EFFECTS OF LOAD LEVEL, CORE DENSITY, AND SHELLING RATIO ON CREEP BEHAVIOR OF HARDBOARD COMPOSITES[1]

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ABSTRACT

Sustained load bending tests were conducted on large size ¾-inch-thick, 12- by 39-inch red oak veneered-hardboard composites, hardboards, and red oak lumber. A greater initial elastic deflection generally resulted in a greater total creep and irrecoverable creep deflections. Creep deflections of all composite panels were affected by the load level, core density, and shelling ratio in this study. The red oak lumber exhibited the most creep resistance. However, the composite panel with a shelling ratio of 0.262 was nearly as resistant to creep as red oak lumber. Creep deflections of all composite panels were very well described by a power-law function, based on two separate test models of 2 to 10 min and 10 to 100 min. The extrapolation of log-log regression for the approximation of creep appeared to give reasonable values for up to three weeks. Three multivariable regression models were developed to predict the initial, total, and irrecoverable creep deflections as a function of shelling ratio, load level, and hardboard core density. Their R^2 values were 0.96, 0.87, and 0.85, respectively.

Keywords: Quercus spp., rheology, creep deflection, irrecoverable creep deflection, sustained load level, hardboard, core density, shelling ratio, veneer thickness, composite panel, wood-base materials.

INTRODUCTION

The phenomenon of material deflecting under constant load is called creep, and the study of such deflection is known as a part of rheology. Wood and wood-base materials possess rheological properties and are known as viscoelastic materials as reported by both Moslemi (1964) and McNatt (1970, 1975). Wood-base materials, like most structural materials, deflect instantly under load in relation to the stress imposed; and they continue to deflect as the load is maintained. Under sustained bending load, two components of deflection are developed. The first component, initial elastic deflection, can be calculated assuming elastic responses that conform to Hook's Law (Young and Hilbrand 1963). The second component of deflection is creep.

Under a sustained load, creep deflection consists of two portions, recoverable and irrecoverable creep, both of which require time to develop according to the following function:

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$$Y = Y_E + Y_C \qquad (Y_C = Y_R + Y_{IR} \quad \text{or} \quad Y_{IR} = Y_C - Y_R) \tag{1}$$

in which Y = total maximum bending deflection
Y_E = elastic or initial bending deflection
Y_C = total creep deflection
Y_R = recoverable creep deflection
Y_{IR} = irrecoverable creep deflection

A previous investigation (Chow 1970, 1971) found that a creep deflection very close to that of solid walnut was obtained from a walnut-veneered, medium-density particleboard with a shelling ratio of 0.333. Shelling ratio is defined as the ratio of the total face-veneer thickness to the total thickness of the veneered panel. Although the tests were conducted on small specimens, 2 by 20 inches in size, the results indicated that an improved hardwood composite panel might be possible by laminating dense hardwood veneers onto higher density composition board. Furthermore, little information on creepbehavior for large-sized panels made from hardwood composite is available (Iwashita 1974).

The primary objectives of this study were: 1) To determine the effect of density of hardboard core, load level, and shelling ratio less than 0.333 on the initial, total, and irrecoverable deflections of a full-sized, red oak veneered-hardboard composite panel under sustained bending load at a constant normal humidity and temperature; and 2) To develop models to both describe and predict creep behavior.

EXPERIMENT

Materials

Table 1 shows five different constructions of composite panels evaluated in this study. The red oak veneers (No. 1 face grade), 12½ by 40½ inches in size with thickness of ⅛ inch, ¹⁄₁₀ inch, ¹⁄₁₆ inch, and ¹⁄₂₈ inch were purchased from a veneer manufacturer. The dry-process hardboards of the same size as that of the veneer in the thicknesses of ¾ inch, ¹¹⁄₁₆ inch, ⅝ inch, ⁹⁄₁₆ inch, and ½ inch were similarly obtained. Each thickness of the hardboard core had three density groups: 55 lbs/ft^3, 60 lbs/ft^3, and 65 lbs/ft^3. The total thickness of each composite was maintained at approximately ¾ inch including the glue lines. The composites were hot-pressed at 265 F and 150 psi. All panels with shelling ratios (SR) of 0.000, 0.094, 0.167, and 0.333 were constructed from various thicknesses of hardboards and face veneers using a melamine-urea formaldehyde adhesive. The rate of glue spread was about 40 to 50 pounds per thousand square feet. All cured panels were trimmed to a size of 12 by 39 inches and were conditioned at a temperature of 75(±2) F and 50(±5)% relative humidity. In all cases, the grain direction of the veneer was parallel to the 39-inch length of the specimens.

Tests

Three constant load levels (LL), 43.75 pounds (light load), 87.50 pounds (medium load), and 175.00 pounds (heavy load) were chosen for sustained loading tests. They were applied across to the midspan of the specimens 12 by 39 inches in size, simply supported over a 36-inch span by a level-arm system. These three midspan loads correspond to uniform loads of 23.3, 46.6, and 93.2 pounds per

TABLE 1. *Shelling ratio of red oak veneered hardboard.*

Thickness (inches)		Total thickness including glue line (inches)	Shelling[2] ratio
Face veneer	Hardboard core[1]		
1/8	1/2	0.750	0.333
1/10	9/16	0.763	0.262
1/16	5/8	0.750	0.167
1/28	11/16	0.759	0.094
None	3/4	0.750	0.000

[1] Each hardboard core has three density classes, 55, 60, and 65 lbs/ft³.
[2] Shelling ratio = $\frac{2t}{2t + c}$ (t = thickness of face, c = thickness of core).

square foot and are equivalent to total uniformly distributed loads of about 70, 140, and 280 pounds over the 12- by 36-inch loading area on the shelf, respectively. All specimens were tested at 75(±2) F and 50(±5)% relative humidity.

For the purpose of specifying the LL in the bending creep test, replicates of each composite type were statically tested to determine the ultimate strength of the material. Table 2 shows the percentage of ultimate bending stress levels of three sustained loads imposed on specimens of three core densities (CD) and SR. The tests also indicated that the stiffness of the hardboard core of each density class was essentially the same regardless of core thicknesses.

Duplicate sustained loading tests of each material were carried to 100 min and then allowed to recover for 100 min. A Kuhl dial gauge was used to measure the center deflection to the nearest 0.00039 inch (0.001 millimeter). Deflection was read every minute for the first 10 min and every 5 min thereafter. In this study deflection at 1 min after loading was defined as the initial elastic deflection (Y_E)

TABLE 2. *Constant load levels expressed in terms of percentage of stresses at ultimate strength of the ¾-inch by 12-inch by 39-inch specimens at three core densities and five shelling ratios.*

Shelling ratio	Core density classes (lbs./ft³)	Percentage of maximum bending stresses — Constant load levels (midspan loading)		
		Low (43.75 pounds)	Medium (87.50 pounds)	High (175.00 pounds)
0.000	55	12	23	46
	60	11	22	44
	65	9	18	36
0.094	55	7	14	27
	60	6	12	24
	65	5	10	20
0.167	55	6	12	24
	60	5	10	20
	65	4	8	16
0.262	55	4	8	16
	60	3	6	12
	65	3	6	12
0.333	55	4	8	16
	60	3	6	12
	65	3	6	12

TABLE 3. *Average elastic (Y_E), total creep (Y_C), and irrecoverable creep (Y_{IR}) deflections of composites.*

Shelling ratio	Core density classes (lbs/ft³)	Panel[1] density (lbs/ft³)	Constant load levels (midspan loading) 43.75 pounds Y_E	Y_C	Y_{IR}	87.5 pounds Y_E	Y_C	Y_{IR}	175 pounds Y_E	Y_C	Y_{IR}
			(Inches)			(Inches)			(Inches)		
0.333	55	53	.0884	.0040	.0022	.1771	.0074	.0058	.3226	.0111	.0051
0.262	55	53	.0866	.0042	.0031	.1601	.0083	.0051	.3022	.0156	.0076
0.167	55	54	.1339	.0080	.0078	.2469	.0172	.0071	.4613	.0348	.0095
0.094	55	55	.1282	.0065	.0050	.2557	.0213	.0122	.4485	.0261	.0120
0.000	55	56	.1882	.0120	.0086	.3709	.0299	.0167	.7612	.0539	.0273
0.333	60	57	.0758	.0031	.0031	.1562	.0080	.0034	.2866	.0129	.0064
0.262	60	58	.0774	.0035	.0027	.1391	.0074	.0031	.2882	.0112	.0048
0.167	60	58	.1125	.0066	.0056	.2107	.0128	.0068	.3902	.0197	.0089
0.094	60	60	.1130	.0066	.0047	.2401	.0157	.0078	.4053	.0244	.0119
0.000	60	60	.1852	.0135	.0114	.3806	.0299	.0194	.6760	.0449	.0217
0.333	65	62	.0662	.0034	.0019	.1696	.0099	.0054	.3001	.0165	.0073
0.262	65	62	.0711	.0042	.0026	.1574	.0085	.0043	.2825	.0136	.0042
0.167	65	64	.1010	.0047	.0036	.1903	.0103	.0046	.3687	.0202	.0090
0.094	65	65	.0892	.0070	.0042	.1843	.0112	.0072	.3676	.0205	.0097
0.000	65	66	.1459	.0092	.0068	.2944	.0178	.0104	.5428	.0297	.0181
Red oak lumber		41	.0732	.0032	—	.1294	.0052	.0043	.2502	.0091	.0066

[1] Each value is an average for two tests. Density is based on air dry weight and volume.

under the given level of load. For comparison, several specimens were subjected to creep tests over a 3-week period. In addition, specimens of red oak lumber were also tested in the same manner as those of the hardboard composite panels.

Statistical analysis and predicting models

Statistical analysis was conducted on the dependent variables of Y_E, Y_C, and Y_{IR} as shown in equation (1) for the composite panel specimens. The design was a 3 by 5 by 3 factorial arranged as a split plot: factor A, B, C, represented 3 LL, 5 SR, and 3 CD, respectively. The criterion for grouping blocks was the hardboard core density (Steel and Torrie 1960).

To develop a model for predicting Y_E, Y_C, and Y_{IR} as functions of factor A, B, C, A^2, B^2, C^2, and their interactions, a backward elimination multiple regression technique was used (Draper and Smith 1967).

Power law or log-log linear relationships were developed to predict the total creep in inches (Y_C) as a function of time under load in minutes (Johnson 1966 and Chow 1970). These models describe Y_C as a function of time using a two-stage relationship for each specimen. The equations are:

$$Y_C = Y_{C1} + Y_{C2} \tag{2}$$

$$Y_{C1} = A_1(t-1)^{1/b_1} \tag{3}$$

$$Y_{C2} = A_2(t-1)^{1/b_2} \tag{4}$$

in which Y_C = total creep deflection at 100 min (inches)

TABLE 4. *Analysis of variance and F-ratio values at factorial levels of elastic (Y_E), total creep (Y_C), and irrecoverable creep (Y_{IR}) deflections.*

Source	Degrees of freedom	F-ratio		
		Y_E	Y_C	Y_{IR}
Total	89			
Replications (REP)	1			
Load level (LL)	2	HS[1]	HS	HS
REP × LL	2	N[2]	N	N
Shelling ratio (SR)	4	HS	HS	HS
REP × SR	4	N	N	N
LL × SR	8	HS	HS	HS
REP × LL × SR	8	N	N	N
Core density (CD)	2	HS	HS	HS
REP × CD	2	N	N	N
LL × CD	4	HS	N	N
REP × LL × CD	4	N	N	N
SR × CD	8	HS	HS	S
REP × SR × CD	8	N	N	N
LL × SR × CD	16	S[3]	N	N
REP × LL × SR × CD	16	N	N	N

[1] HS—significant at 1% level.
[2] N—not significant at 5% level.
[3] S—significant at 5% level.

Y_{C1} = creep deflection between 2 to 10 min (inches)
Y_{C2} = creep deflection between 10 to 100 min (inches)
t = time in min
A_1, A_2, b_1, b_2 = constants

RESULTS AND DISCUSSION

Table 3 shows the averages for Y_E, Y_C, and Y_{IR} for the ¾-inch thick, 12- by 39-inch full-sized specimens. Table 4 shows the results of the analysis of variance for the creep tests. The results indicate that all three dependent variables of Y_E, Y_C and Y_{IR} were significantly affected by the three main independent factors of LL, SR, CD, and some of their interactions. In all cases, the greater Y_E value resulted in a greater Y_C value as was found in an earlier study (Chow 1970). High Y_C also resulted in greater Y_{IR}.

Load level

Results show that the average Y_E, Y_C, and Y_{IR} deflections increased with increasing LL. As the LL was increased from 43.75 pounds to 87.50 pounds, both the average values of Y_E and Y_C were about doubled. This would be expected for Y_E values because the external loads were within the proportional limit of the composite panels. On the average the Y_C at 100 min loading was between 4 to 8% of the Y_E values. The average Y_{IR} of all specimens was about 50% of the Y_C.

Shelling ratio

In general, the plain hardboards, or specimens with a SR of 0.000, had the greatest Y_C in all levels of SR, LL, and CD. The application of 1/28-inch red oak

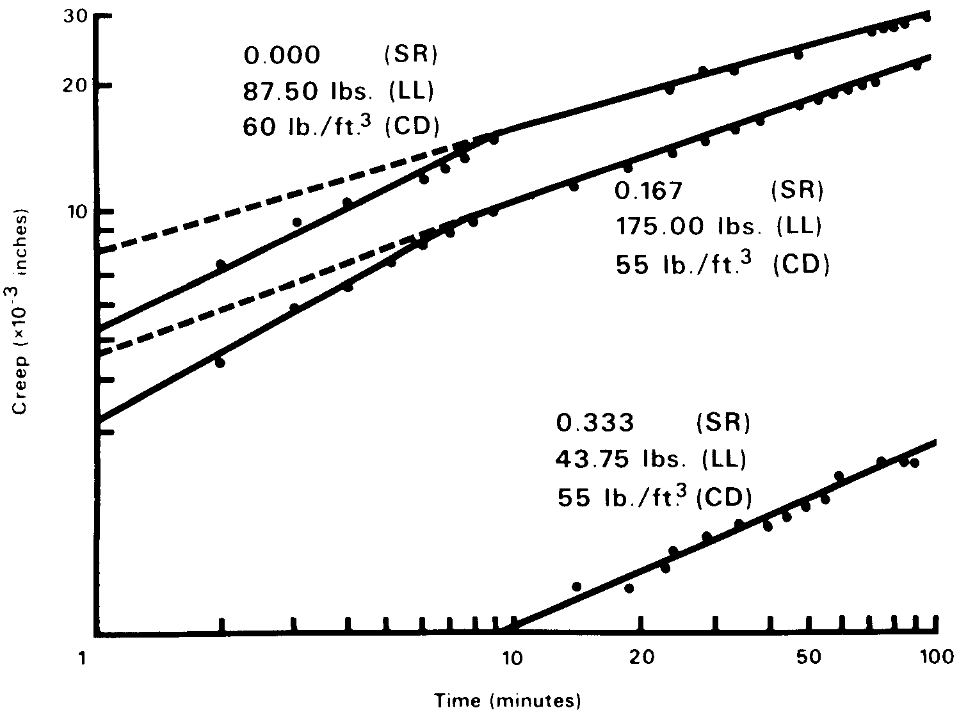

FIG. 1. The relationship between creep deflection and time for three composite panels in log-log scale. Dot lines are projected from lines derived from actual test data from 10 to 100 min (SR = shelling ratio, LL = load level, and CD = hardboard core density).

veneers to the hardboard core (SR = 0.094) greatly reduced the Y_E, Y_C, and Y_{IR} values to about 60% of those of the plain hardboards. Further reduction of Y_C and Y_{IR} was not substantial until the SR reached 0.262. Increasing the veneer thickness to an SR of 0.333 did not again decrease the values of Y_C and Y_{IR}. This indicates that 1/10-inch veneer faces carry most of the bending stresses in the 3/4-inch hardboard composite beam. For panels with SR values of 0.262 and greater, values of Y_E, Y_C, and Y_{IR} approached those of red oak lumber (Table 3).

Core density

By averaging overall SR and LL, the specimens with higher CD levels had greater resistance to creep deflections and showed lower Y_{IR}. However, CD did not have the same degree of effect on Y_C as did SR and LL.

Interactions

The statistical analysis (Table 4) shows that the interactions between LL and SR, and between SR and CD accounted for significant portions of the variation in Y_E, Y_C, and Y_{IR}. The increased LL caused greater Y_C at low SR. At high SR, panels were stiffer and increased LL did not cause as much change in deflections as occurred at the lower levels of SR. On the other hand, the panel CD had a greater influence on the Y_E. At high SR the veneer faces carry almost all of the

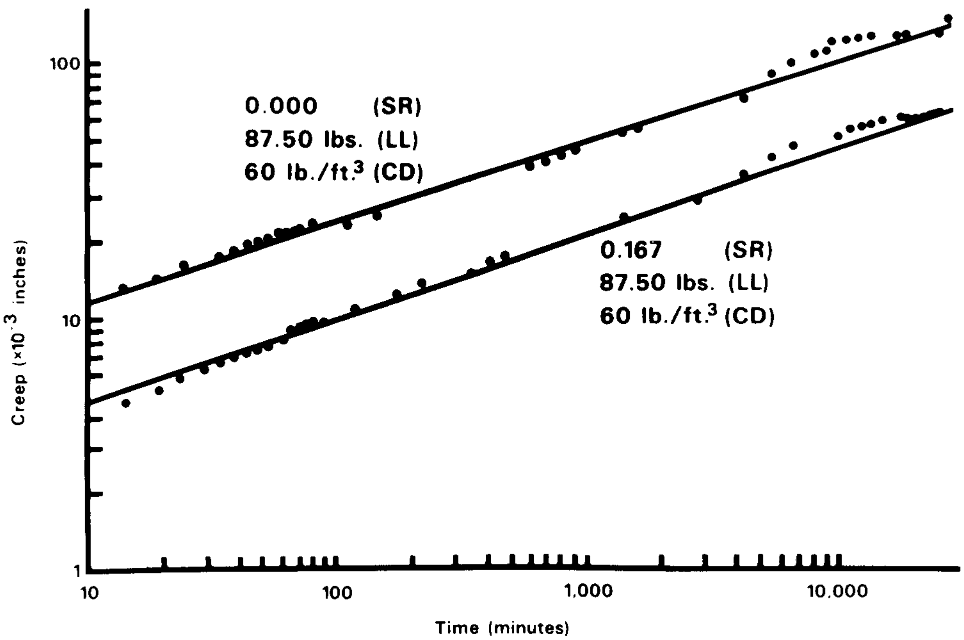

FIG. 2. The relationship between creep deflection and time for two composite panels under sustained loading creep tests for 21 days (log-log scale).

bending load and the core material accounts for most of the shear deflection. The results show that at high SR, specimens with high CD did not always demonstrate better resistance to creep. It is possible that the variations existing in thick veneer could have more effect on creep properties of panels at high SR than the factor of CD alone (Timoshenko 1972).

Multiple regression equations

The results of the backward elimination multiple regression analysis of Y_E, Y_C, and Y_{IR} as a function of LL, CD, SR, their squared terms, and their interactions are given:

$$\begin{aligned} Y_E = {} & 5.36 \times 10^{-1} + 5.39 \times 10^{-3}(LL) - 3.23 \times 10^{-3}(SR) - 8.12 \times 10^{-3}(CD) \\ & - 6.03 \times 10^{-6}(SRLL) - 3.29 \times 10^{-5}(CDLL) + 4.08 \times 10^{-5}(SRCD) \\ & + 2.21 \times 10^{-6}(SR)^2 \\ R^2 = {} & 0.96 \end{aligned} \tag{5}$$

$$\begin{aligned} Y_C = {} & 5.48 \times 10^{-1} + 5.62 \times 10^{-4}(LL) - 3.52 \times 10^{-4}(SR) + 9.26 \times 10^{-4}(CD) \\ & - 5.0 \times 10^{-7}(SRLL) - 3.51 \times 10^{-6}(CDLL) + 4.95 \times 10^{-6}(SRCD) \\ & + 5.70 \times 10^{-7}(LL)^2 + 1.40 \times 10^{-7}(SR)^2 \\ R^2 = {} & 0.87 \end{aligned} \tag{6}$$

$$\begin{aligned} Y_{IR} = {} & 3.76 \times 10^{-2} + 1.55 \times 10^{-4}(LL) - 1.77 \times 10^{-4}(SR) - 5.58 \times 10^{-4}(CD) \\ & + 1.30 \times 10^{-7}(SR)^2 - 2.30 \times 10^{-7}(SRLL) + 2.06 \times 10^{-5}(SRCD) \\ & - 3.10 \times 10^{-7}(LL)^2 \\ R^2 = {} & 0.85 \end{aligned} \tag{7}$$

in which Y_E = initial deflection at 1 min (inches)
Y_C = total creep deflection at 100 min (inches)
Y_{IR} = irrecoverable creep deflection after 100 min unloading (inches)
LL = load level (pounds)
SR = shelling ratio × 1000
CD = hardboard core density (lbs/ft^3)

Equations (5), (6), and (7) accounted for 96, 87, and 85% of the variation in Y_E, Y_C, and Y_{IR}, respectively. The F-values for all partial regression coefficients were also significant. The statistics of fit suggest these models give a reasonable prediction of Y_E, Y_C, and Y_{IR} over the range of the parameters studied.

Extrapolation

Figure 1 shows typical plots of Y_C versus time for three representative composite panels with various levels of SR, LL, and CD. The data were plotted on a log-log scale of a power-law form. The model shows two portions of creep, between 2 and 10 min, and 10 and 100 min. The data seem to fit equations 3 and 4 very well. Two separate log-log simple linear regression equations on Y_C were obtained for each composite panel. In most cases, the correlation coefficients or R^2 values of each regression model exceed 0.90.

Data of long-term Y_C from two composite panel specimens tested for three weeks are plotted in Fig. 2. Creep data were recorded from 10 min on during the 3-week testing period. The R^2 values of 0.99 and 0.98 for two specimens indicate that the model $Y_C = A(t - 1)^{1/6}$ can be used to accurately describe the creep behavior of these hardboard composite panels up to 3 weeks.

The log-log regression was also analyzed on each of the two panels using the data from 10 to 100 min only. The slope and intercept obtained for both of the panels were almost identical to those values obtained from data of 3 weeks. It shows that a reliable Y_C for 3 weeks could be approximated from data derived from a short-term 100-min sustained loading test.

SUMMARY

1) A greater Y_E generally resulted in a greater Y_C and Y_{IR}. A greater Y_C generally resulted in a greater Y_{IR} .

2) Creep deflections of all composite panels were affected by the load level, core density of hardboard, and shelling ratio in this study.

3) The red oak lumber exhibited the most creep resistance. However, the composite panel with an SR of 0.262 was nearly as resistant to creep as red oak lumber.

4) Creep deflections of all panels were very well described by a power-law function, based on separate test models of 2 to 10 min and 10 to 100 min. The extrapolation of log-log regression for the approximation of creep appeared to give reasonable values for up to 3 weeks.

5) Average values of Y_E, Y_C, and Y_{IR} can be predicted from three multivariable regression models as a function of SR, LL, and CD of hardboard. The R^2 values for three models were 0.96, 0.87, and 0.85, respectively.

REFERENCES

CHOW, POO. 1970. The deflection of composite furniture panels under constant bending stresses. For. Prod. J. 20(12):44–51.

———. 1971. Particleboard shelving tests. Furniture Design and Mfg. 32(2):74–76.

DRAPER, N. R., AND H. SMITH. 1967. Applied regression analysis. John Wiley and Sons, Inc. N.Y. 407 pp.

IWASHITA, M. 1974. Studies on particleboard (XII) on the evaluation of adoptable qualities for furniture or building materials (1). Jap. Bull. of the Gov. For. Exp. Sta. No. 263. 65–72 pp.

JOHNSON, L. H. 1966. Normography and empirical equations. John Wiley and Sons, Inc. N.Y. 150 pp.

MCNATT, J. D. 1970. Design stresses for hardboard. For. Prod. J. 20(1):53–60.

———. 1975. Effect of rate of loading and duration of load on properties of particleboard. USDA For. Ser. Res. Paper FPL 270. 15 pp.

MOSLEMI, A. A. 1964. Some aspects of viscoelastic behavior of hardboard. For. Prod. J. 14(8):337–342.

STEEL, R. G. D., AND J. H. TORRIE. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc., New York. 481 pp.

TIMOSHENKO, S. P. 1972. Mechanics of materials. D. VanNostrand Co., N.Y. 552 pp.

YOUNG, R. L., AND H. C. HILBRAND. 1963. Time related flexural behavior of small Douglas-fir beam under prolonged loading. For. Prod. J. 13(6):227–232.