SHORT-TERM CREEP AS RELATED TO MICROFIBRIL ANGLE[1]

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ABSTRACT

Relationship between creep response and microfibril angle within the S_2 layer of some coniferous wood tissues was examined. Constant loads corresponding to predetermined initial strain levels of 3,000 μinches/inch (A) and 6,000 μinches/inch (B) were applied to small wood strips. Microfibril angle was measured by the mercury impregnation method.

A positive linear relationship was found between microfibril angle and total creep ($r =$ 0.82 and 0.83 for samples tested at constant loads corresponding to strain levels (A) and (B), respectively). A phenomenological approach is presented to explain the role of microfibril angle of the S_2 layer in controlling creep response. Total creep was also found to be positively correlated with magnitude of applied load corresponding to a given deformation.

INTRODUCTION

Although the usefulness of wood in several of its applications is based on its elastic properties, rheological studies reveal that wood exhibits both elastic and plastic properties. Frequently the plastic properties dominate in its behavior.

Basically, elastic properties of wood, under the same environmental conditions, are determined by factors inherent in its structure. These may be summarized as: (a) the supermolecular arrangement and orientation of cell-wall material in the different tissues (Cowdrey and Preston 1965, 1966; Wellwood 1962); (b) the proportionate chemical composition of the primary components of the cell wall (Arganbright 1971; Ifju 1963); (c) the amount of the cell-wall substance present in a given volume of wood (specific gravity) (Brown et al. 1952; Ifju et al. 1965); and (d) the kind, size, proportions and arrangement of the cells making up the woody tissues (Schniewind 1959).

Virtually nothing is known about the role that the above-noted factors play in controlling rheological properties. It is anticipated, however, that these factors would influence and control creep response of wood and/or wood tissues.

The purpose of this paper is to examine short-term creep response of tissues of certain coniferous woods in tension parallel to the grain as a function of the microfibril angle in the tracheid cell wall. Information derived should provide basic knowledge as to the mechanism of wood tissue deformation under creep-inducing stress.

MATERIALS AND METHODS

Wood samples

The experimental material was carefully chosen from normal wood of single trees of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and from compression wood of Douglas-fir, available from the University of British Columbia Research Forest, Haney, B. C. The diameters at breast height were 26, 22, 28 and 14 inches outside bark for Douglas-fir normal and compression wood, Sitka spruce, and western hemlock, respectively. One disc was chosen from each tree at breast height. Two adjacent tangential

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blocks (nominal 2.5 inches longitudinally, 1.5 inches radially and 0.75 inch tangentially) were cut from each disc. Each block included at least one annual increment that exhibited a minimum of curvature.

Preparation of test specimens

Prior to sectioning tangentially on a sliding microtome, blocks were aspirated under vacuum in a vacuum/pressure cylinder until waterlogged. The slicing angle between grain direction and the travel direction of the microtome knife was set at 10° to minimize the number of slip planes (Kennedy and Chan 1970) that might develop. Matched specimens were secured from two contiguous microtome sections from each block at the same relative position within each annual increment (Numbers 71, 80, 187 and 60 for Douglas-fir normal wood and compression wood, Sitka spruce normal wood, and western hemlock normal wood, respectively). One section provided strips for the creep experiment, the other for microfibril angle measurements.

The sections assigned for the creep experiment were punched into strips using a specially machined cutting die fixed to a half-ton arbor press. Rectangular strips (nominal 0.098 inch width, 2.5 inches length and 0.011 inch thick) were utilized. Care was taken to ensure a cut parallel to the grain by noting the direction of ink flow along the grain. Strips were kept in a controlled temperature and humidity (CTH) room, maintained at 73 ± 3.5 F and 50 ± 2% relative humidity, for eight days, after which no change in specimen weight could be observed when weighing to an accuracy of ± 0.0005 g.

Micro-creep test

A. *Testing machine.* A table model Instron testing machine was modified for conducting creep tests in tension parallel to the grain. A strain gauge extensometer with 0.5-inch gauge length and 10% strain limit was connected to a five-pin adapter feeding directly to the load cell amplifier. Calibration of the chart was carried out using an extensometer calibrator. Sensitivity was increased by using Range One on the Instron panel, which provided a sensitivity of ± 5 μinches/inch.

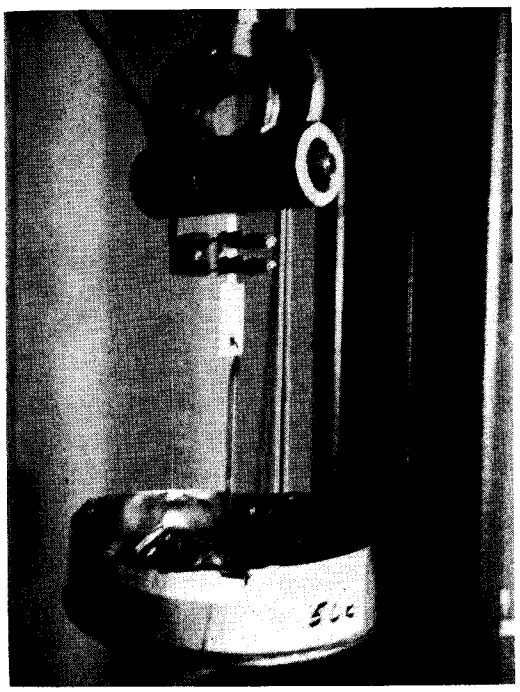

FIG. 1. Creep parallel to the grain testing set-up and loading system.

B. *Loading system.* The experimental technique for the creep test required two constant load levels corresponding to initial strains of 3,000 μinches/inch (A) or 6,000 μinches/inch (B). One strain level was applied to the wood strips (varying from 1 to 6) taken from one block per wood type, the other strain level from those obtained from the matched blocks. The load required to give the predetermined strain level was kept constant over a 60-min time period using the loading system described below.

Test specimens were glued at both ends between aluminum sheets, using Eastman 910 adhesive, to facilitate loading the strips. The assembly was carefully aligned in the upper grips of the testing machine. A hooked-end wire was attached to the lower end of the specimen and put through a hole in the bottom of a bucket resting on the

lower crosshead of the machine. A 100-g weight was hung at the lower end of the wire to straighten out the specimen and to facilitate mounting the strain gauge on it. Some lead shot, depending on the tensile strength of each species, was then put into the bucket without loading the specimen. After about 15 min, during which the zero strain point was suppressed to either 2,600 or 5,600 μinches/inch, the lower crosshead was automatically moved down. More lead shot was immediately poured into the bucket, so that the initial required strain level of either 3,000 or 6,000 μinches/inch was reached in about 30 sec. After that, the load was kept constant for 60 min. This system (Fig. 1) provided an accurate and rapid means of loading the assembly.

Measurements of total creep, the total deformation due to a constant load imposed over a 60-min time period, were taken under CTH room conditions.

Microfibril angle determination

The mercury impregnation method of Page (1969), with some modification, was used to determine microfibril angle of the wood tissues. Tangential surfaces of the samples were matched with those used for creep tests and subjected to a mild delignification (equal parts of acetic acid and hydrogen peroxide). This procedure facilitated splitting the section surface manually along the middle lamella, as required for obtaining single walls.

Samples were then dehydrated using acetone, following which they were put into a small pressure cylinder. Mercury was introduced and a pressure of 1,000 psi was applied for a few minutes through a piston in the cylinder. The pressure was then released and the specimens were examined in a polarizing microscope using incident (epi-) illumination.

Under epi-illumination with the polarizer and analyzer (polars) crossed, a tracheid with a mercury-filled lumen has an extinction position where the fibrils in the S2 layer are parallel to the plane of one of the polars. The microfibril angle was then measured as the angle between this plane and the longitudinal axis of the tracheid in the extinction position.

Twenty-nine to 40 measurements were taken on each matched section from each block and the average was considered to represent the mean microfibril angle for each of the individual strips used for creep tests. This procedure was necessary because of the difficulty in assigning a precise value for each strip individually.

RESULTS AND DISCUSSION

If microfibrils were arranged parallel to longitudinal axes of tracheids, they would most effectively resist deformation originating from creep-inducing stress. In fact, these structural elements are oriented at an angle to the longitudinal axis of the tracheid in the thick S2 layer. This angle differs between species as well as across the annual increment from early- to latewood (Hiller 1964, 1968).

It can be seen from the experimental values presented in Table 1 that Sitka spruce latewood is characterized by the lowest microfibril angle (9.22°), whereas the earlywood of Douglas-fir compression wood is characterized by the highest angle (28.22°) among the wood tissues examined. In general earlywood has a larger angle than latewood. The variability is directly related to tracheid length where, within one annual increment, earlywood has shorter tracheids than latewood (Preston 1965; Wardrop and Preston 1950). Accordingly, species and/or wood tissues are expected to react differently to an applied constant stress, depending largely on the magnitude of microfibril angle.

Empirical equations were constructed between total creep (Y) and microfibril angle (X), using simple regression analysis with the least-squares-method fit. These equations are as follows:

(A) Strain level specimens:

$$Y = 28.22 + 9.19\ X \quad \ldots\ldots (1)$$

$$SEE = 38.75$$

$$r = 0.82^*$$

$$N = 34 \qquad \text{and}$$

* Significant at the 0.5% level.

TABLE 1. *Microfibril angle and total creep for the samples tested at 3,000 and 6,000 μinches/inch initial strain*

Species		Microfibril angle (degree)	Total creep at 3,000 μinches/inch (μinches/inch)	Total creep at 6,000 μinches/inch (μinches/inch)
Douglas-fir				
Normal wood				
Earlywood	1		324	674
	2		207	607
	3		197	724
	4	21.63 (4.98)[a]	180	610
	5		234	596
	6		214	616
Average			226.0	637.8
Latewood	1	12.95 (2.48)	200	485
Compression wood				
Earlywood	1		370	714
	2		285	787
	3	28.22 (4.03)	255	720
	4		254	767
	5		274	–
Average			287.6	747.0
Latewood	1		230	636
	2	17.37 (2.74)	190	590
	3		220	610
Average			213.3	612.0
Sitka spruce				
Earlywood	1		140	314
	2		145	327
	3		130	307
	4	14.30 (2.74)	164	293
	5		160	323
	6		110	–
Average			141.5	312.8
Latewood	1		84	270
	2		110	250
	3	9.22 (1.80)	107	320
	4		167	234
	5		104	290
Average			114.6	272.8
Western hemlock				
Earlywood	1		217	427
	2		182	394
	3	20.74 (4.00)	177	454
	4		167	407
Average			185.8	420.5
Latewood	1		298	494
	2		254	393
	3	21.26 (2.01)	220	440
	4		230	480
	5		–	527
	6		–	510
Average			250.5	474.0

[a] Values in parentheses are the standard deviations of the averages reported and are based upon 31 to 73 measurements.

(B) Strain level specimens:

$$Y = 39.12 + 24.00\ X \quad \ldots\ldots (2)$$
$$SEE = 94.10$$
$$r = 0.83^{*}$$
$$N = 34$$

Examination of the above two mathematical models indicates the high degree of association between total creep and the magnitude of microfibril angle.

A specimen having a large microfibril angle prior to application of an initial strain level could logically be expected to respond to a greater degree than a specimen having a relatively small microfibril angle. This response is substantiated in Figs. 2 and 3.

Microfibril angle was not measured on completion of the creep test, during the course of this work, because of some experimental limitations. However, close examination of the graphs presented in Figs. 4 and 5, for example, indicates that creep rate at both strain levels is larger in the case of Douglas-fir earlywood (Fig. 4, microfibril angle of 21.63°) than in the case of spruce latewood (Fig. 5, microfibril angle of 9.22°). The larger rate of creep could be considered a result of the large movement of microfibrils in orienting themselves to the applied initial strain.

The argument presented above is supported by the work of Jentzen (1964) on longleaf pine early- and latewood pulps.

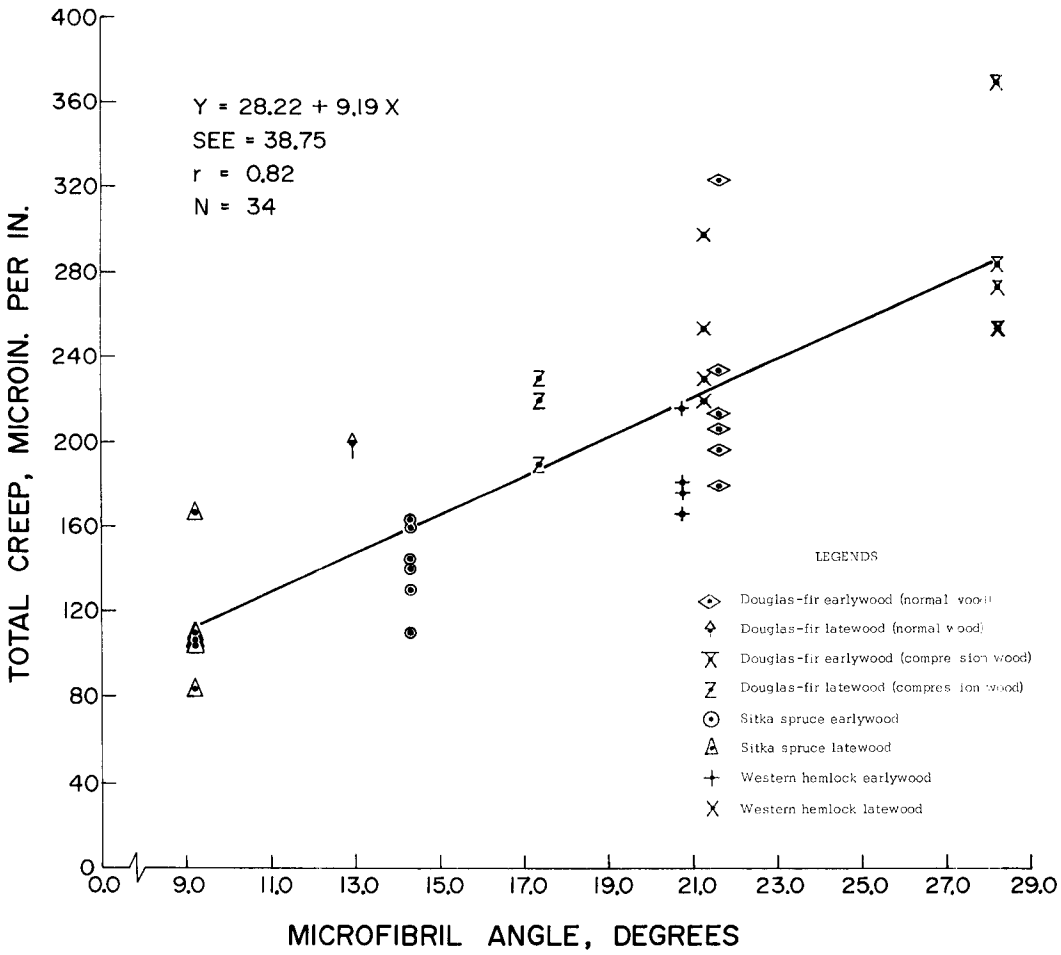

FIG. 2. Relationship between total creep (Y) and microfibril angle (X) at 3,000 μinches/inch initial strain level.

Jentzen has stated that earlywood tracheid skeletons underwent a greater change in their "crystallite orientation" than did the latewood tracheid skeletons under the same drying load in tension parallel to the grain. Similar results were also reported by Hill (1967) for a latewood pulp of the same species. Working on sisal fibers, Balashov et al. (1957) were able to record a decrease in microfibril angle under tensile strains that increased from 5 to 20%.

If one accepts the fact that microfibril angle becomes smaller under a creep-inducing stress, it follows that the change towards a smaller angle can be expected to be larger for a specimen having a larger initial angle. This, in turn, leads to higher creep deformation because of the large expected movement associated with adjustment of the stiff, inextensible microfibrils, to accommodate the applied load without failure. The possibility also exists that microfibrils might slip past each other if the applied strain is large enough, as in the case of initial strain of 6,000 μinches/inch, giving rise to the higher observed creep (Balashov et al. 1957; Preston 1960).

It is clear also from Table 1 that total creep increases as initial applied strain increases. In addition, the average creep

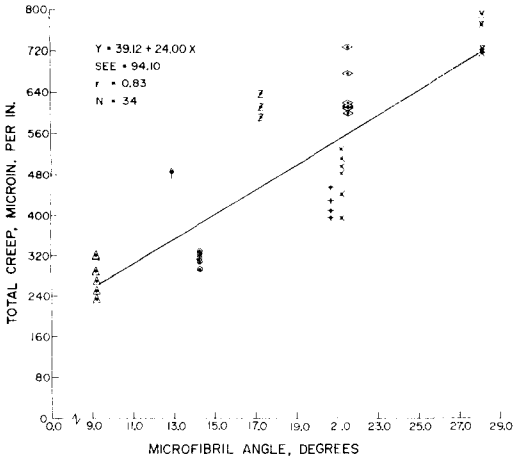

FIG. 3. Relationship between total creep (Y) and microfibril angle (X) at 6,000 μinches/inch initial strain level. See Fig. 2 for legend.

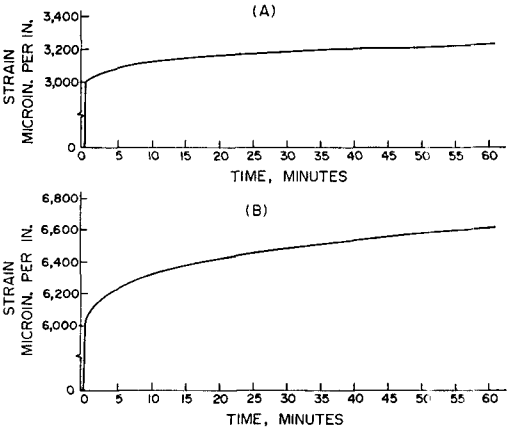

FIG. 4. Strain-time relationship for Douglas-fir earlywood (normal wood) at (A) 3,000 μinches/inch (specimen No. 5) and (B) 6,000 μinches/inch (specimen No. 4) initial strain.

response at strain level (B) was more than twice the average response at strain level (A), implying that the effect of microfibril angle becomes more pronounced as initial strain level increases. This result is in agreement with Bhatnagar 1964; Hill 1967; King 1961; and Kingston 1962.

The results of this investigation substantiate that microfibril angle of the S2 layer of the tracheid wall is a fundamental cell-wall characteristic and exerts a profound effect on creep response of wood tissues. Therefore, determination of microfibril angle should be considered as basic in selecting material for a specific purpose where strain is a major criterion.

CONCLUSIONS

The following conclusions are drawn from the results of this study of creep in wood tissues in tension parallel to grain.

1. Total creep over a 60-min time period is highly correlated with microfibril angle of the S2 layer of the tracheid wall ($r = 0.82$ and 0.83) for strain levels of 3,000 and 6,000 μinches/inch.
2. Total creep increases with increase in initial microfibril angle. It is proposed that creep-inducing stresses cause reorientation of microfibrils by forcing them into an alignment more nearly parallel to the longitudinal tracheid axis. As a result, microfibril angle becomes smaller. The change in angle appears to be larger for a specimen having a larger angle prior to the application of an initial strain.
3. Total creep is affected by magnitude of applied load corresponding to a given initial deformation, increasing as load (initial deformation) is increased.

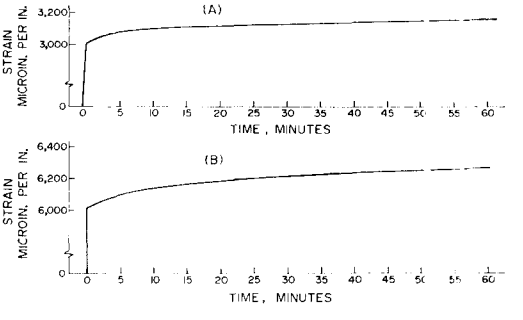

FIG. 5. Strain-time relationship for Sitka Spruce latewood at (A) 3,000 μinches/inch (specimen No. 4) and (B) 6,000 μinches/inch (specimen No. 1) initial strain.

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