AN ANALYSIS OF CREEP-INDUCING STRESS IN SITKA SPRUCE[1]

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ABSTRACT

Small specimens of Sitka spruce (*Picea sitchensis*) were placed under a parallel-to-the-grain compressive loading situation in a water-saturated state to examine the adequacy of three-element and four-element spring and dashpot model analogs in describing creep response curves for wood. Stress levels of 10, 20, 40, and 60% of ultimate compressive strength were studied for load durations up to 20 days. Deformation-time measurements were analyzed statistically by means of a computerized, nonlinear, least squares regression analysis and with the aid of graphic analysis.

Creep deformation was found to occur at stress levels as low as 10% and at very short time periods. In general, three- or four-element model analogs were adequate to describe time-dependent deformation phenomena for applied purposes; further refinements were deemed superfluous. For time periods of 24 hr or longer, the use of a four-element model is advised, particularly at higher stress levels.

INTRODUCTION

All materials deform when a load is placed upon them. After an immediate, elastic deflection, loaded materials continue to deform at a reduced rate for a period of time. Wood is no exception; thus it is said to be viscoelastic in that it responds to a force by undergoing elastic, or recoverable, deformation and inelastic, or nonrecoverable, deformation under load. The amount of continued deformation, referred to as creep, is dependent upon a number of factors including the magnitude of the load, the duration of load, wood moisture content, and temperature. The purpose of this study was to try to analyze the phenomenon of creep in terms of two of these parameters, magnitude and duration of load, for small specimens of Sitka spruce loaded in compression parallel to the grain.

Time-dependent properties of wood are of very practical importance. Creep can occur at stress levels presently allowed and may become more important as grading research leads to possible increases in these allowable stresses. Relaxation provides the means of molding wood into new shapes as in traditional steam bending. The dependency of wood strength on load duration is well known and is a fundamental part of even the most elementary wood engineering design. Perhaps the earliest reference to time-dependent properties in wood is that of Thurston (1880), who conducted a series of bending tests on Southern yellow pine. He reported that creep occurs in beams loaded well below their short-time load-carrying capacity. Wood (1951) describes early duration-of-load studies conducted at the U. S. Forest Products Laboratory that resulted in the widely used curve relating duration of maximum load to the ratio of working stress to recommended stress for long-time loading (50 yr). This relationship forms the basis for corrections to basic stresses for stress-graded lumber to take duration of load into account (ASTM 1965); and it presents a very practical aspect of the effect of creep response in wood. More recent studies (Forest Products Laboratory 1964; Youngs 1957) have examined the effect of creep in such diverse areas as structural failure and the effect of shrinkage stresses imposed on wood by high humidities and high temperatures during kiln drying.

Factors affecting creep response in wood have been studied by numerous investi-

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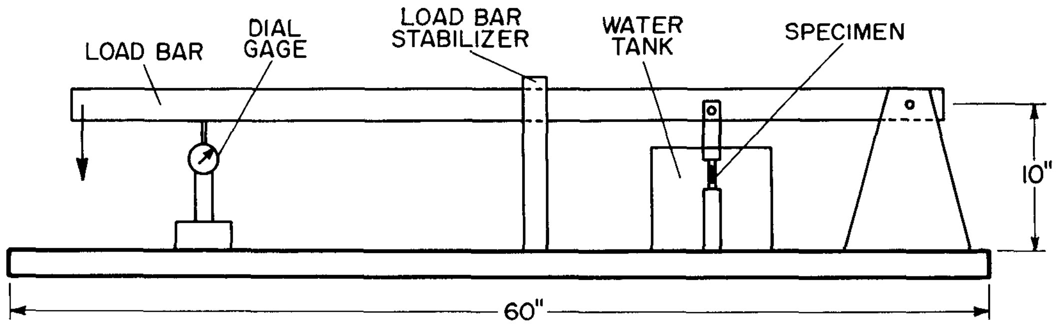

FIG. 2. Schematic diagram of loading apparatus. The apparatus was enclosed in an insulated, temperature-regulated chamber. The load bar stabilizer did not impose any frictional load on the bar; it served to align and vertically guide the load bars. Four specimens utilizing four load bars were tested at a time, one for each stress level studied.

Four specimens taken from the same general area in the log were tested in compression parallel to the grain. The specimens were 2 inches by $1\frac{5}{8}$ inches by 8 inches long and were tested in the standard ASTM procedure in the green condition (average MC was 93%). The average strength in compression parallel to the grain of the four specimens was 2160 psi; this was taken as the ultimate strength for further testing purposes.

The 28 specimens were randomly assigned to the stress level and duration of load period combination to be imposed. Load levels were 10, 20, 40, and 60% of ultimate strength in compression; corresponding stress values in pounds per square inch were 216, 432, 864, and 1296 psi, respectively. Durations of load intervals were 5 min, 1 hr, 8 hr, 1 day, 4 days, 10 days, and 20 days.

The durations of load intervals for this study were chosen to yield anatomical information; this phase of the investigation failed to produce positive results and is not reported here.

The water-saturated specimens were tested under water in a small aquarium so that any influence of changing moisture content would be completely eliminated. The test set-up, Fig. 2, permitted the use of four loading bars. This allowed the testing of four specimens at a time; thus a complete replication of the four stress levels could be completed in one time interval. Preliminary investigation revealed that even though the tests were conducted at a relatively stable room temperature, a noticeable fluctuation in dial gage deformation readings was observable as the temperature within the test area changed throughout the day. Since the exact cause of the fluctuation in dial gage readings due to temperature variations could not be pinpointed or eliminated, an attempt was made to minimize and correct for this influence. Thermometers and a small thermostatically controlled immersion heater were utilized to maintain the water temperature within the tank at 31.1 ± 0.05 C. In this way dial gage fluctuations due to variable ambient temperature could be greatly reduced. In addition, the loading apparatus was enclosed in an insulated compartment, and the deflectometers were calibrated so that subsequent data readings could be mathematically corrected to compensate for minor small shifts in temperature in the testing apparatus. Such corrections were generally small, but they were particularly useful for those specimens tested for longer periods where small deformations could easily have been offset by temperature effects.

Specimens were placed in the water tank prior to loading and allowed to come to the same temperature as the water in the tank. The specimens were shimmed so that the loading bars were as nearly horizontal as possible during loading. Any nonaxial load-

TABLE 1. *Summary of "goodness of fit" for three- and four-element models for creep response in compression specimens of Sitka spruce*

Stress level (% of ultimate)	Duration of load	R^2 Three-element	Four-element
10	5 min	0.429	0.773
20	5 Min	0.935	0.948
40	5 Min	0.977	0.988
60	5 Min	0.963	0.991
10	1 Hour	0.515	0.515
20	1 Hour	0.869	0.869
40	1 Hour	0.853	0.992
60	1 Hour	0.835	0.943
10	8 Hours	0.948	0.948
20	8 Hours	0.983	0.984
40	8 Hours	0.883	0.968
60	8 Hours	0.860	0.948
10	1 Day	0.522	0.624
20	1 Day	0.904	0.965
40	1 Day	0.822	0.837
60	1 Day	0.804	0.941
10	4 Days	0.656	0.708
20	4 Days	0.104	0.334
40	4 Days	0.608	0.608
60	4 Days	0.878	0.907
10	10 Days	0.260	0.281
20	10 Days	0.877	0.880
40	10 Days	0.859	0.922
60	10 Days	0.834	0.845
10	20 Days	0.555	0.602
20	20 Days	0.738	0.803
40	20 Days	0.404	0.454
60	20 Days	0.568	0.756

In an effort to gain insight into physical interpretation of the data, a CALCOMP plotter was utilized. This device is used in conjunction with a computer to plot automatically both actual and mathematically derived data in graphic form, to scale, complete with graph title and labeled axes. In this manner, the computed model equations could be plotted along with the actual experimental data points.

There are, however, several things that should be pointed out about the analysis used. Because of the computational procedure utilized, a general lack of numerical similarity was apparent in the parameter values for the equations. Also, in several instances negative parameter values were obtained; this is satisfactory from a mathematical point of view, but is often meaningless from a physical, interpretive point of view. These occasional unrealistic solutions indicate the difficulty in measuring relatively small deformations over long periods of time and the hazard that exists in correcting data to "zero time" (i.e., forcing the B_1 term to have a value of zero).

An example of the analysis of creep response data obtained in a 60% stress level compression test for one-day duration is shown in Fig. 3. Assuming that these data represent a typical set of deformation-time responses, it may be seen that both the three- and four-element models result in relatively high R-squared values. As would be expected, the four-element model was somewhat more satisfactory than the three-element model. The data obtained for the 10- and 20-day duration of load periods tended to be somewhat more erratic than the data obtained for shorter periods of time, such as the one day illustration of Fig. 3, because of difficulty in satisfactorily measuring the very small changes in deformation that occurred as loading progressed beyond several days. The effects of even minor variations in temperature and moisture content may be very influential.

The attempts at precise control in these experiments demonstrated the sensitivity of the time-dependent processes to the related parameters of moisture content and temperature. Additional conclusions can also be drawn that reinforce the findings of other, broader experiments that could not impose the control refinements possible in this case. Subject to the limitations imposed by the experimental procedure, the following conclusions have been drawn from the data of this study:

1. Creep deformation does occur at stress levels as low as 10% of ultimate green strength in compression parallel to the grain in Sitka spruce.
2. Creep deformation occurs during very short time periods; it increases as either the stress level or the duration of load increases.
3. For time periods of 24 hr or longer, the use of a four-element model is advisable, particularly for stress levels

of 40% or higher, in view of the fact that a three-element model can not accommodate flow.

4. Three-element and four-element spring and dashpot model analogs may be used to describe satisfactorily time-dependent deformation phenomena for stress levels up to 60% and time periods up to 20 days. In view of the variation in deformation observed in this experiment, model refinements beyond the three- and four-element types may not be expected to produce substantially better correlations between deformation and time-stress variables for practical applications.

REFERENCES

ALFREY, T., JR. 1948. Mechanical behaviour of high polymers. Interscience Publishers, Inc., New York.

AMERICAN SOCIETY FOR TESTING AND MATERIALS. 1965. Standard methods of testing small clear specimens of timber, D143-52 (1965). Philadelphia, Pa.

ARMSTRONG, L. D., AND R. S. T. KINGSTON. 1962. The effect of moisture content changes on the deformation of wood under stress. Australian J. Appl. Sci., **13**:257–276.

CHRISTENSEN, G. N. 1962. The use of small specimens for studying the effect of moisture content changes on the deformation of wood under load. Australian J. Appl. Sci., **13**:242–256.

DAVIDSON, R. W. 1962. The influence of temperature on creep in wood. Forest Prod. J., **12**(8):377–381.

FLUGGE, W. 1967. Viscoelasticity. Blaisdell Pub. Co., Waltham, Mass.

FOREST PRODUCTS LABORATORY. 1964. Annual report of research at the Forest Products Laboratory. U. S. Forest Products Laboratory, Madison, Wisconsin.

JAYNE, B. A. 1963. Mechanical tests for wood, p. 105–118. *In* The mechanical behaviour of wood.

NARAYANAMURTI, D. 1960. Rheology of wood. Proceedings of the Fifth World Forestry Congress, p. 1326–1331.

PENTONEY, R. E. 1963. Time-dependent mechanical properties of wood, p. 96–104. *In* The mechanical behaviour of wood.

SCHNIEWIND, A. P. 1966. On the influence of moisture content changes on the creep of beech wood perpendicular to the grain including the effects of temperature and temperature changes, Holz als Roh- und Werkstoff, **24**(3):87–98.

———. 1967. Creep-rupture life of Douglas-fir under cyclic environmental conditions. Wood Sci. Technol., **1**:278–288.

SENFT, J. F. 1967. Study of wood ultrastructure in relation to creep-inducing stress. Unpublished doctoral thesis, Purdue University, Lafayette, Indiana.

SZABO, T., and G. IFJU. 1970. Influence of stress on creep and moisture distribution in wooden beams under sorption conditions. Wood Sci., **2**(3):159–167.

THURSTON, R. H. 1880. Experiments on the strength of yellow pine. J. Franklin Institute, **110**:157–163.

WOOD, L. W. 1951. Relation of strength of wood to duration of load. U. S. D. A. Forest Prod. Lab. Rept. No. 1916, Madison, Wisconsin.

YOUNGS, R. L. 1957. The perpendicular-to-grain mechanical properties of red oak as related to temperature, moisture content, and time. U.S.D.A. Forest Prod. Lab. Rept. No. 2079, Madison, Wisconsin.