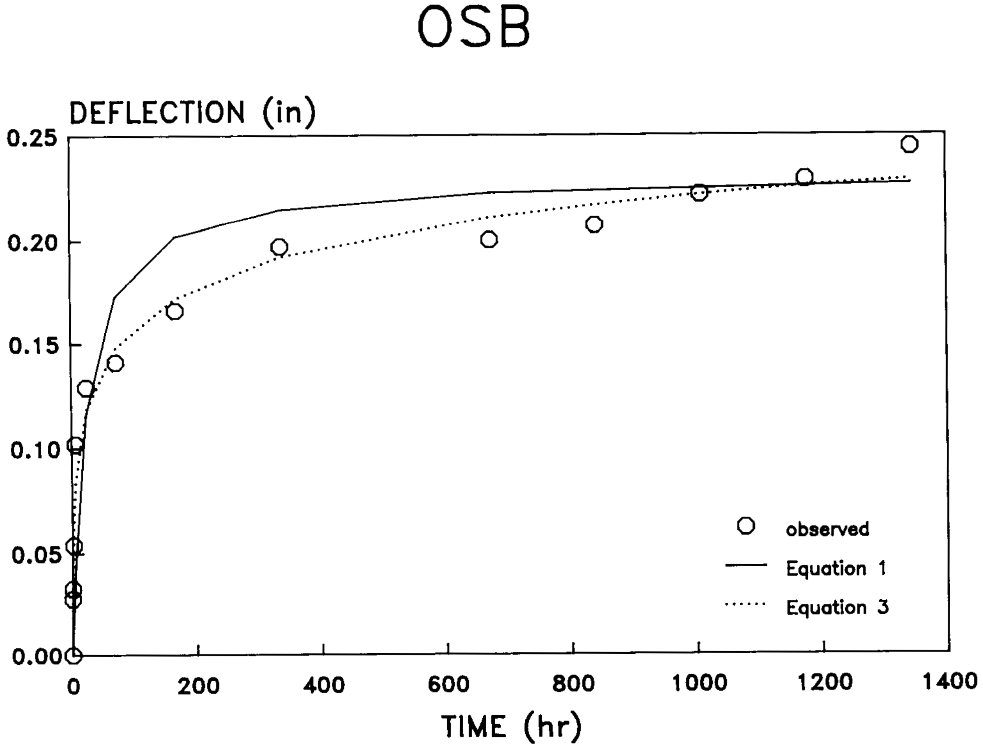

FIG. 3. Observed and regression-calculated creep deflection vs. time for oriented strandboard (Laufenberg 1987; O'Halloran 1987).

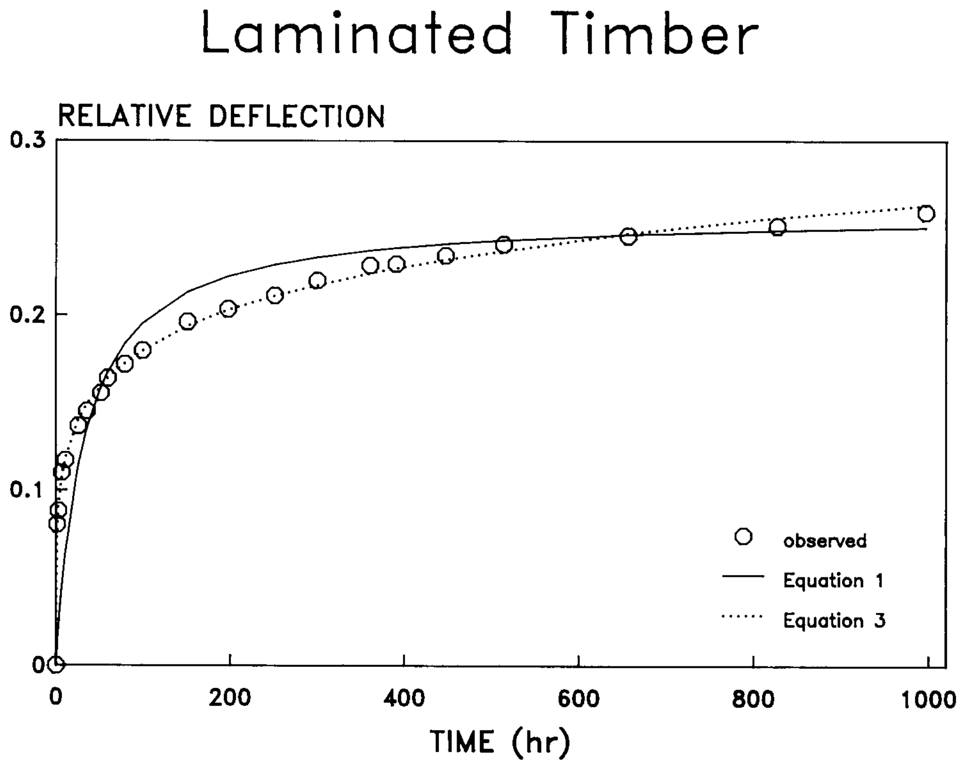

FIG. 4. Observed and regression-calculated relative creep deflection vs. time for laminated timber (Hoyle 1987; Anderson 1987).

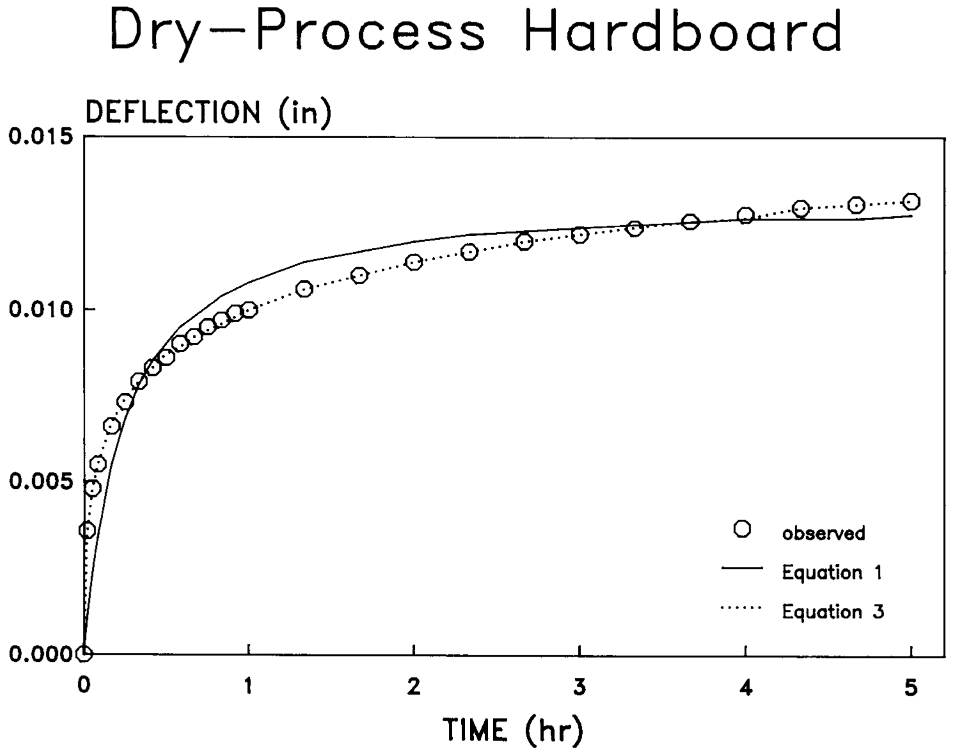

FIG. 5. Observed and regression-calculated creep deflection vs. time for dry-process hardboard (Smulski and Ifju 1987).

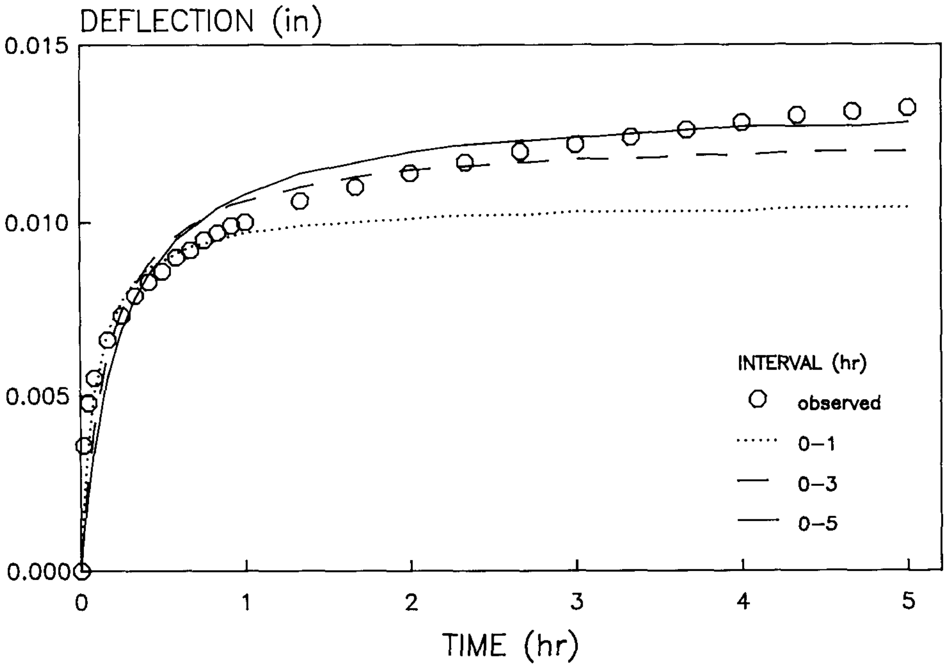

FIG. 6. Effect of time interval over which data are analyzed on regression curve shape using Eq. [1] (hardboard—Smulski and Ifju 1987).

Nonlinear function

The creep of plywood, OSB, laminated timber, and hardboard was consistently better represented by the ACI equation under the present loading and environmental conditions (Tables 2–5). Concrete shares with wood-based materials the attribute of dimensional instability due to moisture exchange with the environment (Kong et al. 1983). Factors affecting the creep of wood-based materials—stress, time, temperature, and relative humidity—strongly influence creep of concrete, and likely account for the similarity in behavior between the two.

The ACI function was moderately well-suited for describing the creep of plywood (Fig. 2) and OSB (Fig. 3). The percent difference between observed and

TABLE 6. *Regression-estimated constants for ACI (1988) creep equation (Eq. [3]).*

	Fig.	a (hr in^{-1})	b (in^{-1})	m	*r* coef. corr.
Plywood	2	49.081	−5.041	0.1780	0.996
OSB	3	16.390	2.986	0.3439	0.993
Laminated timber*	4	12.193	1.272	0.2277	0.999
Hardboard					
0–5 hr	5, 7	55.197	44.713	0.3611	0.999
0–4 hr	7	55.066	44.846	0.3617	0.999
0–3 hr	7	55.473	44.433	0.3599	0.999
0–2 hr	7	56.711	43.145	0.3551	0.999
0–1 hr	7	64.665	34.613	0.3281	0.999

* Constants dimensionless as data were expressed as relative creep.

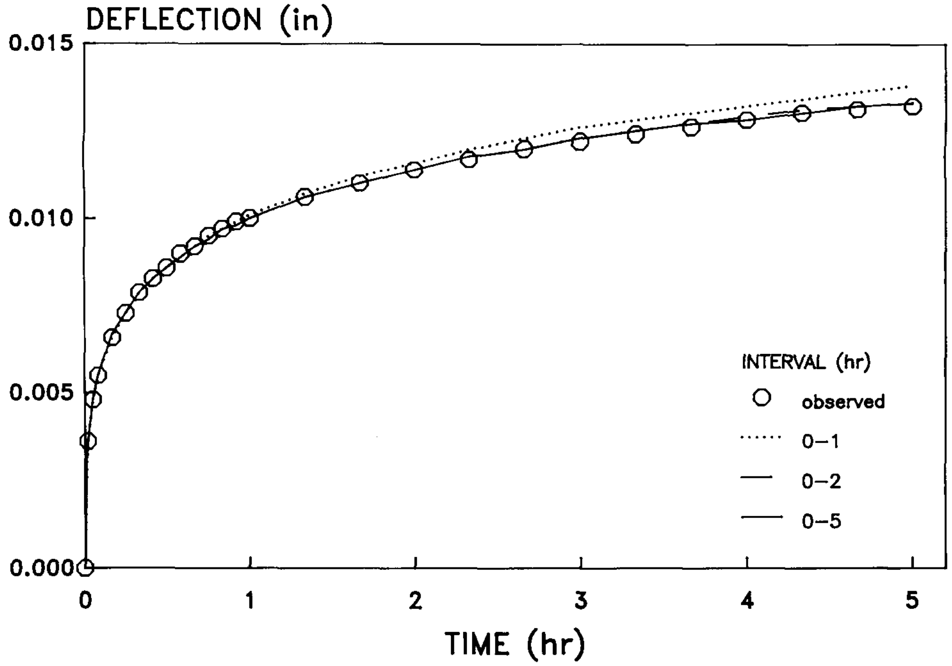

FIG. 7. Effect of time interval over which data are analyzed on regression curve shape using Eq. [3] (hardboard—Smulski and Ifju 1987).

regression values for plywood over 1,344 hours' time ranged from −10.8 to +11.1. For OSB, the discrepancy was as great as +27.3% during the first 6 hours of a 1,344-hour interval. Beyond 6 hours' time, observed and regression values differed by at most −8.5 and +5.5%. The fair fit of Eq. [3] to plywood and OSB is owed in part to irregularities in these data.

The relative creep of laminated timber was accurately represented with this function. Over a 1,000-hour interval, regression values were at most 7.5% lower and 2.9% higher than observed values (Fig. 4).

When superimposed on observed creep data points, the estimated regression curve for hardboard showed a near-perfect fit (Fig. 5). Regression estimates deviated from observed values by at most −2.8 and +1.5% over the 5-hour interval of available data.

Predictive capability was indicated with the ACI function. When the same hardboard data were analyzed in five subsets as described previously, estimates for a, b, and m were statistically different at $\alpha = 0.01$ for the 0- to 1-hour interval only (Table 6). Correspondence with subsequent observations was near-perfect when either the 0- to 2-, 0- to 3-, or 0- to 4-hour regression curve was extrapolated over the entire 5-hour interval (Fig. 7). The results suggest that realistic predictions of creep outside of the time interval over which data are collected may be possible.

SUMMARY

Two related functions, each used to describe creep in non-wood materials, were fitted to experimental data to assess their adequacy for describing creep of wood composites. The first is linear in its constants; their evaluation requires only linear regression. With the second function, nonlinear methods are needed. Both functions are strictly empirical, having no mechanistic or molecular basis.

The linearizable function was unsatisfactory for representing the creep of plywood, OSB, laminated timber, and hardboard under the present loading and environmental conditions.

Creep of plywood and OSB was adequately described by the second nonlinear function, while creep of laminated timber and hardboard was exceptionally well represented. Preliminary analysis suggests that the function may possess some predictive capability outside of the range of available data.

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