THE EFFECT OF MOISTURE CYCLING ON CREEP OF SMALL GLUED LAMINATED BEAMS

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ABSTRACT

Creep information for sawn lumber exposed to constant and cyclic humidity environments previously published by the authors is supplemented by this study using glued laminated material of about the same size, tested on the same apparatus, and using the same general procedure.

For both sawn and glued laminated material, the relative creep was measured at about 55% of their average ultimate strength. Relative creep was measured for specimens matched with respect to modulus of elasticity (MOE) and exposed to a constant relative humidity (65 F and 65% RH) for about 1,000 hours, and a cyclic relative humidity (65 F and 90% RH for 82 hours followed by 65 F and 40% RH for 82 hours). This 164-hour cycle was repeated six times for about 1,000 hours of cyclic exposure. This is a more severe change in equilibrium moisture content of the environment than is likely to occur in building structures.

The result showed relative creep of the glued laminated material increased by 40% to 72% as a result of cycling. One very low MOE pair showed an increase of 167%. The increase for solid sawn lumber previously reported was 200% to 400% due to cycling. Results also showed that the ratio of relative creep for cycled to constant humidity exposure did not change appreciably as time under load was increased. These differences are attributed to permeability differences between glued laminated wood and sawn lumber. The gluelines are believed to retard water vapor movement and reduce the moisture change rate and extremes of wood moisture content in any given cycle.

Keywords: Douglas fir, glued laminated, creep, humidity, cycled.

INTRODUCTION

Research results on the creep behavior of nominal 4- by 4-inch Douglas fir beams from two studies conducted at Washington State University's Department of Civil and Environmental Engineering have been published in this journal (Hoyle et al. 1985, 1986). The species was Interior North Douglas fir (*Pseudotsuga menziesii*) and the grade was No. 2 and Better (Western Wood Products Association).

The first results (1985) were for exposure to a constant relative humidity environment of 70 F and 65% RH for 400 hours. The second results (1986) were obtained in cyclic humidity environments, one of which was 70 F and 90% RH for 84 hours, then at 70 F and 40% RH for 84 hours; the 168-hour cycle repeated for 1,250 hours.

This paper reports test results for glued laminated beams of the same species and of similar

TABLE 1. *Regression models.*

Beam	Constant RH A	B	C 10^{-3}	R^2	Beam	Cycled RH A	B	C 10^{-3}	R^2
				Model 1: $\delta_R = A(1 - e^{-BT})$					
1A	0.2101	0.05009	*	0.977	2B	0.3796	0.00761	*	0.994
3A	0.1954	0.02263	*	0.980	3B	0.3552	0.01008	*	0.992
4A	0.2383	0.02565	*	0.975	4B	0.4903	0.00839	*	0.992
5A	0.1729	0.09492	*	0.988	5B	0.4348	0.01077	*	0.992
6A	0.1908	0.03921	*	0.980	6B	0.3125	0.01050	*	0.994
Group A	0.2002	0.03912	*	0.968	Group B	0.3940	0.00932	*	0.970
				Model 2: $\delta_R = A(1 - e^{-BT}) + Ct$					
1A	0.1660	0.1369	0.131	0.991	2B	0.2631	0.01549	0.185	0.998
3A	0.1495	0.0452	0.126	0.994	3B	0.2659	0.01864	0.154	0.997
4A	0.1722	0.0777	0.174	0.994	4B	0.3367	0.01837	0.253	0.998
5A	0.1518	0.1477	0.072	0.996	5B	0.3262	0.02047	0.191	0.997
6A	0.1488	0.0904	0.122	0.995	6B	0.2340	0.01946	0.138	0.999
Group A	0.1557	0.0992	0.128	0.998	Group B	0.2843	0.01862	0.186	0.975
				Model 3: $\delta_R = At^B$					
1A	0.07716	0.1813	*	0.9997	2B	0.04349	0.3402	*	0.9969
3A	0.04656	0.2481	*	0.9999	3B	0.05305	0.3033	*	0.9940
4A	0.06159	0.2362	*	0.9998	4B	0.06153	0.3279	*	0.9963
5A	0.08051	0.1421	*	0.9978	5B	0.06873	0.2953	*	0.9940
6A	0.06115	0.2031	*	0.9992	6B	0.04614	0.3061	*	0.9938
Group A	0.06465	0.2017	*	0.9992	Group B	0.05446	0.3144	*	0.9723

* Not applicable.

size (3- by 3.75-inch versus 3.5- by 3.5-inch) subjected to the same humidity cycle at 65 F, and loaded to approximately the same stress level. Each glued laminated beam consisted of five ¾-inch laminations with gluelines arranged horizontally.

The object of this study was to compare the creep behavior of glued laminated and solid sawn beams under very similar conditions of cyclic humidity environments.

LITERATURE REVIEW

The papers previously published provide a discussion of the literature on creep. Those discussions of the mathematical models for creep will be of interest, since we have employed the same models (see Table 1) in the analysis of results for the glued laminated beams. Anderson's thesis (1985) contains tables of relative creep for all the readings taken in this study and may possibly be useful to readers who wish to examine creep with a view of testing other mathematical models.

MATERIAL TESTED

Six 12-foot-long glued laminated beams were obtained from a laminator. Each beam consisted of five laminations of nominal 1- by 8-inch Douglas fir lumber. The finished size of the beams was 3.75 by 6.75 inches. All laminations were visually graded to Western Wood Products Association (WWPA) Rules 81 (1981) for Stress Rated Boards (SRB). (Stress Rated Boards of nominal 1 by 8 size are graded by the same rules as Structural Joists and Planks.) The outside laminations were No. 1 SRB (F_b = 1,350 psi), and the three interior laminations were No. 2 SRB (F_b = 875 psi). These grades were selected so the lumber quality would be similar to that of the previously tested No. 2 and Better solid sawn beams. The adhesive used in their manufacture was phenol-resor-

TABLE 2. *Relative creep for cycled and uncycled Douglas fir glulam beams.**

Beam	Elastic modulus (ksi)	Time under load (hours) 400	600	800	1,000
5A	1,590	0.1837 (0.1884)	0.1937 (0.1996)	0.1943 (0.2079)	0.2088 (0.2146)
4B	1,580	0.4037 (0.4337)	0.4854 (0.4885)	0.5348 (0.5391)	0.5580 (0.5897)
4B/5A		2.19 (2.30)	2.51 (2.45)	2.75 (2.59)	2.67 (2.75)
1A	1,740	0.2297 (0.2286)	0.2425 (0.2461)	0.2512 (0.2593)	0.2592 (0.2700)
3B	1,730	0.3192 (0.3275)	0.3519 (0.3583)	0.3840 (0.3893)	0.3974 (0.4202)
3B/1A		1.39 (1.43)	1.45 (1.46)	1.53 (1.50)	1.53 (1.56)
4A	1,730	0.2531 (0.2536)	0.2798 (0.2791)	0.2813 (0.2987)	0.3106 (0.3148)
5B	1,720	0.4226 (0.4025)	0.4562 (0.4409)	0.4568 (0.4791)	0.4840 (0.5173)
5B/4A		1.67 (1.58)	1.63 (1.58)	1.62 (1.60)	1.56 (1.64)
3A	1,820	0.2073 (0.2059)	0.2237 (0.2276)	0.2337 (0.2445)	0.2420 (0.2584)
2B	1,860	0.3432 (0.3356)	0.3753 (0.3730)	0.3940 (0.4100)	0.4171 (0.4476)
2B/3A		1.66 (1.63)	1.68 (1.64)	1.69 (1.68)	1.72 (1.73)
6A	2,300	0.1998 (0.2065)	0.2214 (0.2242)	0.2324 (0.2377)	0.2497 (0.2487)
6B	2,400	0.2894 (0.2891)	0.3158 (0.3168)	0.3403 (0.3444)	0.3506 (0.3720)
6B/6A		1.45 (1.40)	1.43 (1.41)	1.46 (1.45)	1.40 (1.50)

* Numbers in parentheses are from regression. Other numbers are from actual measured relative creep.

cinol resin, a common laminating adhesive for glued laminated beams.

Each of the six beams was sawed longitudinally, and the sawn edges were surfaced to form two 3-inch-wide by 3.75-inch-deep pieces, which were marked 1 through 6, A and B, it being assumed that the A and B pieces would be reasonably well matched in terms of modulus of elasticity (MOE). This did not prove to be the case when the pieces were statically tested, so they were matched on the basis of MOE into pairs, one for constant humidity exposure (A); and the other for cyclic humidity exposure (B). The MOE values of the specimens as paired are given in Table 2. Two beams were omitted in the reporting of test results because the pins driven into those beams to support the deflection measuring bridge were accidentally disturbed during the creep tests, creating errors that could not be reliably corrected. Thus the test material consisted of five pairs of beams, well matched on the basis of MOE.

METHOD OF TESTING

Test material was stored at 65 F and 65% RH for over 30 days prior to testing. This material had been seasoned to 12% moisture content prior to laminating, and the storage conditions were to maintain this moisture level.

The applied load was chosen to cause a bending stress high enough to produce measurable creep in a reasonable time, but below a level that would cause rapid creep to failure. Past experience has suggested that stress below 55% of the ultimate strength of the specimens would not cause tertiary creep (i.e., deflection at an accelerating rate, culminating in failure). The ultimate strength of the material was determined by reversing the procedure of deriving allowable stresses for design. Recognizing the actual size and moisture content of the glued laminated material and using the allowable bending stresses for the outer laminations (1,350 psi), it was determined that 2,600 psi would be about 53% of the average ultimate strength of the glued laminated material. (This glued laminated material is of a lower quality and strength than that customarily used in the manufacture of commercial glued laminated beams). In this study, we purposely used a quality level to match the solid sawn 4 by 4s in the earlier creep studies.

All beams were loaded to the 2,600 psi stress level. Loads were applied at three equally spaced locations along the 140-inch simple span. The beams were supported on a knife edge at one end and a roller at the other. The loads were at midspan and quarter-points.

Previous experience showed that upon initial loading there will be a period of rapid dial gage motion during the first minute or two after loading, which ceases within 2 minutes. It was our practice to take as the initial deflection the reading when that motion stopped, always in less than 2 minutes after the last of the three loads was in place. The room conditions during this loading period were 65 F and 65% RH. We allowed the loaded beam to remain at this condition for 7 hours before beginning the exposure regimes for constant humidity and for cyclic humidity. The reason for this may be of interest. It takes about 1 hour to load six beams, and we wished to have the six beams in a given set to have about equal time under load before starting the test exposure. This technique made the preliminary period 7 hours, to 7 hours and 50 minutes, rather than zero minute to 50 minutes had we started the test exposure immediately after the sixth beam was loaded. There was probably very little moisture absorption or desorption during this period.

Following the 7-hour period, the relative humidity was continued at 65% for the "A" specimens, requiring about 10 minutes, and continued at this relative humidity and 65 F for the entire period of 989 additional hours.

Following the 7-hour period, the relative humidity for the "B" specimens was raised to 90% for 82 hours and then changed to 40% for another 82 hours, all at 65 F. The equilibrium moisture contents for these conditions were 21% and 8%, although, of course, the specimens did not come to these moisture contents during the 82-hour periods. (We had targeted these periods to be 84 hours, but did not actually expose them exactly that long). The cycle of 164 hours was repeated six times for a total exposure of 993 hours, including the initial 7-hour period at 65 F and 65% RH. The time required to reduce humidity was about 2 hours.

RESULTS

Deflection data were used to compute the relative creep for each reading taken on each beam. Relative creep is the ratio of the constant load deflection at any given reading time to the initial deflection taken at 2 minutes after the three loads had been applied to each beam. Thus, 0.25 relative creep means that creep was 25% of the initial elastic deflection.

Three regression models for relative creep versus time (hours) were fitted to the data. These models are given in Table 1. We had selected these models from the creep literature and had gained experience with them in the studies mentioned in the introduction. Consistent with those studies, we employed the same models for this one. We believe the creep fundamentals do not change for the glued laminated specimens, although the rates would be expected to differ for sawn versus glued laminated material, and the cycling would increase the breaking of hydrogen bonds that is supposed to aggravate creep. The regressions for each of the three models were performed by SAS NLIN (Statistical Analysis System NonLinear) program using the D.U.D. method (Council and Helwig 1979). The fitted equations are given in Table 1.

Table 2 lists creep at periods of 400, 600, 800, and approximately 1,000 hours (actually 996 and 993 hours), actual measured values and values from regression in parentheses. Ratios of relative creep, cycled to constant relative humidity, are also tabulated for specimens matched according to MOE. While the original intent was to physically match specimens cut from the same 3.75- by 6.75-inch beam, it was found that there were great differences in the MOE of members of these pairs. In retrospect, we believe this is due to the fact that dividing a graded member does not result in two members of equal grade, a principle well recognized by the grading agencies. The halves no longer contain the same growth characteristics. Modulus of elasticity was measured on all specimens before creep testing, so it was possible

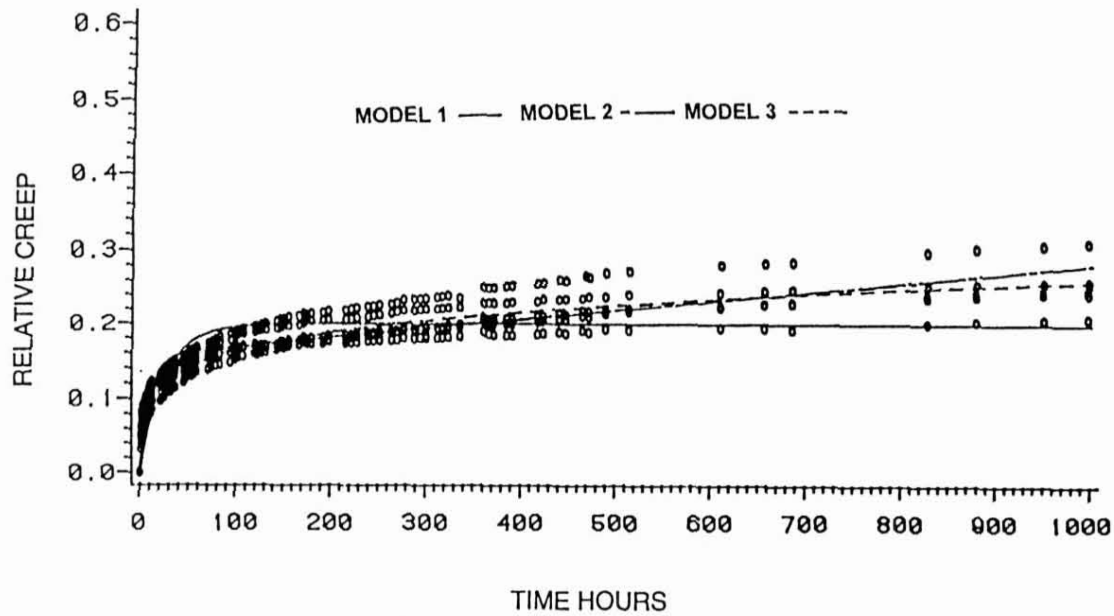

FIG. 1. *Beams tested in constant humidity.*

to identify and match A and B specimens based on elastic modulus.

DISCUSSION AND CONCLUSIONS

Table 1 lists the regression coefficients and the squares of the correlation coefficients. The values of R^2 are nearly unity for all models and specimens, which indicates that the variation in relative creep is due almost entirely to time and humidity. The models all fit well by this procedure. The graphical presentations in Figs. 1 and 2 make us prefer model 3 for

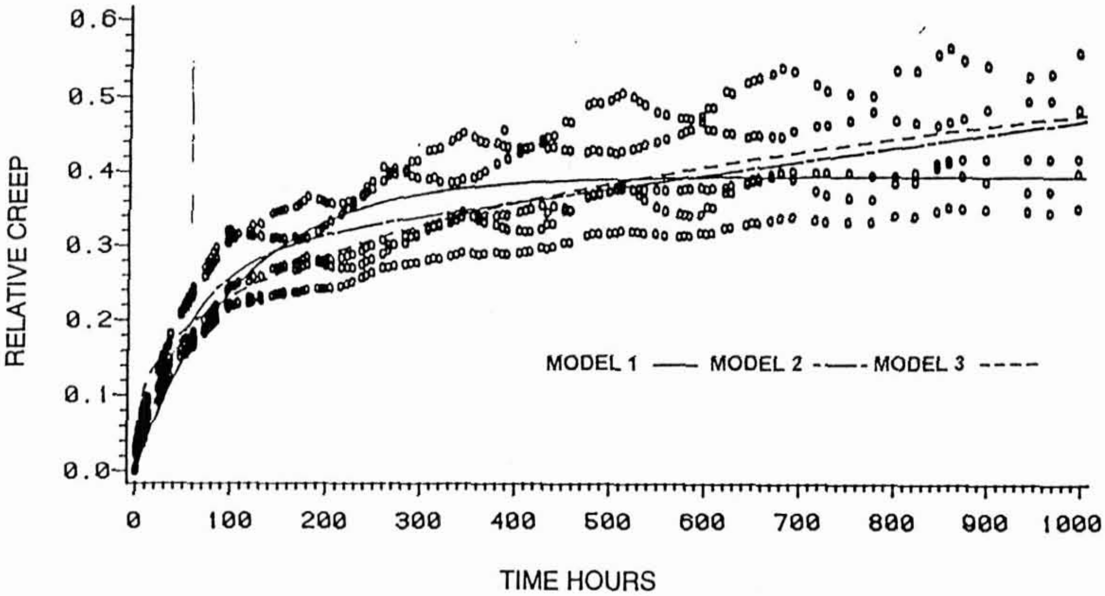

FIG. 2. Beams tested in cyclic humidity.

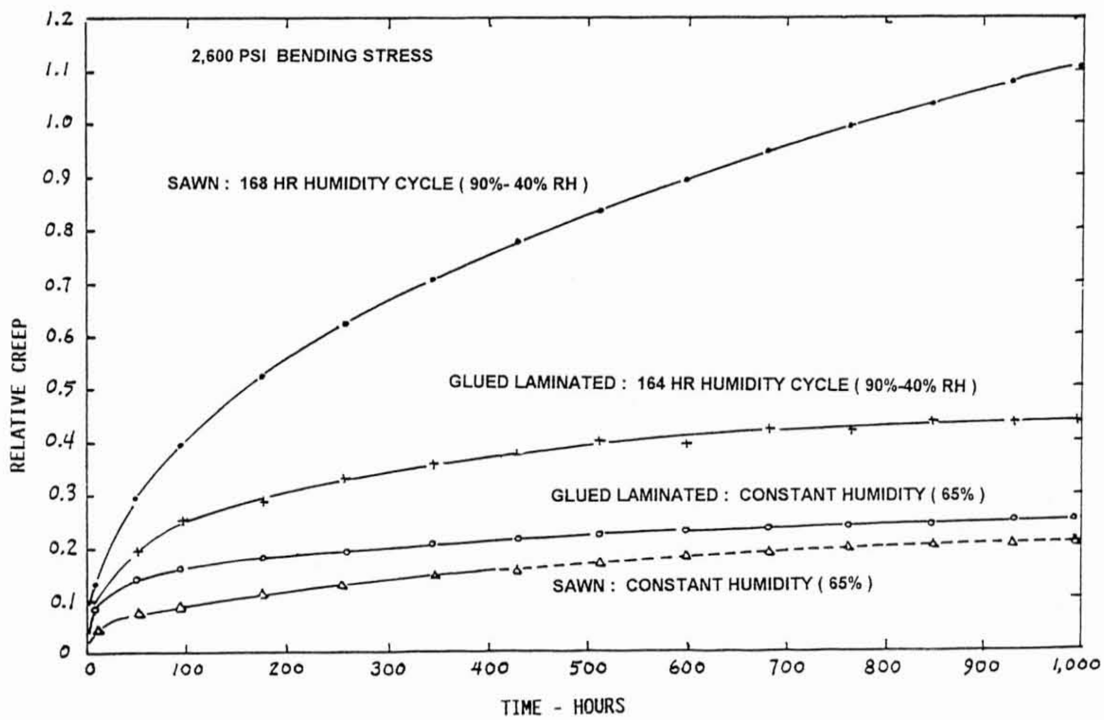

FIG. 3. Relative creep vs. time for sawn and glued laminated wood beams.

the constant humidity data, with little difference between models 2 and 3 for the cyclic humidity data. Model 1 is a poorer fit in all cases.

The information in Table 2 permits observing relative creep in terms of time and MOE. This experiment was not designed to detect the influence of MOE on creep and there is not a sufficient range of MOE to permit any conclusions about its influence. The creep in the low MOE specimens was more affected by humidity variation than in the case of the higher MOE beams. To learn more about the MOE influences, it would be good to have more replications of beams at each of a wider range of MOE levels. This noticeably different behavior of the low MOE specimen could be just a random variation in creep behavior.

The particular finding that is of interest is the ratio of relative creep of cycled (B) beams to constant humidity beams (A). It seems clear that cycling increases relative creep, a result we had expected from the prior work on sawn lumber beams. This ratio does not appear to increase or decrease very much with increasing time under load.

The effect of cyclic humidity on the glued laminated material was not as great as had been seen for the solid sawn material. To compare the creep of glued laminated wood and sawn wood of the same general size, quality, and at the same stress level, Fig. 3 is presented using data from this study for the glued laminated wood; for sawn wood at constant humidity from the Hoyle et al. (1985) paper; and for sawn wood in a cyclic humidity environment from the Hoyle et al. (1986) study.

The curves for the glued laminated wood are the average relative creep for five specimens each for the constant and cycled humidity conditions at approximately 84-hour intervals. Each plotted point is the average of five (A) specimens for the constant humidity condition and five (B) specimens for the cyclic humidity conditions.

The regression relative creep values at the same times are plotted for the sawn wood studies, using Model 3 regression equations. The portion of the constant humidity curve for the sawn wood shown as a dashed line is the part at times exceeding 400 hours, and since that study had a maximum duration of 400 hours, this is an extrapolation.

All of the curves in Fig. 3 were for a constant applied stress of 2,600 psi, with very similar temperature and humidity conditions.

The cyclic fluctuation of relative creep is not as evident as it actually was, because the regressions were not fitted to a model that would show these fluctuations, in the case of the sawn material. For the glued laminated material, there is a small fluctuation of points plotted for the cycled glued laminated material. But the important feature of Fig. 3 is the relative position of the curves for the several conditions, showing the large effect of the cyclic humidity on solid sawn as opposed to the much smaller effect on glued laminated material.

Laminated members benefit by the dispersion of growth characteristics and by seasoning prior to gluing. This makes them more uniform in moisture content and less susceptible to the development of drying stresses. The grain deviation around knots is often supported by straighter grained adjacent laminations, which would reinforce the areas of distorted grain and reduce creep. The action of gluelines to impede moisture migration in the glued laminated material would be expected to restrain the development of creep, since internal moisture changes and creep are related directly. Thus we believe the relative position of the curves is logical, and the figure provides evidence of the magnitude of this difference.

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