Effects of Strain-Rate on the Transverse Strength of Pinus Radiata Wood

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Summary

The effects of strain-rate, moisture content, and bulk density on the transverse fracture properties of Pinus radiata wood are described. As the strain-rate is increased from $2 \times 10^{-6}$ sec$^{-1}$ to $10^3$ sec$^{-1}$, the strengths of both wet and airdry woods increase, with the greater increase occurring in wet wood. At the same time, the failure strain tends to decrease. The energy absorbed by airdry wood decreases, and that absorbed by wet wood increases. An explanation of the variation of strength with strain-rate is developed. Initially the measured strength of latewood is related to the strength of the compound middle lamella matrix connecting adjacent tracheids, and then by making the assumption that wood failure occurs when a certain proportion of the load bearing hydrogen bonds in the matrix have failed, and by applying reaction rate theory to the formation and rupture of the stressed hydrogen bonds, a strength versus time to failure relationship that is in good agreement with the experimental data is derived.

Introduction

It has long been known that the strength of wood, or wood based materials, increases as the rate of loading is increased. Garrett [1931], Liska [1955], and Panshin and De Zeeuw [1970] described the behaviour of airdry wood, while Rance [1948] studied the fracture of a number of types of paper. All found that strength increased as strain-rate was increased. James [1962] carried out experiments on both green and airdry woods, and observed that the strength of green wood increased 50% more than the strength of airdry wood for the same increase in strain-rate.

A variety of reasons have been advanced to explain the above phenomena. Panshin and De Zeeuw assumed that failure occurred when a certain critical strain was reached. At low rates of loading viscous flow or creep was able to occur, and, therefore, failure occurred at lower loads. Ylinen [1959] combined the same assumption of constant failure strain with Maxwell’s relaxation theory and obtained an expression relating strain-rate and strength. However, the data that he quoted covered only a limited range of strain-rates and did not accord
with changes in gradient of his theoretical curve. Furthermore, James [1968] showed that linear viscoelasticity theory did not adequately describe the observed load-deflection behaviour of wood.

A different approach was used by Kingston and Clarke [1961] who treated creep in wood as a rate process and calculated its activation energy. This type of treatment was further discussed by Kauman [1966] who pointed out that the activation energies and heats of reaction derived from the temperature dependence of many of the rheological properties of wood were similar in magnitude to those of chemical reactions involving the rupture of hydrogen bonds. On the basis of this evidence it seemed reasonable to suggest that the rheological properties of wood were governed by the properties of its hydrogen bonds.

Indeed, this idea had been used earlier by Nissan and Sternstein [1962] to explain the phenomenon of stress relaxation in paper. They assumed that all deformation was due to the extension of hydrogen bonds (an assumption that was later severely criticised [Page 1963]) and derived an equation relating material stress and strain to the density of load bearing hydrogen bonds. They then combined this equation with the observed stress relaxation behaviour of the paper to calculate the way in which bond density varied with time. The relationship between bond density and time appeared to be linear, and the activation energy obtained from it was in good agreement with activation energies of other hydrogen bond reactions. The theory also suggested that the rupture of hydrogen bonds in paper was a cooperative process, with bonds breaking only in groups of 6.

A somewhat different approach is used in the present work on wood. The assumption that all deformation is due to the extension of hydrogen bonds is not made, but is replaced by the assumption that the strength of the amorphous matrix of the cell wall is dependent on hydrogen bonding, and that failure of the matrix will occur when a certain proportion of its component hydrogen bonds have failed. Application of a tensile stress to the hydrogen bonded material biases the normal equilibrium between dissociated and whole bonds in favour of the dissociated state, a situation that ultimately results in instability and macroscopic failure. A study of the rates of rupture and recombination of the stressed hydrogen bonds leads to the prediction that the amorphous matrix of wood is stronger when broken at a high rate than when broken at a low rate. Experimental measurements of the transverse strength of *Pinus radiata* were made and the rate dependence of the strength of the amorphous matrix in late-wood was found to be in good agreement with the predictions of the theory.

**Experimental methods and results**

Small rectangular specimens of *Pinus radiata* were broken by tensile loads applied in the radial direction at strain-rates ranging from $2 \times 10^{-6} \text{ sec}^{-1}$ to $10^2 \text{ sec}^{-1}$. To cover this range of rates three testing machines were employed. At the lowest rates ($2 \times 10^{-6}$ to $10^{-3} \text{ sec}^{-1}$) specimens were broken in an Instron tensile testing machine. At intermediate rates ($10^{-2}$ to $10^0 \text{ sec}^{-1}$) a screw driven machine was used, and at $10^1$ and $10^2 \text{ sec}^{-1}$ a pendulum impact device was necessary. When the latter two machines were in use, load versus displacement or load versus time and velocity versus time curves were displayed on an oscillo-