This is to certify that the

thesis entitled

Measuring Young's Moduli,
Shear Moduli, and Poisson's
Ratios for Wood by a Tension Test

presented by

Ghanbar Ebrahimi

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Forestry
(Wood Science)

Allan Sliker
Major professor

Date April 25, 1979

MEASURING YOUNG'S MODULI, SHEAR MODULI, AND POISSON'S RATIOS FOR WOOD BY A TENSION TEST

By

Ghanbar Ebrahimi

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Forestry

1979

ABSTRACT

MEASURING YOUNG'S MODULI, SHEAR MODULI, AND
POISSON'S RATIOS FOR WOOD BY A TNESION TEST

By

Ghanbar Ebrahimi

To develop a single test method for determinig all elastic constants for wood in a given plane, Young's moduli, shear moduli and Poisson's ratios were determined from the loading of tension specimens at four angels to the grain and at four stress rates and compared with those determined from tension and compression tests made both parallel and perpendicular to the grain and from plate shear tests. Stress rates ranged from 0.3 to 20 Psi per minute; nominal angles of loading to the grain were 20, 35, 50, and 65 degrees. Specially fabricated strain gage rosettes were used to measure strains parallel, perpendicular and at 45 degrees to the load in tnesion specimens. Measurements were made on a radial-longitudinal plane for Liriodendron tulipifera, Sequoia sempervirens, and Tilia americana, and on a tangential-longitudinal plane for Pinus lambertiana.

Except for one specimen, the shear moduli calculated from the specimens loaded at an angle to the grain were from

86 to 130 percent of the values determined from plate shear tests and were from 93 to 116 percent of the plat shear test values when only specimens loaded at 35 degrees or less were considered. Shear moduli increased the most with angle of load to grain for the two species which had the greatest amount of ray tissue oriented parallel ot the surface of the reference plane.

Young's moduli parallel to the grain and Poisson's ratios were not accurately predicted from the specimens loaded at angles to the grain. However, modulus of elasticity perpendicular to the grain could be calculated fairly closely from these same specimens; particularly, at the larger angels of grain to load. For the range of stress rates employed, the rate of loading had very little effect on elastic constants.

ACKNOWLEDGMENTS

I wish to express my sincere appreciation to the chairman of my doctoral committee and major professor Dr. Alan W. Sliker, for his assistance and guidance throughout the course of this investigation. I appreciate the keen interest and cooperation of other committee members, Dr. Otto Suchsland of the Forestry Department, Dr. Larry J. Segerlind of the Department of Agricultural Engineering, Dr. Robert K. Wen of the Department of Civil Engineering. My thanks to Dr. Victor J. Rodulph for his encouragement and Mr. Ivan G. Borton, for his assistance in fabricating samples and parts for testing apparatus. I also appreciate the cooperation of Michigan State University.

I am particularly indebted to the Iranian masses from which, through a scholarship, this graduate work was made possible.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table | Page

LIST OF FIGURES

Figure | Page

LIST OF NOTATIONS

The following symbols represent used notations in the text; they are, however, properly identified when first introduced.

L = Longitudinal direction

R = Radial direction

T = Tangential direction

σ_R = Stress in the R (radial) direction

σ_L = Stress in the L (grain) direction

τ_{RL} = Shearing stress in LR plane

σ_x = Stress in the x direction

σ_y = Stress in the y direction

τ_{xy} = Shearing stress associated with xy plane

θ = The angle of rotation for axis

ε_R = Strain in the R (radial) direction

ε_L = Strain in the L (grain) direction

γ_{RL} = Shearing strain in LR plane

ε_x = Strain in the x direction

ε_y = Strain in the y direction

γ_{xy} = Shearing strain in xy plane

E_i = Modulus of elasticity (Young's modulus)
$i = L, R, T$

G_{Li} = Shear modulus
$i = R, T$

S_i = Slope of strain-stress curve
$i = 1, 2, 3$

μ_{LR} = Poisson's ratio = $\frac{\text{strain along R-axis}}{\text{strain along L-axis}}$

(when uniform σ_L is applied)

μ_{RL} = Poisson's ratio = $\frac{\text{strain along L-axis}}{\text{strain along R-axis}}$

(when uniform σ_R is applied)

ε_{max} = Maximum strain

ε_{min} = Minimum strain

INTRODUCTION

Use of wood as a structural material is complicated by the facts that it is elastically anisotropic and that some of its elastic properties are not well documented. There are twelve elastic constants for wood: three Young's moduli, three moduli of rigidity and six Poisson's ratios. Among these elastic constants of wood, moduli of elasticity were more thoroughly investigated in the past. The reasons for this could be ease of measurement of Young's moduli and the greater need for them in timber design. In the more rigorous design procedures of modern times, however, more information is needed with regard to Poisson's ratios and shear moduli.

Several different methods are used to determine the elastic constants of wood. The Poisson's ratios and Young's moduli are usually measured by making tensile or compression tests both parallel and perpendicular to the grain on properly instrumented specimens. The shearing moduli are determined by conventional method of shear plate testing. Consequently at least three sets of specimens are required to measure the elastic parameters of wood associated with any one of its three principal planes. The use of excessive sets of specimens and the inherent variability in the structure of wood can make it difficult to analyze the elastic properties of a particular specimen of wood.

It is possible that some of the current standard test procedures could be improved to measure moduli of rigidity. The expression from which the shear modulus is computed, was derived from small-deflection plate theory. The useful range of that deflection is limited by the assumptions in this theory. Thus if corner displacement of the plate reaches to a limit beyond which middle-plane stretches non-linearly, the validity of the derived expression is no longer acceptable. Less-dense species of wood are probably good example for this case. Therefore a separate formula based on large-deflection theory is needed to compute their shearing moduli. Such a formula has not been published yet.

To avoid some of the problems mentioned above, transformation equations for stress and strain were utilized by Greszczuk [24]* to develop a single procedure to determine the elastic constants of anisotropic materials among which wood is included. A combined theoretical and experimental investigation on the applicability of this test method, followed by the design of appropriate off-axis tensile test specimen is the subject of this work and presented here.

---

*Numbers in brackets indicate references.

Objective

Development of a single test method for determining all the elastic constants for wood in a given plane.

CHAPTER I

MEASUREMENT OF ELASTIC CONSTANTS

For best and intelligent use of engineering materials, their elastic properties are closely investigated. In doing so various experimental techniques are applied to examine elastic constants. The number of elastic constants needed to define a given material depends on whether it is isotropic or anisotropic; i.e., whether its properties are independent or dependent on the direction of measurement.

Measurement of Elastic Constants in an Isotropic Material

For an isotropic material there are four elastic constants of which any one can be determined from a knowledge of two of the others. The constants are Young's modulus E. bulk modulus E_B, shear modulus G, and Poisson's ratio μ. The following relationships exist between these constants.

$$E = \frac{9E_B - G}{(3E_B + G)} , \quad G = \frac{E}{2(1 + \mu)} , \quad \mu = \frac{3E_B - 2G}{2(3E_B + G)}$$

To measure these constants for a given isotropic material, tension, compression and torsion tests are made on a proper specimen. Because of the vast usage of isotropic materials such as metals in modern industry, numerous test systems and data monitoring have been developed for measuring the elastic parameters of this group of engineering materials.

Measurement of Elastic Constants in Manufactured Filamentous Composites

Filament-reinforced composites consist of a rectangular array of parallel filaments embedded in a matrix. In planes parallel to the filament axes, the filament reinforced materials have five elastic parameters. Two Young's moduli, one shear modulus and two Poisson's ratios. A knowledge of four of the parameters associated with one of these planes is needed to completely define the elastic properties in that plane.

These elastic moduli for filaments composites can be analytically determined from a knowledge of elastic properties of constituent materials (filament and matrix). Greszczuk [25] did this for fiber glass embedded in an epoxy matrix. A reasonable agreement (within 10%) between these analytically predicted elastic moduli and their experimental values was observed.

To experimentally determine elastic constants of filament-reinforced composites, several methods are available. Tension and compression tests are conducted for the determination of Young's moduli and Poisson's ratios [24]. For the same elastic moduli, dynamic tests can also be used. For shear modulus, the plate shear test is the common one.

On properly constructed sample of fiber composite material, triaxial tests could also be made for evaluating their elastic moduli. It is difficult to conduct triaxial test as well as it is somewhat expensive because of requiring sophisticated equipment [24].

One of the latest techniques to measure elastic parameters of filament-reinforced composites, utilizes the anisotropic properties of these materials to generate shear deformation in tension specimens loaded at selected angles to the main filament axis [15, 24, 60, 80]. An advantage of this test method is that, all five elastic constants of a given filamentary composite material can be determined from one type of test specimen. To find the potential of off-axis test, Greszczuk [24] has applied this test technique to measure the elastic moduli of fiber glass. According to his report "good agreement is found to exist among the various properties obtained from tests of specimens with various filament orientations as well as between experimental values and theoretically predicted values of the elastic constants." In addition, off-axis test was regarded well suited for measuring shear modulus.

Measurement of Elastic Constants in Wood

Wood Structure

Wood is a natural product consisting of concentric layers of growth shells. It is produced by trees which grow under diverse ecological conditions that affect their growth rates, shape, structure and strength. Hardwoods are woods from broad-leaved trees and softwoods are woods produced by conifereous species, which have needle-like leaves.

Anisotropic properties of wood arise from its cellular structure. Most of the cells are long, hollow tube-like structures, and,with the exception of vessel segments in hardwood, have closed ends. Depending on the species, anywhere from 70 to 95 percent of the cells have their long axis parallel to the length of the stem to which they belong. The remaining 5 to 30 percent of the cells are oriented from the center of the stem outward in tissues called rays.

Three mutually perpendicular reference directions are recognized for the measurement of wood properties. The grain direction (L) is the direction of the length of the majority of cells, which is parallel to the length of the log containing the wood. A radius of the circular cross-section of a log is designated as the radial direction (R). The long axes of rays are in the radial direction. The third reference direction is the tangential direction (T). It would be perpendicular to a radius and tangent to the circular cross-section. Reference planes in wood are denoted by the directions which define them: the RT plane is the cross-sectional or transverse surface of a log where most cells are viewed in cross-section; the RL plane or radial surface is defined by a radius of the log and the grain direction; the TL plane or tangential surface is defined by a tangent to the log cross-section and the grain direction. Rays are seen on side view on the radial surface and in cross-section on the tangential surface.

Besides the anisotropy due to the cell orientations, wood is non-homogeneous because of the number of cell types present, their variability in cell wall thickness and diameter, and their variability in cell wall structure. Hardwoods have more cell types than softwoods and so are more complex with respect to relative arrangements and numbers of cell types present. Hardwoods are also more variable with respect to the amount of ray tissue present.

There is variability of wood in the radial direction from several growth patterns. Some species have very large differences in the anatomy and physical properties of wood grown in the early part of the growing season (earlywood) as compared to the wood formed towards the end of the growing season (latewood). Also, wood formed in the first fifteen to twenty years growth of a tree has shorter cells and differences in cell wall structure from that grown later. If a tree is leaning when it grows, the wood formed on one side of the tree is different from that on the other side.

It is difficult to obtain a tangential surface on a wide board because of the curvature of the growth rings. This is not a factor in obtaining a radial surface.

Elastic Constants for Wood

Although twelve elastic constants can be defined for wood, all of them can be determined from a knowledge of any nine; i.e., there are only nine independent elastic constants. A Young's modulus exists for each of the three defining axes R, T, L. For each major plane there are two Poisson's ratios dependent on which of the major axes in the plane is loaded and a shear modulus.

Experimental techniques which are used to measure the elastic parameters of wood are similar in principle to those applied for evaluating elastic constants of metals. But there are some differences such as size and shape of specimens and number of constants that are to be measured. Also, measuring equipment for wood testing must possess sensitive load measuring devices, and deflection or strain sensors have to be of low resistance to motion. Test procedures for determining different elastic constants of wood are reviewed in the following paragraphs.

Measuring Modulus of Elasticity

Standard Test Methods.--Several methods for determining Young's moduli parallel to the grain are described in ASTM standard D143-52[1]. Of the methods mentioned, the compression parallel to the grain test gives the best results [42, 59] although the assumption of a state of pure compressive stress in the specimen may be inexact [76]. Young's moduli could be obtained from a tension parallel to the grain test, but the standard sample for this is difficult to fabricate [17, 50]. Values of Young's moduli obtained from a bending test have to be adjusted for a shear deflection component, which makes this calculation subject to additional variables [42, 58, 59].

The only standard test for obtaining modulus of elasticity perpendicular to the grain in ASTM D143-52 is a compression perpendicular to the grain test. Although the test prescribes loading in the tangential direction, it could be used equally well for loading in the radial direction. Load-deflection curves for perpendicular-to-grain loading in compression are not as linear as for parallel-to-grain loading. Little information exists on stiffness in tension loading perpendicular to the grain.

Other Tension and Compression Tests.--Other than the standard tension specimen, tensile samples of very simple construction have been used to determine Young's moduli and Poisson's ratios of wood [66, 67, 68, 69]. Strain measurements were made by two-strand wire strain gages [64]. Rectangular tensile samples containing a hole at each end to apply load at an angle to the grain direction, were also used [63] to determine shear moduli [G_{LR}, G_{LT}, G_{TR}), Young's moduli (E_L, E_R, E_T) and Poisson's ratios (μ_{LT}, μ_{LR}, μ_{TR}) of wood through measuring deflection on this type of specimen and computing required strain data. Sliker included rate of loading as a factor in determining moduli of elasticity in tension. In one paper [68] he found that the effect of rate of loading on modulus of elasticity increased as the angle between the grain direction and the load increased. In an example in another paper [69], modulus of elasticity perpendicular to the grain was more than 10 percent less at a stress rate of 0.561 psi per minute than at a stress rate 20.6 psi per minute.

In compression testing, standard tests for computing Young's moduli and Poisson's ratios are simple in principle and specimens are readily manufactured. Therefore not much effort was made to improve this procedure except by modifying specimens dimensionwise for studying particular factors affecting compression strength of wood [37] and by methods in applying load to specimen [10].

Dynamic Testing.--Moduli of elasticity (E_L, E_R, E_T) can also be obtained from dynamic tests. Some types of dynamic tests for this purpose are flexure vibration, vibration of a column and pulse transmission. Dynamic tests are reported to be less accurate for determining elastic moduli than are static ones [40, 42, 78]. All three Young's moduli measured from dynamic tests were about 10 percent higher than their static value [6, 78]. Hearmon [28] suggests that for evaluating moduli of elasticity from vibration tests, frequency of many modes be measured and statistically analyzed. There are some advantages of dynamic tests as

(a) they are nondestructive, (b) individual specimens can be tested more than once, (c) Young's moduli and shear moduli may be measured from a single test sample, (d) specimens can be tested in service scale with pulse methods.

Russian investigators [3] have recently used an impulse method to determine elastic moduli of wood. They conducted vibration tests and static tests with the application of strain gages. Their report indicates that the results from impulse technique differed from that of strain gage by 4 percent for E_L, 17 percent for E_T. E_R was estimated 12 percent smaller by impulse method. A disadvantage of this procedure is that it requires some information of Poisson's ratios as well.

Plate Testing.--Plate tests have been used for determining Young's moduli, shear moduli and Poisson's ratios of orthotropic materials and studies were made on the validity of this test technique. In conjunction with the idea of plate testing, Hearmon and Adams [30] have compared the experimental values of modulus of elasticity, shear modulus and Poisson's ratio from tests made on plywood plates and theoretically predicted values of these constants. They report that the general agreement between these two sets of values was close (within 10 percent), although in some cases, fairly large (30%) discrepancies were observed. They relate these to the variability within plywood itself. The aptness of plate testing (with 6% differences in value of modulus of elasticity) was confirmed in another study [79], but it must be realized that this experiment is applicable for orthotropic materials in which linear strain-stress relations exist over a definite range of stress.

To evaluate components of compliance matrix (S_{ij}, $\varepsilon_i = S_{ij}\sigma_i$) by making tests on orthotropic plates, Tsai [73] has proposed three steps of testing. Bending a beam (strip) sample with orientation of an elastic symmetry axis at 90 or zero degree. Twisting square plates, one along and another at 45-degree with respect to an elastic symmetry axis. He claims that, the procedure is easy to implement and reliable data are obtained. The idea was carried into effect for determination of elastic constants of plywood and sandwich boards and corresponding report shows that excellent agreement (maximum error 3.3% for all compliance) between theory and experimental results was observed [16]. Plate test was applied to measure Young's moduli, shear moduli and Poisson's ratios of solid wood by Gunnerson et al. [26]. Their observations confirmed the existence of large two-way bending moments in the plates. It was believed that two-way bending effects were created by a triangular load pattern and could cause large deformations in the plate sample. These two-way bending effects were noticed to vary from plate to plate depending upon grain orientation. Finally by making use of orthotropic plate theory, a correcting method was found to treat two-way bending effects which may improve this test procedure, but the calculations for Poisson's ratios remain inaccurate.

Measuring Shearing Moduli

Shear moduli of wood could be determined through one of the following experimental procedures.

Plate Shear Test.--This method of test was recognized as being the most useful to determine shear moduli of plywood and solid wood [42]. The expression from which shear modulus is computed, was derived from linear, small-deflection, plate theory. It is valid for an orientation of the principal axes of elastic symmetry in x, y plane [21], but the useful range of deflection is limited by the assumptions in this theory. If corner deflection reaches to a limit beyond which middle-plane stretches nonlinearly, the aptness of derived expression for shear moduli is not acceptable. In a study of shear modulus of particleboard and plywood by plate shear test, Biblis and Lee [7] observed more accurate values of shear modulus can be obtained by measuring the required deflection at extremities of diagonal of plate.

Torsion Test.--In torsion test on wood, it was noticed that at least two of the shear moduli are involved [27, 42]. Kuenzi [42] states that it is possible to perform torsion test on two sizes of matched specimens and compute apparent shear modulus by solving simultaneous expressions.

The accuracy of doing so is questionable unless extreme care is exercised in matching samples and in measurements.

If involvement of two shear moduli in torsion test is true, then plate shear and torsion test on a given species should not produce the same results. Despite this observation Tang et al. [70] report "the results calculated from rod twisting are in close agreement with the values obtained from the experiments of plate deflections." They concluded this from the testing of scarlet oak and graphically comparing the results of the two test methods.

Flexure Test.--Theoretically it is possible to compute shear modulus by making a flexure test on a beam sample [58]. A complementary compression test on a matched specimen is needed to obtain true Young's modulus of test piece for this calculation. No experimental verification has been made.

Vibration Test.--For vibration test the same objection as to torsion test exists [42]. That is a mixed measurement of two shear moduli would be made by vibration test. Becker [5] has attempted to apply torsional vibration, to determine shear moduli. In this method of testing, he measured the torsional rigidity along an elastic symmetry axis to obtain the values of shear moduli.

Ashkenazi et al. [3] have recently studied an impulse method of measuring shear modulus. Their report indicates that the results of impulse method differed by 30 percent from that of their control method.

Measuring Poisson's Ratios

All six Poisson's ratios of wood can be directly measured by making tensile or compression tests on wood samples and recording strains parallel and perpendicular to the load direction. μ_{RL} and μ_{TL} are very small quantities and are difficult to measure, but they are subject to the following relations:

$$\mu_{RL} = \mu_{LR} \frac{E_R}{E_L}$$

$$\mu_{TL} = \mu_{LT} \frac{E_T}{E_L}$$

Other than strain measurements technique, according to Carrington [12], Poisson's ratio is numerically equal to lateral curvature divided by longitudinal curvature in a flexure test. This procedure was of less interest, perhaps because of lack of accuracy and has not been applied in the past.

CHAPTER II

EQUATIONS

Elastic constants of synthetic anisotropic materials have been determined by loading the materials in a direction other than parallel to one of their axes of symmetry [15, 24 60, 63, 80]. This test method is capable of evaluating up to five elastic parameters for a given anisotropic material. The basic stress and strain transformation equations for determining elastic constants are described in the following paragraphs and in References 24, 56, 57.

If normal and shearing stresses or strains in a plane are given with respect to a set of coordinate axes x and y, stresses or strains associated with another set of coordinate axes R,L in the plane which has a rotation angle of "θ" from the initial set of axis, can be obtained through transformation equations.

$$\begin{Bmatrix} \sigma_R \\ \sigma_L \\ \tau_{RL} \end{Bmatrix} = \begin{bmatrix} \cos^2\theta & \sin^2\theta & \sin 2\theta \\ \sin^2\theta & \cos^2\theta & -\sin 2\theta \\ -\frac{1}{2}\sin 2\theta & \frac{1}{2}\sin 2\theta & \cos 2\theta \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} \qquad (1)$$

$$\begin{Bmatrix} \varepsilon_R \\ \varepsilon_L \\ \gamma_{RL} \end{Bmatrix} = \begin{bmatrix} \cos^2\theta & \sin^2\theta & \tfrac{1}{2}\sin2\theta \\ \sin^2\theta & \cos^2\theta & -\tfrac{1}{2}\sin2\theta \\ -\sin2\theta & \sin2\theta & \cos2\theta \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} \qquad (2)$$

where: σ_R = stress in the R (radial) direction,

σ_L = stress in the L (grain) direction,

σ_x = stress in the x direction,

σ_y = stress in the y direction,

$\tau_{xy} = \tau_{yx}$ = shearing stress associated with xy plane,

$\tau_{RL} = \tau_{LR}$ = shearing stress in LR plane,

ε_R = strain in the R (radial) direction,

ε_L = strain in the L (grain) direction,

$\gamma_{xy} = \gamma_{yx}$ = shearing strain in xy plane,

γ_{RL} = shearing strain in RL plane,

θ = the angle of rotation for axis.

Figure 1 indicates the referred to axes and direction of rotation.

Now if R and L are the axes of elastic symmetry of the material, relationship between the components of stresses and strains could be written as:

$$\varepsilon_R = \frac{\sigma_R}{E_R} - \mu_{LR}\frac{\sigma_L}{E_L} \qquad (3)$$

$$\varepsilon_L = \frac{\sigma_L}{E_L} - \mu_{RL}\frac{\sigma_R}{E_R} \qquad (4)$$

$$\gamma_{RL} = \frac{T_{RL}}{G_{LR}} \qquad (5)$$

where: E_L = Young's modulus parallel to L axis,

E_R = Young's modulus parallel to R axis,

$G_{LR} = G_{RL}$ = shear modulus for RL plane,

μ_{RL} = Poisson's ratio = $\frac{\text{Strain along L-axis}}{\text{Strain along R-axis}}$

(when uniform σ_R is applied)

μ_{LR} = Poisson's ratio = $\frac{\text{Strain along R-axis}}{\text{Strain along L-axis}}$

(when uniform σ_L is applied).

In order to evaluate G_{LR}, E_L and E_R some measurements of stress and strains need to be made. A uniaxial tension test on off-axis (Figure 2a) sample would provide the required data as explained next.

If a uniaxial stress is applied, $\sigma_x = T_{xy} = o$ and Equation 1 will be simplified into:

$$\sigma_R = \sigma_y \sin^2\theta \qquad (6.1)$$

$$\sigma_L = \sigma_y \cos^2\theta \qquad (6.2)$$

$$T_{LR} = \tfrac{1}{2}\sigma_y \sin 2\theta \qquad (6.3)$$

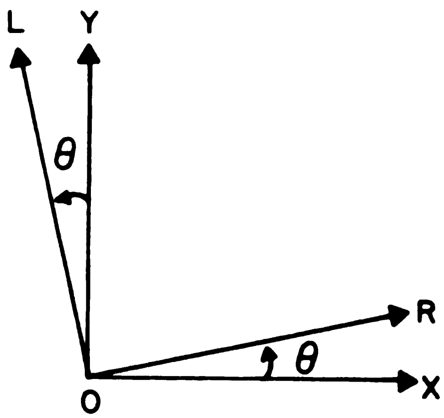
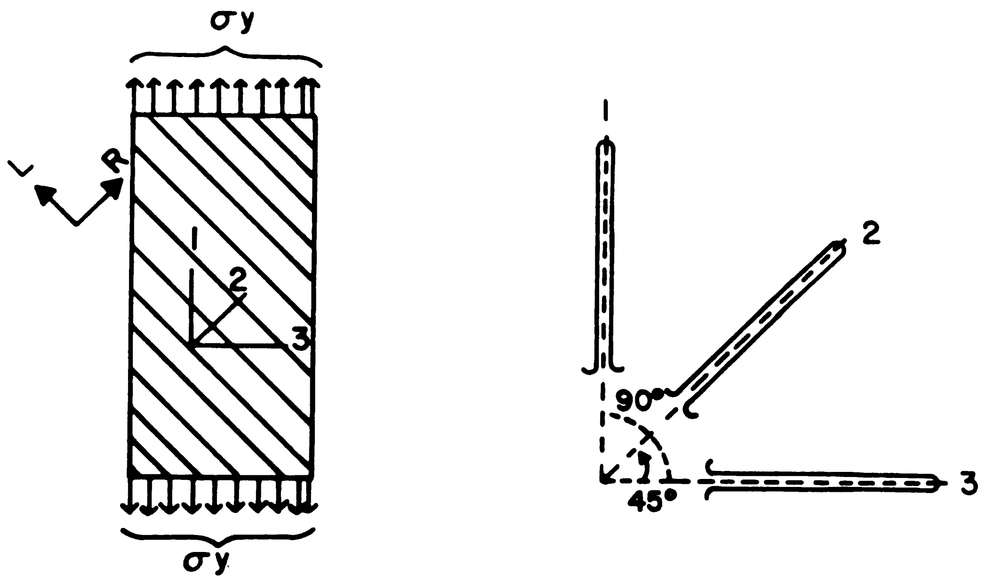


Fig. I Relationship between coordinate axes and two orthogonal ones rotated through angle θ



(a) Orientation of strain gauges on test specimen

(b) Appearance of gauges in forty-five degree rectangular rosette.

Fig. 2

When strains are measured with a rectangular rosette with gauges parallel and perpendicular to the load and with a third gauge at an angle of forty-five degrees to the other two (see Figure 2), the strains are as follows:

$$\varepsilon_y = \varepsilon_1$$

$$\varepsilon_x = \varepsilon_3 \qquad (7)$$

$$\gamma_{xy} = 2\varepsilon_2 - \varepsilon_1 - \varepsilon_3$$

$$\varepsilon_L = \varepsilon_1 \cos^2\theta + \varepsilon_3 \sin^2\theta - \tfrac{1}{2}(2\varepsilon_2 - \varepsilon_1 - \varepsilon_3) \sin 2\theta \quad (8.1)$$

$$\varepsilon_R = \varepsilon_1 \sin^2\theta + \varepsilon_3 \cos^2\theta + \tfrac{1}{2}(2\varepsilon_2 - \varepsilon_1 - \varepsilon_3) \sin 2\theta \quad (8.2)$$

$$\gamma_{RL} = (2\varepsilon_2 - \varepsilon_1 - \varepsilon_3) \cos 2\theta + (\varepsilon_1 - \varepsilon_3) \sin 2\theta \quad (8.3)$$

Thus normal stress and strain associated with symmetric axes R and L are obtained.

Shear Modulus

An equation for determining shear modulus from off-axis tensile specimens can be derived from Equations 5, 6.3, and 8.3.

$$G_{LR} = \frac{\tau_{LR}}{\gamma_{LR}}$$

$$G_{LR} = \frac{\frac{1}{2}\sigma_y \sin 2\theta}{(\varepsilon_1-\varepsilon_3)\sin 2\theta + (2\varepsilon_2-\varepsilon_1-\varepsilon_3)\cos 2\theta}$$

$$G_{LR} = \frac{1}{2(S_1-S_3) + (2S_2-S_1-S_3)(\cot\theta - \tan\theta)} \quad (9)$$

$$S_1 = \varepsilon_1 \div \sigma_y$$

$$S_2 = \varepsilon_2 \div \sigma_y \quad (9.1)$$

$$S_3 = \varepsilon_3 \div \sigma_y$$

Moduli of Elasticity

Modulus of elasticity parallel to the direction of loading of a test specimen equals simply stress divided by strain:

$$E = \frac{\sigma_y}{\varepsilon_1} = \frac{1}{S_1} \quad (10)$$

If the grain direction coincides with the load axis, then the modulus of elasticity of the wood parallel to the grain is obtained from Equation 10. If the perpendicular to the grain direction is parallel to the load, then the modulus of elasticity perpendicular to the grain is obtained. E_R refers to modulus of elasticity in the radial direction and E_T to the value in the tangential direction. Moduli of elasticity at angles other than parallel or perpendicular to the grain are related approximately as described by Hankinson's Equation:

$$E_\theta = \frac{E_L E_R}{E_L \sin^2\theta + E_R \cos^2\theta} \tag{11}$$

A technique in data reduction on off-axis test for determining E_L, E_R and/or E_T is to derive computational expression for each by combining and simplifying the sets of Equations 6 and 8 as well as 3, 4. In doing so at least one Poisson's ratio of the plane being tested, must be known. Then by making use of Maxwell's Reciprocal Theorem ($\mu_{RL} = \mu_{LR} \frac{E_R}{E_L}$) and Equations 3, 4, 6.1, 6.2, 8.1, 8.2 the following relations are obtained:

$$\varepsilon_L = \frac{\sigma_L}{E_L} - \mu_{RL} \frac{\sigma_R}{E_R}$$

$$\varepsilon_L = \frac{\sigma_L}{E_L} - \mu_{LR} \frac{E_R}{E_L} \left(\frac{\sigma_R}{E_R}\right)$$

$$E_L = \frac{\sigma_L}{\varepsilon_L} - \mu_{LR} \frac{\sigma_R}{\varepsilon_L}$$

$$E_L = \frac{\sigma_y \cos^2\theta - \mu_{LR}\sigma_y \sin^2\theta}{\varepsilon_1 \cos^2\theta + \varepsilon_3 \sin^2\theta - (2\varepsilon_2 - \varepsilon_1 - \varepsilon_3)\sin\theta\cos\theta}$$

$$E_L = \frac{1 - \mu_{LR} \tan^2\theta}{S_1 + S_3 \tan^2\theta - (2S_2 - S_1 - S_3)\tan\theta} \tag{12}$$

In similar fashion:

$$E_R = \frac{1}{S_1 + S_3 \cot^2\theta + (2S_2 - S_1 - S_3)\cot\theta + \frac{\mu_{LR}}{E_L}\cot^2\theta} \qquad (13)$$

S_1, S_2, S_3 are defined by Equation 9.1.

A third method for calculating Young's moduli requires data from two off-axis tension specimens with different angles of load to grain. From combination of Equations 3, 6 and 8:

$$E_L = \frac{\sigma_{L_1}\sigma_{R_2} - \sigma_{L_2}\sigma_{R_1}}{\sigma_{R_2}\varepsilon_{L_1} - \sigma_{R_1}\varepsilon_{L_2}} \qquad E_R = \frac{\sigma_{R_1}\sigma_{L_2} - \sigma_{R_2}\sigma_{L_1}}{\sigma_{L_2}\varepsilon_{R_1} - \sigma_{L_1}\varepsilon_{R_2}} \qquad (14)$$

The quantities σ_L's ......ε_R's are computed from test data by the following expressions.

$$\sigma_{L_1} = \sigma_{y_1}\cos^2\theta_1 \qquad \varepsilon_{L_1} = \varepsilon_{31}\sin^2\theta_1 + \varepsilon_{11}\cos^2\theta_1 - \tfrac{1}{2}(2\varepsilon_{21}-\varepsilon_{31}-\varepsilon_{11})\sin 2\theta_1$$

$$\sigma_{R_1} = \sigma_{y_1}\sin^2\theta_1 \qquad \varepsilon_{R_1} = \varepsilon_{31}\cos^2\theta_1 + \varepsilon_{11}\sin^2\theta_1 + \tfrac{1}{2}(2\varepsilon_{21}-\varepsilon_{11}-\varepsilon_{31})\sin 2\theta_1$$

$$\sigma_{L_2} = \sigma_{y_2}\cos^2\theta_2 \qquad \varepsilon_{L_2} = \varepsilon_{32}\sin^2\theta_2 + \varepsilon_{12}\cos^2\theta_2 - \tfrac{1}{2}(2\varepsilon_{22}-\varepsilon_{32}-\varepsilon_{12})\sin 2\theta_2$$

$$\sigma_{R_2} = \sigma_{y_2}\sin^2\theta_2 \qquad \varepsilon_{R_2} = \varepsilon_{32}\cos^2\theta_2 + \varepsilon_{12}\sin^2\theta_2 + \tfrac{1}{2}(2\varepsilon_{22}-\varepsilon_{32}-\varepsilon_{12})\sin 2\theta_2$$

Poisson's Ratio

In a given plane such as the RL plane, there are two Poisson's ratios μ_{LR} and μ_{RL}. μ_{LR} is the ratio of strain in the R direction to that in the L direction when a force is applied in the L direction. μ_{RL} is the ratio of the strain in the L direction to that in the R direction when a force is applied in the R direction. μ_{RL} and μ_{LR} are related by the equation:

$$\frac{\mu_{LR}}{E_L} = \frac{\mu_{RL}}{E_R} \qquad (15)$$

μ_{LR} can be determined from the zero-degree specimen by dividing strain perpendicular to the load by strain parallel to the load. And μ_{RL} can be determined from the 90-degree specimen in similar fashion. When the load is applied perpendicular to the grain, however, the strain perpendicular to the load is difficult to measure so that μ_{RL} is often calculated from measurements of the other three quantities in Equation 15.

A second method for determining Poisson's ratio is to combine data from two off-axis tensile members with different angles of axis to load as follows:

$$\mu_{LR} = \frac{\sigma_{R_1}\varepsilon_{R_2} - \sigma_{R_2}\varepsilon_{R_1}}{\sigma_{R_2}\varepsilon_{L_1} - \sigma_{R_1}\varepsilon_{L_2}}$$

$$(16)$$

$$\mu_{RL} = \frac{\sigma_{L_1}\varepsilon_{L_2} - \sigma_{L_2}\varepsilon_{L_1}}{\sigma_{L_2}\varepsilon_{R_1} - \sigma_{L_1}\varepsilon_{R_2}}$$

Maximum and Minimum Strains

To compute the magnitude of principal strains, the following equations are applied:

$$\varepsilon_{max} = \frac{\varepsilon_x + \varepsilon_y}{2} + \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2}$$

$$\varepsilon_{min} = \frac{\varepsilon_x + \varepsilon_y}{2} - \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2} \qquad (17)$$

The plane on which the maximum and minimum strains act are defined by the Equation 18.

$$\text{Tan } 2\Theta = \frac{\gamma_{xy}}{\varepsilon_x - \varepsilon_y} \qquad (18)$$

ε_{max} = maximum strain,

ε_{min} = minimum strain,

Θ = angle, locating the direction of principal strains with respect to x,y.

CHAPTER III

PROCEDURE

The strategy for the project was to determine elastic constants from strain gauge rosettes mounted on tensile specimens. Each specimen was to be loaded four times, each time at a different rate to see if rate of loading would affect the results. In order to determine safe load limits for the specimens with rosettes, a set of matched specimens was loaded to failure. Shear moduli and Young's moduli parallel and perpendicular to the grain were also determined by Standard ASTM tests for purpose of comparison.

Test Materials

Four species of wood were chosen for testing. These were basswood (Tilia americana L.), yellow poplar (Liriodendron tulipifera L.), sugar pine (Pinus lambertiana Dougl.), and redwood (Sequia sempervirens [D. Don] End L.). Major considerations in this selection were uniformity of cell structure and availability. In addition, quarter sawn or vertical grain boards were favored because the curvature of the growth rings would not be a factor as they would be in plain sawn or flat sawn boards.

Selected trees of basswood and yellow poplar were cut down in the experimental forests of Michigan State University, to obtain 5/8-inch quarter sawn boards and nominal 2 1/2 x 2 1/2-inch squares. The diameter breast high of the yellow poplar tree was 36 inches and that of the basswood was 32 inches. Out of a log from each of these species, a single segment 32 inches long was cut and split parallel to the grain into pie-shaped pieces. The revelant pieces were individually mounted on a positionable carriage and sawn radially into 5/8-inch thick boards and 2 1/2-inch squares. These were end coated and stacked for air drying.

A quarter sawn redwood board (1" x 11" x 14') was selected from the available vertical grain boards of this species in the lumber yard of a wholesale company. Particular attention was paid to straightness of grain and uniformity of growth rate. Moisture content of redwood board at time of purchase was measured 10 percent by a moisture meter.

A flat grain board (1 3/4" x 17" x 16') of sugar pine was already available in the laboratory of wood technology at Michigan State University.

Test materials were stored in the conditioning room (68°F, 65% RH) for three and a half months. By the use of moisture meter, the moisture content of the conditioning materials were inspected at interval until equilibrium was reached. Their moisture contents and specific gravities were determined by the oven-drying method prior to the specimen fabrication (Table 1). Equilibrium moisture contents of nominal 2 1/2 x 2 1/2-inch squares from basswood and yellow poplar were slightly higher (0.66%, 0.93%) than for the 5/8-inch material which indicates they might still have had a slight moisture gradient. The number of rings per inch of test materials were found as 7, 8, 12, and 17 for basswood, yellow poplar, sugar pine and redwood, respectively.

Table 1.--Average Value of Moisture Content and Specific Gravity of Conditioned Test Pieces.

Species	Moisture Content %	Specific Gravity*		
		At test	On oven-dry Weight	At 12% MC
Basswood	11.69	0.39	0.42	0.39
Yellow Poplar	13.09	0.51	0.54	0.51
Sugar Pine	9.37	0.37	0.40	0.36
Redwood	10.20	0.39	0.42	0.39

*Based on oven-dry weight and on volume at moisture content of measurement.

Standard ASTM Test

To determine modulus of elasticity E_i (i = L,R,T), standard specimens were made out of materials from the four species and tested (Figure 3) according to ASTM Specification (D143-52). For sugar pine and redwood, standard test specimens (2 x 2 x 8-inch, 2 x 2 x 6-inch) were made by gluing board pieces together for the required two inches dimension. The cross-head speed of testing machine (Instron) was set at 0.02 in/minute for compression test parallel to the grain and 0.01 in/minute for compression test perpendicular to the grain. The number of specimens for these tests are shown in Tables 2 and 3.

Standard shear plate specimens were manufactured with their length and width equal to twenty-eight times their thickness (28 x 0.5-inch). For yellow poplar, basswood and redwood, two boards were edge glued to fabricate a shear plate specimen. The sugar pine board was wide (17 inches) enough to produce the desired shear plate specimen without any gluing process. In this standard test (Figure 4), ASTM specification (D3044-76) was followed and the cross-head speed of testing machine was set at 0.02 in./minute (0.012 x 14-inches). The number of specimens for each species is shown in Table 4.

Manufacture of Tension Test Specimens

For tension test, three types of specimens were made out of the materials from the four species. Type A,

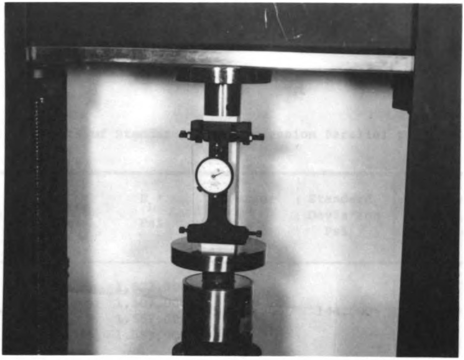


Figure 3. ASTM Stand Compression Parallel to the Grain Test.

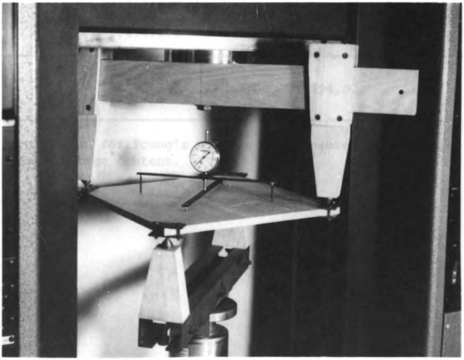


Figure 4. ASTM Standard Plate Shear Test.

Table 2.--Results of Standard ASTM Compression Parallel to the Grain Tests.

Species	Specimen Number	E_L* Psi	Average E_L Psi	Standard Deviation Psi	Coefficient of Variation %
Basswood	1 2 3 4	1,822,500 1,507,000 1,557,000 1,553,000	1,610,000	144,000	9.0
Yellow Poplar	1 2 3	1,701,000 1,687,000 1,727,000	1,705,000	20,000	1.2
Sugar Pine	1 2 3	1,476,900 1,314,400 1,496,100	1,429,000	100,000	7.0
Redwood	1 2	1,204,500 1,479,200	1,342,000	194,000	14.5

*This value for Young's modulus was measured at approximately 12% moisture content.

Table 3.--Results of Standard ASTM Compression Perpendicular to the Grain Tests.

Species	Specimen Number	E_R** (Psi)	Average E_R (Psi)	Standard Deviation PSI	Coefficient of Variation %
Basswood	1	114,000	114,700	5,000	4.4
	2	110,000			
	3	120,000			
Yellow Poplar	1	190,000	177,600	22,100	12.4
	2	150,000			
	3	170,500			
	4	200,000			
Sugar Pine	1	80,000	72,300*	15,000	20.7
	2	55,000			
	3	82,000			
Redwood	1	110,000	100,000	14,100	14.1
	2	90,000			

*This value is E_T for sugar pine.

**This value for Young's modulus was measured at approximately 12% moisture content.

Table 4.--Results of Standard ASTM Plate Shear Test.

Species	Specimen Number	G_{LR}** Psi	$\overline{G}_{LR}$ Psi	Standard Deviation Psi	Coefficient of Variation %
Basswood	1	87,200	87,700	700	0.8
	2	88,200			
Yellow Poplar	1	125,800	127,300	2,100	1.64
	2	128,800			
Sugar Pine	1	100,500	102,500*	2,800	2.73
	2	104,500			
Redwood	1	132,900	132,900	---	---

*This value is G_{LT} for Sugar Pine.

**This value for shear modulus was measured at approximately 12% moisture content.

the off-axis specimens, had an angle of inclination (θ) between grain and load directions, where $\underline{\theta}$ represented angles between 20 and 65 degrees. Type B specimens were those in which the grain was parallel to the load direction. Type C specimens had their grain perpendicular to the load direction. Specimen types are also frequently referred to in this report by the angle between load and grain directions.

Each tension specimen required a 1/2-inch thick by 4-inch wide by 25-inch long board in which the angle between the grain of the wood and the 25-inch dimension of the board was the specified test angle. A board of this dimension could easily be made for the zero-degree specimen but for the other angles extra boards had to be glued to sides as shown in Figure 5. The central test boards had a minimum width of 8 inches. All bonding was with polyvinyl adhesive. Cutting of the boards to achieve the desired angle was done as shown in Figures 6 and 7.

To complete the tensile specimens, boards of red oak were bonded at the ends of the test boards and grooves were cut into them to receive 2 1/2 inches diameter shear plates as shown in Figure 9. Materials for basswood, yellow poplar and sugar pine were sufficiently available to prepare four off-axis tension specimens with the angle of inclination of 20°, 35°, 50°, and 65°. For redwood there was only enough material to make specimens with 35°, 50°, and 65° inclination angles.

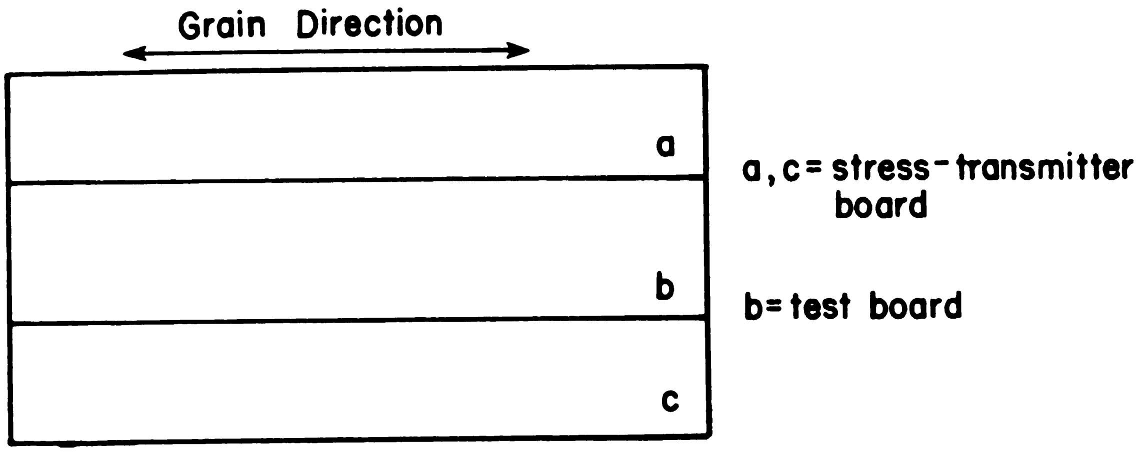


Fig. 5 Laminated piece from which off-axis test pieces were cut.

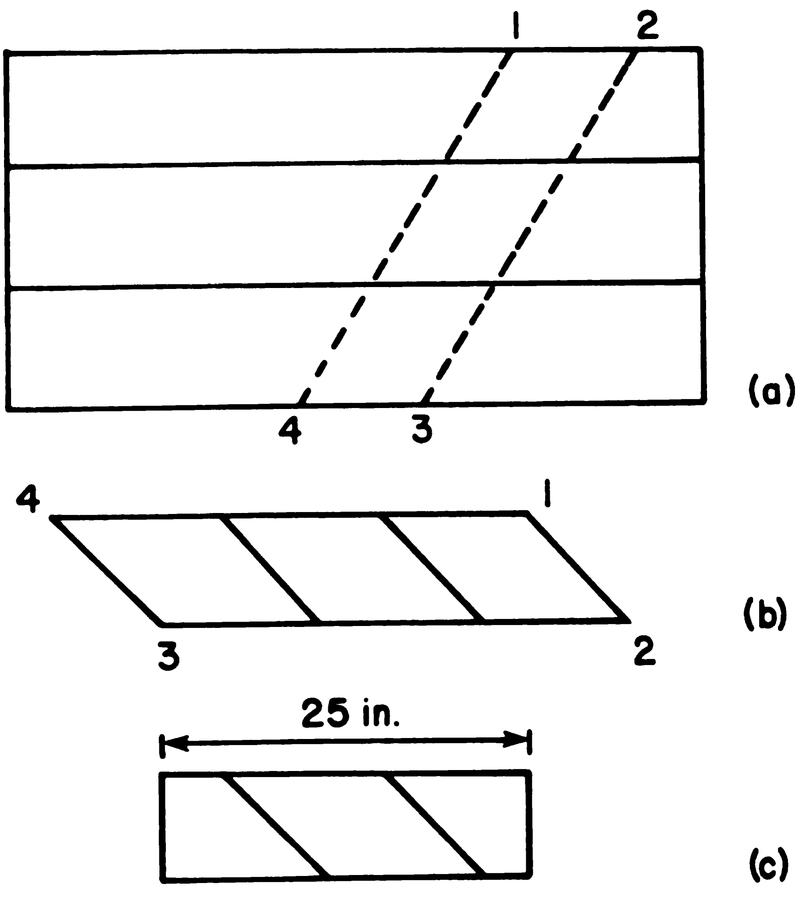


Fig. 6 Cutting and trimming processes for off-axis test piece.

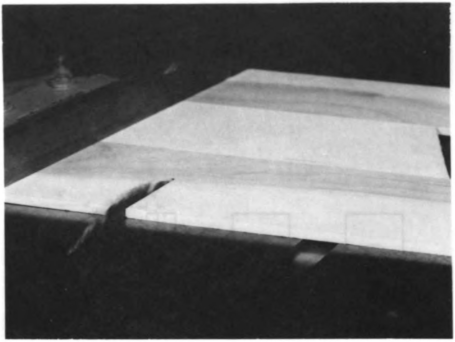


Figure 7. Cutting Off-Axis Test Piece.

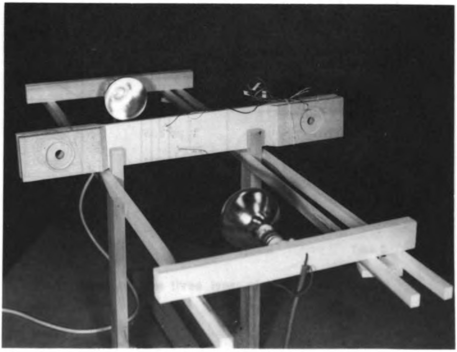


Figure 8. Heat Curing Gauged Area on Specimen.

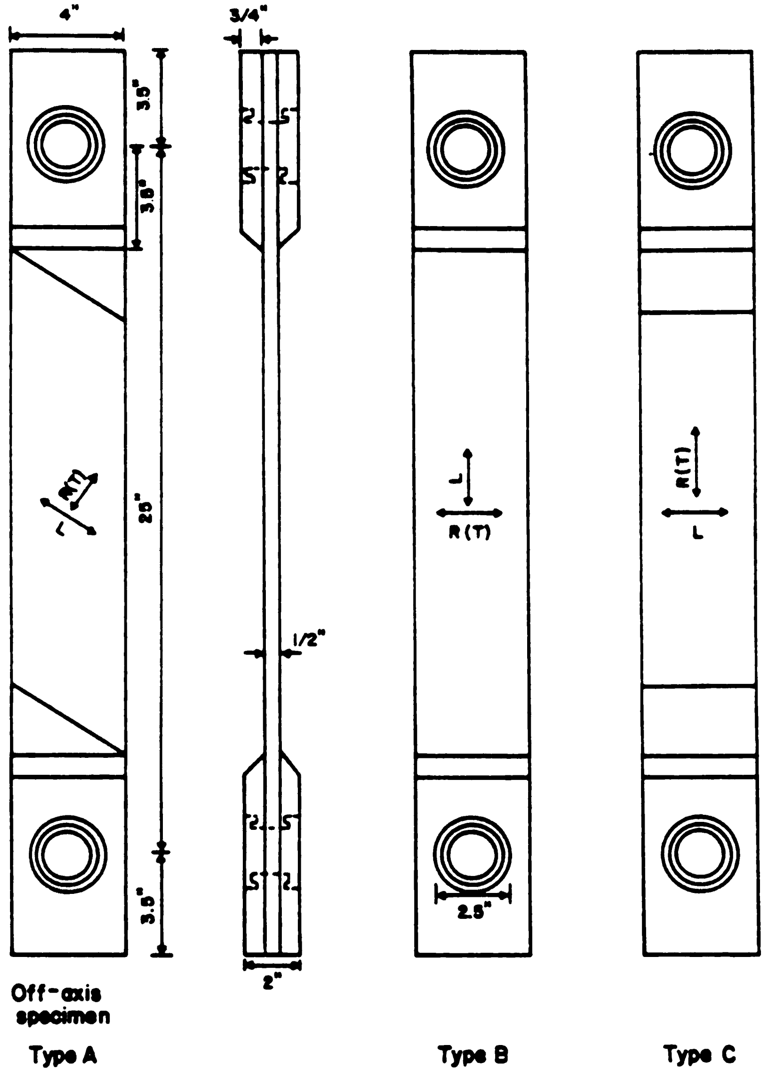


Fig. 9 Geometry of the three types of tension specimens.

Two sets of Type A and Type C specimens were made. Those from one set were loaded to their breaking point. Those from the other were used for determining elastic constants at the specified loading rates.

Strain Measurement

Strain was measured in the wood with rosettes of free-filament bonded electrical resistance strain gauges. These gauges allow rapid reading of strain and at the same time are less apt to restrain movement of their substrate then are gauges with rigid backing materials. Gauges were made essentially as described by Sliker [64] except that the length of the one mil diameter strain sensitive wire in a given gauge was only about four inches. This produced a gauge with a resistance of 90 ohms. After bonding the gauges to the wood in a 2-inch long U-shaped pattern with thinned nitrocellulose cement, the gauge installations were allowed to air cure for 24 hours. This was followed by a conditioning at 100°F for 4 hours (Figure 8).

The gauges were installed as rosettes on the center of opposite broad faces of each test specimen and on matched boards for use as compensating gauges. One gauge was parallel to the member's length, another was perpendicular, and a third was at an angle of 45 degrees to the member's length. This arrangement is shown in Figure 2. Resistance of each gauge to the nearest 0.02 ohms was determined with a Hewelett Packard Digital Multimeter, Type 34072A.

Precautions were taken to protect the gauges and boards from slight fluctuations in the relative humidity and temperature in test area. One of these was to coat end grain surfaces on the narrow edges of boards with wax. Then saran wrap was wrapped around the gauged area and its proximity. In addition a one-inch thickness of a low-density rubber cushioning material was placed over gauges during a test.

Loading of Tensile Specimens to Failure

As was mentioned earlier, by loading one set of tension specimens to their breaking point, the ultimate strength of unbroken specimens could be estimated. This loading was done on an Instron model TTD testing machine with a cross-head speed setting of 0.002 inch/minute. Failure loads were recorded (Tables 5, 6). The zero-degree specimens were not included in this testing because their strength would have exceeded the capacity of the testing machine.

Loading of Gauged Tensile Specimens

The magnitude of maximum test load for each specimen used in strain determinations was proposed. Then it was divided by the corresponding measured ultimate load to compute the reduction factor. Rounded reduction factors ranged from 0.07 to 0.320 (Tables 5, 6).

The maximum test load was applied to each specimen four times, each time at a different rate of loading. Rates

Table 5.--Ultimate Testing Load and Reduction Factor of Hardwood Species.

Nominal Angle of Inclination α-degree	Basswood			Yellow Poplar		
	Ultimate Load lb	Maximum Test Load lb	Reduction Factor	Ultimate Load lb	Maximum Test Load lb	Reduction Factor
0	--	600*	--	--	600	--
20	6320	600	0.095	8700	600	0.070
35	2800	300	0.107	3500	300	0.086
50	2160	300	0.139	2320	300	0.130
65	1500	300	0.200	2125	300	0.141
90	1400	180	0.128	1900	300	0.157

*This value of load was proposed for zero-degree specimens.

Table 6.--Ultimate Testing Load and Reduction Factor of Softwood Species.

Nominal Angle of Inclincation α-degree	Sugar Pine			Redwood		
	Ultimate Load lb	Maximum Test Load lb	Reduction Factor	Ultimate Load lb	Maximum Test Load lb	Reduction Factor
0	--	600	--	--	600	--
20	3575	300	0.084	*	*	*
35	2140	300	0.140	2320	600	0.260
50	900	180	0.200	1950	420	0.220
65	870	180	0.210	925	300	0.320
90	640	180	0.280	1300	180	0.138

*No 20-degree specimen was fabricated for redwood.

of loading were based on the time to reach the maximum load at total test times of 15, 40, 100 and 240 minutes. The order of testing at these rates was randomly chosen for each specimen. The recovery time between two consecutive loading was 7 days at least.

Loading of a specimen at a given test speed was accomplished by adding water to a five-gallon bucket at a constant rate from a twenty-gallon reservoir with a constant head. Calibrated plastic tubes leading from the reservoir to the bucket provided the outlets for different rates of loading. The five-gallon bucket was suspended from one end of a moment arm which was attached at its other end through a load cell to the specimen. The mechanical advantage of the moment arm was 20 to 1, so the weight of water in the bucket was multiplied by 20 at the test specimen. The test frame containing the moment arm is Applied Test System Model 2410.

Test specimens were mounted (Figure 10) individually in series with 1000 pound capacity load cell in the test frame. Two 2 1/2-inches diameter shear plates, one on either side of a specimen's end blocks and a single bolt provided a pin type connection at both extremities of a specimen. Between the specimen and the bottom of the test frame there was a pin-type joint that allowed rotation at 90 degrees to the axis of rotation of the bolt in the specimen. Between the specimen and the load cell there was a universal joint. The load cell was connected by a pin-type joint to the loading

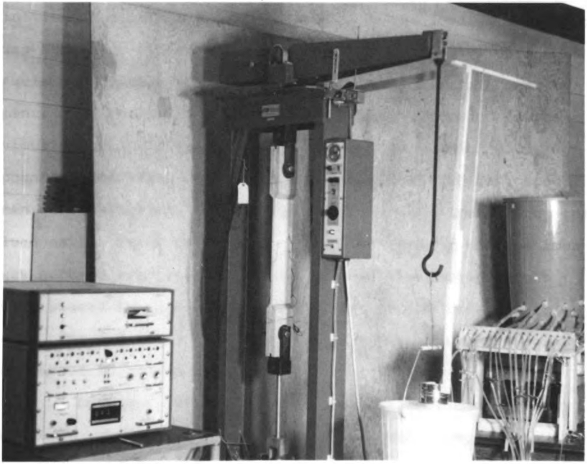


Figure 10. Loading Tension Specimen.

bar, see Figure 10. The rated accuracy of the 1000 pound capacity load cell was plus or minus 0.1 percent. It was calibrated by suspending 100 pounds of dead weight from it.

In preparation for a loading sequence, recording instrumentation was calibrated and then the loading mechanism was attached. Four channels on a B and F Type 161 Data Aquisition System were reserved for load and strain measurement. The channel for the load cell was calibrated as previously mentioned to indicate loads to the nearest 0.20 pounds. The three pairs of strain gauges on the test specimen were calibrated with the specimen hanging freely from the load cell. After calibration, the lower end of the specimen was secured, and the bucket plus a small balancing weight were placed in position at the loading end of the moment arm. The indicated load on the test specimen at this point was about 15 pounds.

Load and strains were measured at specified increments of time during the loading cycle, which began with turning on of the flow of water into the five-gallon bucket. These increments of time are included in the list of raw data (Appendix B). At each of the designated times, the recording channels in the data aquisition system were scanned and the readings were recorded by a printer in the system. Channels were scanned at the rate of two channels per second. Strains were read to the nearest one microstrain up to a strain of 2000 microstrain and to the nearest 2 microstrain beyond that point.

Supplementary Calculations

To calculate stresses, the cross-sectional area of every specimen was computed (Tables 7, 8). In off-axis specimens, the angle of inclination between grain and load direction (Tables 7, 8) was measured in several spots on each constructed specimen, to obtain a more precise value than the nominal one.

To examine the correctness of recording of all data points obtained in any particular speed of loading, a corresponding strain-stress curve was plotted by computer. To compute the required slope of strain-stress curve, multiple regression analysis was made through an available least square subroutine [51] on system of CDC 6500 at Michigan State University. For this analysis simple and quadratic regression equations were tried. Simple regression between strain and stress was found highly valid.

The main calculations for elastic constants were carried out in accordance with three methods of theoretical analysis on off-axis tension tests. Conventional methods were also applied to compute elastic parameters from the results of standard tests.

Table 7.--Computed Value of Cross-Sectional Area and Angle of Load to Grain of Hardwood Specimens.

Nominal Angle of Inclination α-degree	Basswood		Yellow Poplar	
	Cross-sectional area in.^{2}	Measured Value of Inclination Angle α-degree	Cross-sectional area in.^{2}	Measured Value of Inclination Angle α-degree
0	1.95	0	1.98	0
20	1.96	19.8	1.94	18.4
35	1.94	34.7	1.97	36.6
50	1.93	51.8	1.96	52.1
65	1.96	63.9	1.96	65.6
90	1.94	90.00	1.96	90.00

Table 8.--Computed value of Cross-Sectional Area and Angle of Load to Grain of Softwood Specimens.

Nominal Angle of Inclination α-degree	Sugar Pine		Redwood	
	Cross-sectional area in.^{2}	Measured Value of Inclination Angle α-degree	Cross-sectional area in.^{2}	Measured Value of Inclination Angle α-degree
0	1.97	0	1.98	0
20	1.99	26.1	--	--
35	2.00	32.4	1.97	32.9
50	2.00	50.9	1.99	47.7
65	1.99	65.4	1.99	62.6
90	1.92	90.00	2.01	90.00

CHAPTER IV

RESULTS AND DISCUSSION

Standard ASTM Tests

The average moduli of elasticity from standard ASTM tests in compression parallel to the grain and in compression perpendicular to the grain at approximately 12 percent moisture content are given for the four test species in tables 2 and 3. Standard deviations and coefficients of variation for these moduli are also included. For compression parallel to the grain the coefficients of variation were 9.0, 1.2, 7.0, and 14.5 percent for basswood, yellow poplar, sugar pine and redwood respectively. For compression perpendicular to the grain these coefficients were 4.4, 12.4, 20.7, and 14.1 percent in the same order. Part of the reason for these large standard deviations were the small number of samples taken. Also, strain and stress data were not as linear in the perpendicular to grain loading as in the parallel to grain loading. Average shear moduli from standard ASTM tests for the four species are given (Table 4) along with the individual test values. The differences between the paired values for basswood, yellow poplar and sugar pine were less than 4 percent. Only one sample of redwood was tested.

Tensile Specimens Loaded Parallel to Grain

The slope and associated standard errors of strain versus stress parallel (S_1), perpendicular (S_3), and at 45° (S_2) to the load is shown in tables 9-12 at four loading rates for individual specimens of each species loaded parallel to the grain. Since the grain is also parallel to the load, the strains are parallel, perpendicular and at 45° to the grain. Most of the standard errors of the slopes are in the range from 0.002 to 0.004. In all but two cases this is less than 0.6 percent of the slope reading parallel to the grain and 1.0 percent or less of the reading perpendicular to the grain for the sixteen recorded slopes at each angle. Percent errors for the perpendicular to the grain readings are about double those of the parallel to grain slopes because the perpendicular readings have the same standard errors as the parallel ones but are about half as great in magnitude. For the gauges at 45° to the grain, the magnitude of errors would be much larger percentage-wise because the slopes are smaller.

There is no consistent pattern of strain-stress slopes as a function of loading time for the four species. Variations among the slopes taken at different loading rates are apparently related to variables in the reapplication of loads such as specimen alignment, gauge calibration, etc. Coefficients of variation for the four parallel to the grain slope measurements for a given specimen ranged from 1

TABLE 9.--Strain-Stress Slope Values of Basswood Specimens.

Angle of Load to Grain θ (degree)	15 Minutes Loading	Standard Error	40 Minutes Loading	Standard Error	100 Minutes Loading	Standard Error	240 Minutes Loading	Standard Error
				$S_1 = \varepsilon_1 \div \sigma$ ($10^{-6} \div$ psi)				
0	0.602	0.002	0.604	0.002	0.636	0.003	0.617	0.004
19.8	1.531	0.002	1.541	0.001	1.596	0.003	1.577	0.005
34.7	3.501	0.004	3.511	0.004	3.572	0.004	3.608	0.004
51.8	7.520	0.142	7.176	0.089	7.442	0.129	7.568	0.063
63.9	8.911	0.016	9.152	0.024	9.113	0.023	9.166	0.028
90	11.875	0.014	12.102	0.020	12.328	0.027	12.303	0.031
				$S_3 = \varepsilon_3 \div \sigma$ ($10^{-6} \div$ psi)				
0	-0.280	0.002	-0.274	0.002	-0.270	0.003	-0.238	0.003
19.8	-0.158	0.001	-0.124	0.001	-0.145	0.003	-0.128	0.003
34.7	-0.012	0.002	0.00003	0.00001	0.00009	0.00001	0.095	0.004
51.8	0.010	0.00002	0.001	0.00003	0.002	0.00003	0.003	0.0001
63.9	0.181	0.010	0.011	0.0003	0.839	0.098	0.007	0.001
90	-0.903×10^{-3}	0.45×10^{-4}	-0.358×10^{-3}	0.168×10^{-3}	-0.105×10^{-2}	-0.259×10^{-3}	0.121	0.125
				$S_2 = \varepsilon_2 \div \sigma$ ($10^{-6} \div$ psi)				
0	0.222	0.002	0.215	0.001	0.233	0.001	0.253	0.004
19.8	2.111	0.005	2.183	0.004	2.225	0.006	2.248	0.005
34.7	4.130	0.018	4.057	0.006	4.272	0.020	4.344	0.005
51.8	5.638	0.013	5.700	0.008	5.845	0.011	5.847	0.007
63.9	6.925	0.012	7.054	0.029	7.226	0.014	7.308	0.011
90	7.793	0.015	7.849	0.009	8.122	0.017	8.353	0.077

TABLE 10.--Strain-Stress Slope Values of Yellow Poplar Specimens.

Angle of Load to Grain θ (degree)	15 Minutes Loading	Standard Error	40 Minutes Loading	Standard Error	100 Minutes Loading	Standard Error	240 Minutes Loading	Standard Error
$S_1 = \varepsilon_1 \div \sigma$ ($10^{-6} \div$ psi)								
0	0.624	0.003	0.614	0.003	0.620	0.002	0.606	0.002
18.4	1.301	0.002	1.285	0.002	1.274	0.003	1.346	0.003
36.6	2.538	0.009	2.524	0.006	2.594	0.003	2.601	0.008
52.1	3.482	0.005	3.485	0.013	3.634	0.015	3.590	0.007
65.6	5.269	0.021	5.259	0.010	5.484	0.006	5.330	0.011
90	5.998	0.023	6.206	0.022	5.954	0.013	8.368	0.076
$S_3 = \varepsilon_3 \div \sigma$ ($10^{-6} \div$ psi)								
0	-0.247	0.002	-0.261	0.002	-0.250	0.002	-0.219	0.003
18.4	-0.220	0.001	-0.197	0.001	-0.210	0.002	-0.178	0.002
36.6	-0.253	0.005	-0.248	0.005	-0.247	0.005	-0.244	0.004
52.1	-0.377	0.004	-0.375	0.003	-0.399	0.005	-0.320	0.006
65.6	-0.187	0.006	-0.177	0.004	-0.149	0.007	-0.107	0.005
90	-0.177	0.007	-0.187	0.007	-0.177	0.007	-0.253	0.008
$S_2 = \varepsilon_2 \div \sigma$ ($10^{-6} \div$ psi)								
0	0.213	0.003	0.249	0.0002	0.214	0.001	0.231	0.005
18.4	1.544	0.001	1.576	0.003	1.582	0.002	1.585	0.002
36.6	2.080	0.005	2.098	0.003	2.166	0.003	2.149	0.004
52.1	2.772	0.004	2.788	0.005	2.812	0.008	2.978	0.011
65.6	3.928	0.013	3.944	0.007	4.164	0.018	3.949	0.006
90	3.105	0.009	3.105	0.006	3.163	0.003	3.169	0.011

TABLE 11.--Strain-Stress Slope Values of Sugar Pine Specimens.

Angle of Load to Grain θ (degree)	15 Minutes Loading	Standard Error	40 Minutes Loading	Standard Error	100 Minutes Loading	Standard Error	240 Minutes Loading	Standard Error
				$S_1 = \varepsilon_1 \div \sigma$ ($10^{-6} \div$ psi)				
0	0.837	0.005	0.789	0.010	0.821	0.012	0.900	0.003
26.1	1.854	0.030	2.051	0.016	1.969	0.008	2.086	0.011
32.4	3.668	0.005	3.718	0.005	3.727	0.003	4.483	0.066
50.9	8.532	0.081	8.776	0.099	8.099	0.058	7.950	0.086
65.4	9.143	0.025	9.078	0.029	9.465	0.033	9.615	0.080
90	12.431	0.048	11.898	0.079	12.895	0.137	12.006	0.071
				$S_3 = \varepsilon_3 \div \sigma$ ($10^{-6} \div$ psi)				
0	-0.523	0.003	-0.508	0.001	-0.528	0.002	-0.514	0.003
26.1	1.197	0.017	1.636	0.013	1.471	0.018	1.375	0.024
32.4	0.831	0.007	0.857	0.004	0.890	0.006	0.862	0.017
50.9	0.972	0.007	0.967	0.009	1.026	0.008	1.089	0.015
65.4	0.151	0.004	0.184	0.008	0.192	0.006	0.202	0.007
90	-0.341	0.013	-0.345	0.004	-0.421	0.009	-0.426	0.015
				$S_2 = \varepsilon_2 \div \sigma$ ($10^{-6} \div$ psi)				
0	0.196	0.002	0.204	0.001	0.196	0.002	0.189	0.003
26.1	2.472	0.004	2.446	0.004	2.396	0.006	2.455	0.015
32.4	4.268	0.008	4.274	0.008	4.293	0.005	4.371	0.045
50.9	6.576	0.021	6.626	0.024	6.725	0.027	7.050	0.052
65.4	7.295	0.057	7.320	0.046	7.380	0.059	7.708	0.068
90	6.578	0.016	6.567	0.037	6.798	0.037	6.766	0.021

TABLE 12.--Strain-Stress Slope Values of Redwood Specimen.

Angle of Load to Grain θ (degree)	15 Minutes Loading	Standard Error	40 Minutes Loading	Standard Error	100 Minutes Loading	Standard Error	240 Minutes Loading	Standard Error
				$S_1 = \varepsilon_1 \div \sigma$ ($10^{-6} \div$ psi)				
0	0.706	0.001	0.691	0.002	0.686	0.002	0.686	0.003
32.9	2.491	0.003	2.498	0.003	2.544	0.005	2.544	0.003
47.7	3.617	0.006	3.632	0.006	3.593	0.005	3.619	0.015
62.6	4.193	0.011	4.197	0.012	4.365	0.024	4.335	0.021
90	6.373	0.030	6.500	0.013	6.662	0.025	6.636	0.016
				$S_3 = \varepsilon_3 \div \sigma$ ($10^{-6} \div$ psi)				
0	-0.286	0.002	-0.281	0.002	-0.302	0.003	-0.307	0.003
32.9	-0.468	0.002	-0.453	0.001	-0.451	0.007	-0.466	0.002
47.7	-0.380	0.012	-0.363	0.006	-0.397	0.009	-0.425	0.012
62.6	-0.417	0.003	-0.403	0.003	-0.405	0.004	-0.399	0.005
90	-0.401	0.005	-0.411	0.007	-0.420	0.009	-0.377	0.007
				$S_2 = \varepsilon_2 \div \sigma$ ($10^{-6} \div$ psi)				
0	0.280	0.002	0.286	0.002	0.277	0.002	0.289	0.003
32.9	2.116	0.010	2.155	0.007	2.127	0.014	2.279	0.009
47.7	3.052	0.010	3.046	0.004	3.065	0.010	3.060	0.007
62.6	2.829	0.004	2.864	0.005	2.959	0.005	3.165	0.017
90	2.972	0.020	3.039	0.008	3.134	0.010	3.104	0.008

percent to 5 percent for the parallel to grain gauges, from 1 percent to 7 percent for the perpendicular to the grain gauges and from 2 percent to 8 percent for the gauges at 45° to the grain.

In order to obtain some verification of the accuracy of the rosettes and measuring system, maximum strain (ε_{max}) per unit stress, minimum strain (ε_{min}) per unit stress and the direction of the principal strains were determined from the three rosette guagues under the assumption that maximum and minimum strains and their directions were unknowns. The calculated values for ε_{max} and ε_{min} were generally within one standard error of the measured ones, see Table 13. The calculated principal strains were acting at an angle of 5° or less with the direction of measured strains. The reasons for this deviation in the sense of principal strains could be rosette construction, grain direction not parallel to specimen load axis, grain deviation along the gauge and non-uniformity in strain field due to non-homogeneous nature of wood.

Tensile Specimens Loaded Perpendicular to the Grain

The arrangement of the three gauges in the rosette in the specimens loaded perpendicular to the grain was such that the gauge parallel to the load was oriented perpendicular to the grain, the gauge perpendicular to the load had its long axis parallel to the grain and the gauge at forty-five degrees to the grain had its long axis at forty-five

Table 13.--Principal Strains and Their Directions for Zero-degree Specimens.

Species	Loading time (minute)	$a = \frac{\gamma_{xy}^{*}}{\sigma}$ $10^{-6} \div$ Psi	$b = \frac{\epsilon_{1(y)}}{\sigma}$ $10^{-6} \div$ Psi	Standard Error $10^{-6} \div$ Psi	$c = \frac{\epsilon_{3(x)}}{\sigma}$ $10^{-6} \div$ Psi	Standard Error $10^{-6} \div$ Psi	Calculated $\epsilon_{max} \div \sigma$ $10^{-6} \div$ Psi	Calculated $\epsilon_{min} \div \sigma$ $10^{-6} \div$ Psi	Direction of Principal Strains θ (degree)
Basswood	15	0.120	0.602	0.002	-0.280	0.002	0.606	-0.284	-3.87
	40	0.100	0.604	0.002	-0.274	0.002	0.606	-0.276	-3.25
	100	0.100	0.636	0.003	-0.270	0.003	0.638	-0.272	-3.14
	240	0.120	0.617	0.004	-0.238	0.003	0.621	-0.272	-3.99
Yellow Poplar	15	0.050	0.624	0.003	-0.247	0.002	0.624	-0.247	-1.64
	40	0.110	0.614	0.003	-0.261	0.002	0.617	-0.264	-3.58
	100	0.060	0.620	0.002	-0.250	0.002	0.621	-0.251	-1.97
	240	0.070	0.606	0.002	-0.219	0.003	0.607	-0.220	-2.42
Sugar Pine	15	0.070	0.837	0.005	-0.523	0.003	0.837	-0.523	-1.47
	40	0.110	0.798	0.010	-0.508	0.001	0.800	-0.510	-2.40
	100	0.100	0.821	0.012	-0.528	0.002	0.822	-0.529	-2.11
	240	-0.006	0.900	0.003	-0.514	0.003	0.900	-0.514	0.121
Redwood	15	0.140	0.706	0.001	-0.286	0.002	0.710	-0.290	-4.01
	40	0.160	0.691	0.002	-0.281	0.002	0.697	-0.287	-4.67
	100	0.170	0.686	0.002	-0.302	0.003	0.693	-0.309	-4.88
	240	0.170	0.686	0.003	-0.307	0.003	0.693	-0.314	-4.85

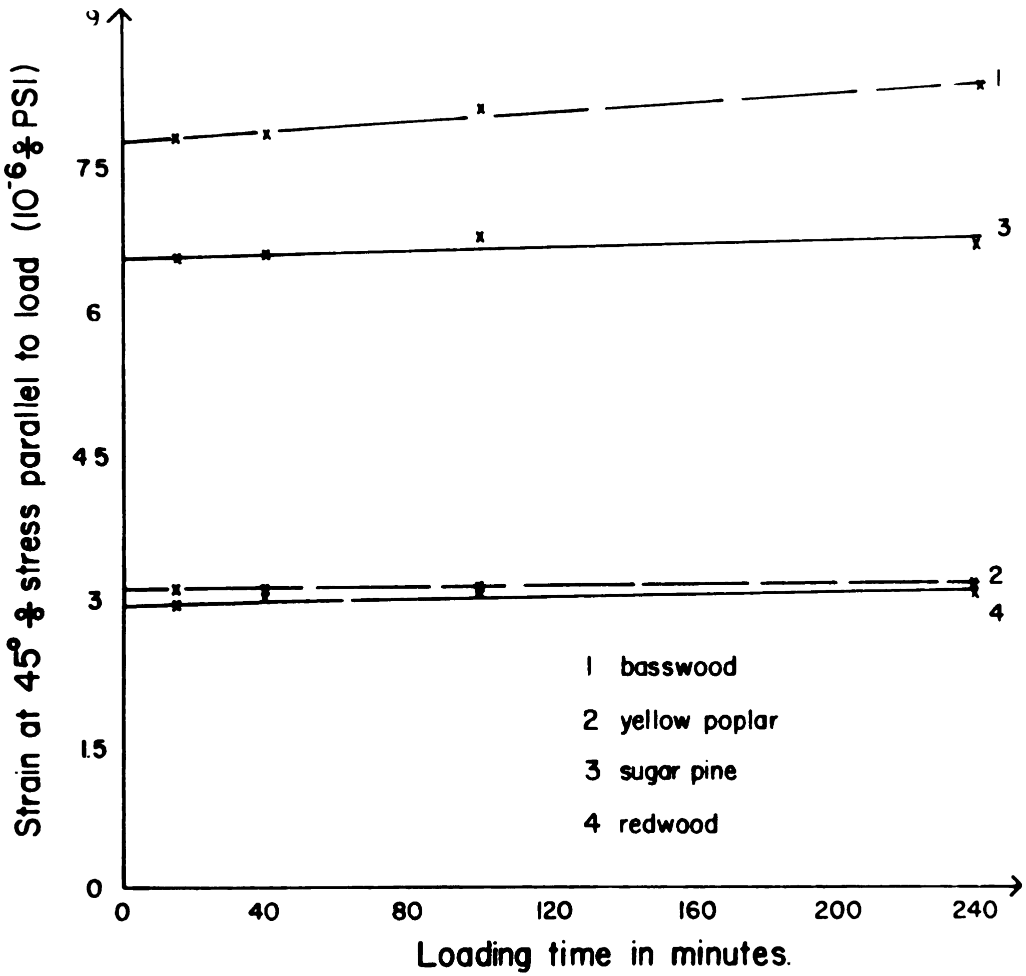
*Slope of γ_{xy} at each measurement time as a function of stress.

degrees to the grain. The slopes of the strain-stress curves of these gauges and corresponding standard errors are given in tables 9-12. With the exclusion of basswood readings perpendicular to the load, the range of standard errors is at most 2.2, 75, 4.5 percent of slope readings for parallel, perpendicular and 45-degree to load gauges of all test species respectively. The reason for the large error percentages for the strains measured perpendicular to the load was that the strains were very small in this direction. Even for basswood the magnitude of the standard errors perpendicular to the load were not any larger than in the other two directions. Generally, most researchers do not try to make this type of strain measurement because it is so small.

The coefficients of variation for the four computed slopes of strain-stress curves for each specimen varied from 2 percent to 18 percent for the gauge perpendicular to the grain (parallel with the load), from 5 percent to 18 percent for the gauge parallel to the grain (excluding basswood) and from 1 percent to 5 percent for the gauge at 45° with respect to the grain. If one reading for the yellow poplar specimen parallel to the load is ignored, the coefficients of variation for these slopes were 2 percent to 4 percent.

When the slopes of the strain-stress curves were plotted against loading time, a slight increase in most of these slopes was observed with loading time. This is shown in Figure 11 for the gauges oriented at forty-five degrees to

Fig 11 Slope of strain÷stress versus loading time for gage at 45 degrees to load axis on specimens loaded perpendicular to the grain



the grain for the specimens loaded perpendicular to the grain. The three gauges on the basswood specimen showed greater change with loading rate than the gauges on any of the other species. More replications and a greater range of loading times is probably needed to certify the changes of strain-stress slopes with loading rate. However, the implications are that apparent modulus of elasticity perpendicular to the grain should decrease with increase in loading rate since it would be equivalent to the reciprocal of the strain-stress slope parallel to the load.

The accuracy of measurement of this type specimen was also examined with readings from the rosette by assuming that the magnitude of the principal strains and their direction was not known (see table 14). Except for the basswood, the calculated maximum strain per unit stress parallel to the load (perpendicular to the grain) was within one standard error of the value measured by the gauge parallel to the load. A similar situation existed in many cases for the calculated minimum strain per unit stress and the strain per unit stress measured perpendicular to the load. In the cases where the differences between minimum strain and the measured strain were larger than one standard error, the direction of principal strains from the load axis was more than two degrees. For the basswood, the indicated deviation from the load axis was about nine degrees for all four loadings. Also, for the basswood, calculated maximum

Table 14.--Principal Strains and Their Directions for 90-degree specimens.

Species	Loading time (minute)	$a = \frac{\gamma_{xy}^*}{\sigma}$ 10^{-6} : Psi	$b = \frac{\epsilon_{1(y)}}{\sigma}$ 10^{-6} : Psi	Standard Error 10^{-6} : Psi	$c = \frac{\epsilon_{3(x)}}{\sigma}$ 10^{-6} : Psi	Standard Error 10^{-6} : Psi	Calculated ϵ_{max} : σ 10^{-6} : Psi	Calculated ϵ_{min} : σ 10^{-6} : Psi	Direction of Principal Strains θ °degree)
Basswood	15	3.85	11.875	0.014	-0.903×10^{-3}	0.415×10^{-4}	12.18	-0.305	-8.98
	40	4.07	12.102	0.020	-0.358×10^{-2}	0.168×10^{-3}	12.43	-0.336	-9.29
	100	4.05	12.328	0.027	-0.105×10^{-2}	0.259×10^{-3}	12.65	-0.325	-9.09
	240	4.24	12.303	0.031	0.121	0.125	12.65	-0.237	-9.59
Yellow Poplar	15	0.40	5.998	0.023	-0.177	0.007	6.00	-0.183	-1.85
	40	0.19	6.206	0.022	-0.187	0.007	6.21	-0.188	-0.85
	100	0.54	5.954	0.013	-0.177	0.007	5.96	-0.188	-2.51
	240	-1.52	8.368	0.076	-0.253	0.008	8.43	-0.319	4.99
Sugar Pine	15	1.08	12.431	0.048	-0.342	0.013	12.45	-0.364	-2.41
	40	1.54	11.898	0.079	-0.345	0.004	11.94	-0.393	-3.58
	100	1.13	12.895	0.137	-0.422	0.009	12.92	-0.445	-2.42
	240	1.96	12.006	0.071	-0.427	0.015	12.08	-0.503	-4.47
Redwood	15	-0.010	6.373	0.030	-0.402	0.005	6.37	-0.402	0.042
	40	-0.009	6.500	0.013	-0.412	0.007	6.50	-0.412	0.037
	100	0.002	6.662	0.025	-0.420	0.009	6.66	-0.420	-0.008
	240	-0.060	6.636	0.016	-0.378	0.007	6.64	-0.378	0.244

*Slope of γ_{xy} at each measurement time as a function of stress.

and minimum strains per unit stress were considerably different than the strains per unit stress measured parallel and perpendicular to the load. Why this should be consistently so for the basswood is difficult to explain, but it indicates why very samll negative strains or even positive strains were recoreded perpendicular to the direction of loading. More realistic numbers for Poisson's ratio are obtained if the calculated maximum and minimum strains per unit stress are used.

Young's Moduli and Poisson's Ratios from Parallel and Perpendicular to Grain Testing

Except for the sugar pine, the difference between the average modulus of elasticity from the parallel to grain tension test and that from the ASTM standard compression test differed by less than 7 percent (Tables 15, 17). For some reason in the case of the sugar pine, the modulus of elasticity from the ASTm test was 20 percent greater than the value in the tension test. The moduli of elasticity from the four replications at different loading rates of the tension specimens showed only random variation of a very small order (5% at most), which was expected.

When comparing the muduli of elasticity perpendicular to the grain from the ASTM test and the tension test perpendicular to the grain, relative large differences were noted. Based on average these ranged from minus 34 percent to plus 39 percent of the tension test value (Tables 16, 18). Several reasons might be noted for these differences. One of them is that there

Table 15.--Comparison for the Values of Young's Modulus Parellel to the Grain Measured by Tension Tests and Compressions Tests on Hardwoods at 12% Moisture Content.

Species	Average E_L from Zero-degree Specimen Psi (1)	Average E_L from ASTM Compression Test Psi (2)	Difference in % $\frac{2-1}{1}$ x 100 (3)	E_L* Determined from Off-axis Specimens: Use of Equation (12): Angle of Load to Grain (degree) (4)	Use of Equation (12): $\bar{E}_L$ Psi (5)	Use of Equation (12): Difference in % $\frac{5-1}{1}$ x 100 (6)	Use of Equations (14): Nominal Angle of Specimens (degree) (7)	Use of Equations (14): $\bar{E}_L$ Psi (8)	Use of Equations (14): Difference in % $\frac{8-1}{1}$ x 100 (9)
Basswood	1,625,000	1,610,000 (±144,000)	0.4	19.8	1,980,000	22	20-35	1,747,500	8
				34.7	3,980,000	145	20-50	3,795,000	133
							20-65	2,650,000	63
				51.8	137,800	-91	35-50	1,835,000	13
				63.9	637,700	-61	35-65	2,740,000	69
							50-65	268,000	-83
Yellow Poplar	1,620,000	1,705,000 (±20,000)	5	18.4	1,590,000	-2	20-35	1,955,000	21
				36.6	785,500	-51	20-50	1,495,000	-8
							20-65	1,520,000	-6
				52.1	1,663,000	3	35-50	625,000	-61
				65.6	579,000	-64	35-65	766,000	-53
							50-65	1,932,500	19

*Average calculated value from tests at four loading rates.

Table 16.--Comparison for the Values of Young's Modulus Perpendicular to the Grain Measured by Tension Tests and Compression Tests on Hardwoods at 12% Moisture Content.

Species	Average E_R from 90-degree Tension Specimen Psi (1)	Average E_R from ASTM Compression Test Psi (2)	Difference in % $\frac{2-1}{1} \times 100$ (3)	E_R* Determined from Off-axis Specimens: Use of equation (13): Angle of Load to Grain (degree) (4)	Use of equation (13): $\bar{E}_R$ Psi (5)	Use of equation (13): Difference in % $\frac{5-1}{1} \times 100$ (6)	Use of equations (14): Nominal Angle of Specimens (degree) (7)	Use of equations (14): $\bar{E}_R$ Psi (8)	Use of equations (14): Difference in % $\frac{8-1}{1} \times 100$ (9)
Basswood	82,300	114,700 (±5,000)	39	19.8	96,300	17	20-35	89,700	9
							20-50	93,300	13
				34.7	92,300	12	20-65	87,300	6
				51.8	78,700	-4	35-50	96,000	17
							35-65	87,600	6
				63.9	86,600	5	50-65	83,900	2
Yellow Poplar	153,500	177,600 (±22,100)	16	18.4	127,000	-17	20-35	223,000	45
							20-50	190,000	24
				36.6	177,000	15	20-65	151,500	-1
				52.1	196,500	28	35-50	179,500	17
							35-65	147,000	-4
				65.6	148,000	-4	50-65	138,000	-10

*Average calculated value from tests at four loading rates.

Table 17.--Comparison for the Values of Young's Modulus Parallel to the Grain Measured by Tension Tests and Standard Compression Tests of Softwoods at 12% Moisture Content.

Species	Average E_L from Zero-degree Specimen Psi (1)	Average E_L from ASTM Compression Test Psi (2)	Difference in % $\frac{2-1}{1} \times 100$ (3)	E_L* Determined from Off-axis Specimens: Use of equation (12): Angle of Load to Grain (degree) (4)	Use of equation (12): E_L (Psi) (5)	Use of equation (12): Difference in % $\frac{5-1}{1} \times 100$ (6)	Use of equations (14): Nominal Angle of Specimens (degree) (7)	Use of equations (14): E_L (Psi) (8)	Use of equations (14): Difference in % $\frac{8-1}{1} \times 100$ (9)
Sugar Pine	1,190,000	1,429,100 (±100,000)	20	26.1	540,000	-54	20-35	792,000	-33
							20-50	1,007,500	-15
				32.4	437,700	-63	20-65	568,500	-52
				50.9	13,800	-99	35-50	1,849,000	55
							35-65	495,000	-58
				65.4	1,495,000	26	50-65	1,418,000	-88
Redwood	1,437,500	1,342,000 (±194,000)	-7	32.9	973,000	-32	35-50	658,800	-54
				47.7	8,829,000	514	35-65	867,800	-40
				62.6	528,000	63	50-65	2,497,500	74

*Average calculated value from tests at four loading rates.

Table 18.--Comparison for the Values of Young's Modulus Perpendicular to the Grain Measured by Tensions Tests and Standard Compression Tests on Softwood at 12% Moisture Content.

Species	Average E_T* from 90-degree Tension Specimen Psi (1)	Average E_T* from ASTM Compression Test Psi (2)	Difference in % $\frac{2-1}{1}$ x 100 (3)	E_T* Determined from Off-axis Specimens: Use of equation (13): Angle of Load to Grain (degree) (4)	Use of equation (13): E_T* (Psi) (5)	Use of equation (13): Difference in % $\frac{5-1}{1}$ x 100 (6)	Use of equations (14): Nominal Angle of Specimens (degree) (7)	Use of equations (14): E_T* (Psi) (8)	Use of equations (14): Difference in % $\frac{8-1}{1}$ x 100 (9)
Sugar Pine	81,000	72,300 (±15,000)	-11	26.1	63,400	-22	20-35	71,600	-12
							20-50	78,700	-3
				32.4	63,500	-22	20-65	85,300	5
				50.9	19,400	-76	35-50	80,500	-0.6
							35-65	84,800	5
				65.4	83,900	4	50-65	87,600	8
Redwood	152,200	100,000 (±14,100)	-34	32.9	166,300	9	35-50	151,300	-0.6
				47.7	169,500	11	35-65	190,300	25
				62.6	183,000	20	50-65	211,800	39

* Average calculated value from tests at four loading rates.

* For Redwood this is E_R.

were large standard deviations associated with ASTM compression perpendicular to the grain tests. Also the load-deflection curves for this testing were not as linear as those for the parallel to grain testing and so were open to more interpretation. In addition, modulus of elasticity perpendicular to the grain is sensitive to loading rate. This was noticeable for the yellow poplar and basswood. For these two species, the apparent elastic modulus perpindicular to the grain was greater for the relatively fast ASTM test and decrease of modulus with decrease of loading rate was not evident for the tension test.

The reciprocal relationship $\mu_{RL} \div E_R = \mu_{LR} \div E_L$ can be used to check the accuracy of measurements of these elastic constants made in a given plane. μ_{RL} is the one which usually contains the greatest error since its strain perpendicular to the load is small. The results of dividing Poisson's ratios by elastic moduli are given in Table 19. Except for the basswood, agreement between the relationships from the parallel to grain loading and those from the perpendicular to the grain loading are good. $(\mu_{RL} \div E_R) \div (\mu_{LR} \div E_L)$ was from 0.65 to 1.47. In the case of the basswood, however the indicated Poisson's ratios were very small for the loading perpendicular to the grain which resulted in an extremely small number for Poisson's ratio

TABLE 19.--Comparison of Module of Elasticity and Poisson's ratios from Loading of Zero-Degree and 90-Degree Tension Specimens.

Species	Loading Time	Loading Parallel to Grain					Loading Perpendicular to the Grain										
		ϵ_1/σ 10^{-6}/Psi	ϵ_3/σ 10^{-6}/Psi	$E_L = \frac{\sigma}{\epsilon_1}$ Psi/10^{-6}	$\mu_{LR} = \frac{\epsilon_3}{\epsilon_1}$	μ_{LR}/E_L 10^{-6}/Psi	ϵ_1/σ 10^{-6}/Psi	ϵ_3/σ 10^{-6}/Psi	$E_R = \frac{\sigma}{\epsilon_3}$ 10^{-6}/Psi	$\mu_{RL} = \frac{\epsilon_3}{\epsilon_1}$	μ_{RL}/E_R 10^{-6}/Psi	ϵ_{max}/σ 10^{-6}/Psi	ϵ_{min}/σ 10^{-6}/Psi	$\mu'_{RL} = \frac{\epsilon_{min}}{\epsilon_{max}}$	μ'_{RL}/E_R 10^{-6}/Psi	$\frac{\mu_{RL}/E_R}{\mu_{LR}/E_R}$	$\frac{\mu'_{RL}/E_R}{\mu_{LR}/E_R}$
BASSWOOD:	15	0.602	-0.280	1.661	0.465	0.280	11.875	-0.903×10^{-3}	0.0842	0.076×10^{-3}	0.00090	12.18	-0.305	-0.025	0.297	0.0032	1.06
	40	0.604	-0.274	1.656	0.454	0.274	12.102	-0.358×10^{-3}	0.0826	0.03×10^{-3}	0.00036	12.43	-0.336	-0.270	0.327	0.0013	1.19
	100	0.636	-0.270	1.572	0.425	0.270	12.328	$-0.105\ 10^{-2}$	0.0811	0.085×10^{-3}	0.00105	12.65	-0.325	-0.0257	0.317	0.0039	1.17
	240	0.617	-0.238	1.621	0.386	0.238	12.303	-0.121	0.0813	-0.0098	-0.121	12.65	-0.237	-0.0187	0.230	-0.508	0.97
YELLOW POPLAR:	15	0.624	-0.247	1.603	0.396	0.247	5.998	-0.177	0.1667	0.0295	0.177	6.00	-0.183	-0.0305	0.183	0.72	0.74
	40	0.614	-0.261	1.629	0.425	0.261	6.206	-0.187	0.1610	0.0301	0.187	6.21	-0.188	-0.303	0.188	0.72	0.72
	100	0.620	-0.250	1.613	0.403	0.250	5.954	-0.177	0.1681	0.0297	0.177	5.96	-0.188	-0.0315	0.187	0.71	0.75
	240	0.606	-0.219	1.650	0.361	0.219	8.368	-0.253	0.1195	0.0302	0.253	8.43	-0.319	-0.0378	0.317	1.16	1.44
SUGAR PINE:	15	0.837	-0.523	1.195	0.625	0.523	12.431	-0.342	0.0805	0.0275	0.342	12.45	-0.364	-0.0292	0.363	0.65	0.69
	40	0.798	-0.508	1.253	0.637	0.508	11.898	-0.345	0.0840	0.0290	0.345	11.94	-0.393	-0.0329	0.392	0.68	0.77
	100	0.821	-0.528	1.218	0.643	0.528	12.895	-0.422	0.0775	0.0327	0.422	12.92	-0.445	-0.0344	0.444	0.80	0.84
	240	0.900	-0.514	1.111	0.571	0.514	12.006	-0.427	0.0833	0.0356	0.427	12.08	-0.503	-0.0416	0.499	0.83	0.97
REDWOOD:	15	0.706	-0.286	1.427	0.405	0.284	6.373	-0.402	0.1570	0.0631	0.402	6.37	-0.402	-0.0631	0.402	1.42	1.42
	40	0.691	-0.281	1.447	0.407	0.281	6.500	-0.412	0.1538	0.0634	0.412	6.50	-0.412	-0.0634	0.412	1.47	1.47
	100	0.686	-0.302	1.458	0.440	0.302	6.662	-0.420	0.1502	0.0631	0.420	6.66	-0.420	-0.631	0.420	1.39	1.39
	240	0.686	-0.307	1.458	0.448	0.307	6.636	-0.378	0.1506	0.0569	0.378	6.64	-0.378	-0.0569	0.378	1.23	1.23

over modulus of elasticity. Looking again at the calculations for ε_{max}, ε_{min} and the angle of principal strains from the rosette analysis suggests that Poisson's ratio μ_{RL} might better be represented by $\varepsilon_{min} \div \sigma$ divided by $\varepsilon_{max} \div \sigma$. Indeed, this type of calculation produces a more realistic Poisson's ratio for the basswood. In all cases, except for the yellow poplar loading at 240 minutes, it produces a Poisson's ratio μ_{RL} that is closer to the one expected from the reciprocal relationship from parallel and perpendicular to the grain loading than was produced by taking the strain divided by stress readings from the perpendicular and parallel to the load readings. The use of the calculated principal strains values divided by stress for obtaining Poisson's ratios suggests that modulus of elasticity perpendicular to the grain might also be corrected. However, because the mechanism which is causing the apparent discrepancy between ε_{max} and load direction is not known, this might be left for further investigation.

In a few cases Poisson's ratios appear to change systematically with loading rate but it is by no means consistent for all species. μ_{LR} decreases with an increase in loading rate for basswood, increases with loading rate for redwood, and shows no distinct pattern for yellow poplar and sugar pine. μ_{RL} increases with loading rate for yellow poplar, like so μ_{TL} for sugar pine, but no discernible pattern for basswood and redwood.

Tensile Specimens Loaded at an Angle to the Grain

Slopes of strain-stress curves for each gauge of the rectangular rosettes are given in Tables 9-12 for the four test species at four rates of loading. At the smaller angles for some species, the measured slopes were greater at forty-five degrees to the load than they were parallel to load. Standard errors of these calculated slope values ranged from 0.001 to 0.086 for gauges parallel to load direction, from 0.00001 to 0.098 for gauges perpendicular to load, and from 0.001 to 0.02 for gauges at 45° to load. For parallel and 45° gauges the ranges of standard errors are at most 1.9 percent and 0.87 percent of the corresponding recorded slope. This percentage-wise comparison for gauges perpendicular to load is larger because of their small slope readings. However, since the strain-stress slopes perpendicular to grain are only added or subtracted to the slopes from other gauges in the calculations for elastic constants, their standard error is more significant than their percentage error. The standard errors of all the gauges in a given rosette are about the same.

About half of the strain-stress slopes show a slight increase with decrease in loading rate. These increases were evident with the slopes from the gauges oriented at 45° to the load direction. The types of increase indicated would be expected with a time dependent material since during the slower loadings there is more time for creep to take place. However, since the increases were so small, tests over a wider range of testing speeds and more replications should be performed before making definite conclusion.

Shear Moduli.--Shear moduli from the tension tests (tables 20-23) were from 69 percent to 361 percent of those from the plate shear tests. If the sugar pine is eliminated from the camparison, the shear moduli from tension tests are from 86 percent to 130 percent of those from the plate shear tests. Gresczuk [24] obtained values for shear modulus that were within a few percent of those from the plate shear test when he loaded fiber galss laminates at various angles to the filament axis.

For the basswood samples, the shear moduli ranged from 86 percent to 119 percent of the average from the plate shear test. There was no consistent change of shear modulus either with angle between the load axis and the grain direction or with the test rate (Figure 12, 13). If just the two lowest angles of lading to the grain are considered, the shear moduli from the tension specimens were from 105 to 111 percent of those from the plate shear test. The average of the four replications at the twenty degree angle of loading was 8 percent greater and that at the 35 degree angle was 7 percent greater than that from the plate shear test (Table 24).

Table 20.--Computed Values of Shear Modulus of Basswood by Off-axis Tension Test.

Angle of Load to Grain θ (degree)	$G_{LR} = 1 \div [2(S_1-S_3)+(2S_2-S_3-S_1)(Cot\theta-Tan\theta)]$ (psi)				Average G_{LR} (psi)	Standard Deviation (psi)
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading		
19.8	97,400	95,600	93,200	92,800	94,700	2,200
34.7	94,000	95,400	91,900	92,800	93,500	1,500
51.8	75,700	81,200	78,000	76,000	77,700	2,500
63.9	99,200	94,200	104,500	101,000	100,000	4,300

Table 21.--Computed Values of Shear Modulus of Yellow Poplar by Off-axis Tension Test.

Angle of Load to Grain θ (degree)	(Psi) $G_{LR} = 1 \div [2(S_1-S_3)+(2S_2-S_3-S_1)(\text{Cot}\theta-\text{Tan}\theta)]$				Average G_{LR} (psi)	Standard Deviation (psi)
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading		
18.4	118,900	117,900	116,500	119,000	118,000	1,100
36.6	148,900	149,200	145,300	145,700	147,300	2,000
52.1	154,200	154,500	145,800	154,800	152,300	4,400
65.6	165,100	167,800	166,000	161,500	165,100	2,700

Table 22.--Computed Values of Shear Modulus of Sugar Pine by Off-axis Tension Test.

Angle of Load to Grain θ (degree)	$G_{LT} = 1 \div [2(S_1-S_3)+(2S_2-S_3-S_1)(\cot\theta-\tan\theta)]$ (psi)				Average G_{LT} (psi)	Standard Deviation (psi)
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading		
26.1	235,000	370,500	323,300	272,500	300,300	59,100
32.4	105,500	105,700	106,300	95,800	103,300	5,000
50.9	73,600	70,700	81,000	86,100	77,800	7,000
65.4	113,100	117,600	102,700	109,200	110,600	6,300

Table 23.--Computed Values of Shear Modulus of Redwood by Off-axis Tension Test.

Angle of Load to Grain (degree)	$G_{LR} = 1 \quad [2(S_1-S_3)+(2S_2-S_3-S_1)(\text{Cot} - \text{Tan})]$ (psi)				Average G_{LR} (psi)	Standard Deviation (psi)
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading		
32.9	126,500	126,000	126,100	121,200	125,000	2,500
47.7	134,200	134,100	134,700	132,700	133,900	900
62.6	152,300	154,500	147,500	164,000	154,600	6,900

Table 24.--Comparison for the Values of Shear Modulus Measured by Off-axis and Standard Plate Tests.

Species	Angle of Load to Grain (degrees)	$\overline{G}_{LR}$* (Psi)		Differences in Percent
		Off-axis Tests (1)	Average From Standard Plate Shear Test (2)	$\frac{1-2}{2}$ x 100
Basswood	19.8	94,700	87,700	8
	34.7	93,500		7
	51.8	77,700		-11
	63.9	100,000		14
Yellow Poplar	18.4	118,000	127,300	-7
	36.6	147,300		16
	52.1	152,300		20
	65.6	165,100		30
Sugar Pine	26.1	300,300	102,500	193
	32.4	103,300		1
	50.9	77,800		-24
	65.4	110,600		8
Redwood	32.9	125,000	132,900	-6
	47.7	133,900		1
	62.6	154,600		16

*This is G_{LT} value for Sugar Pine.

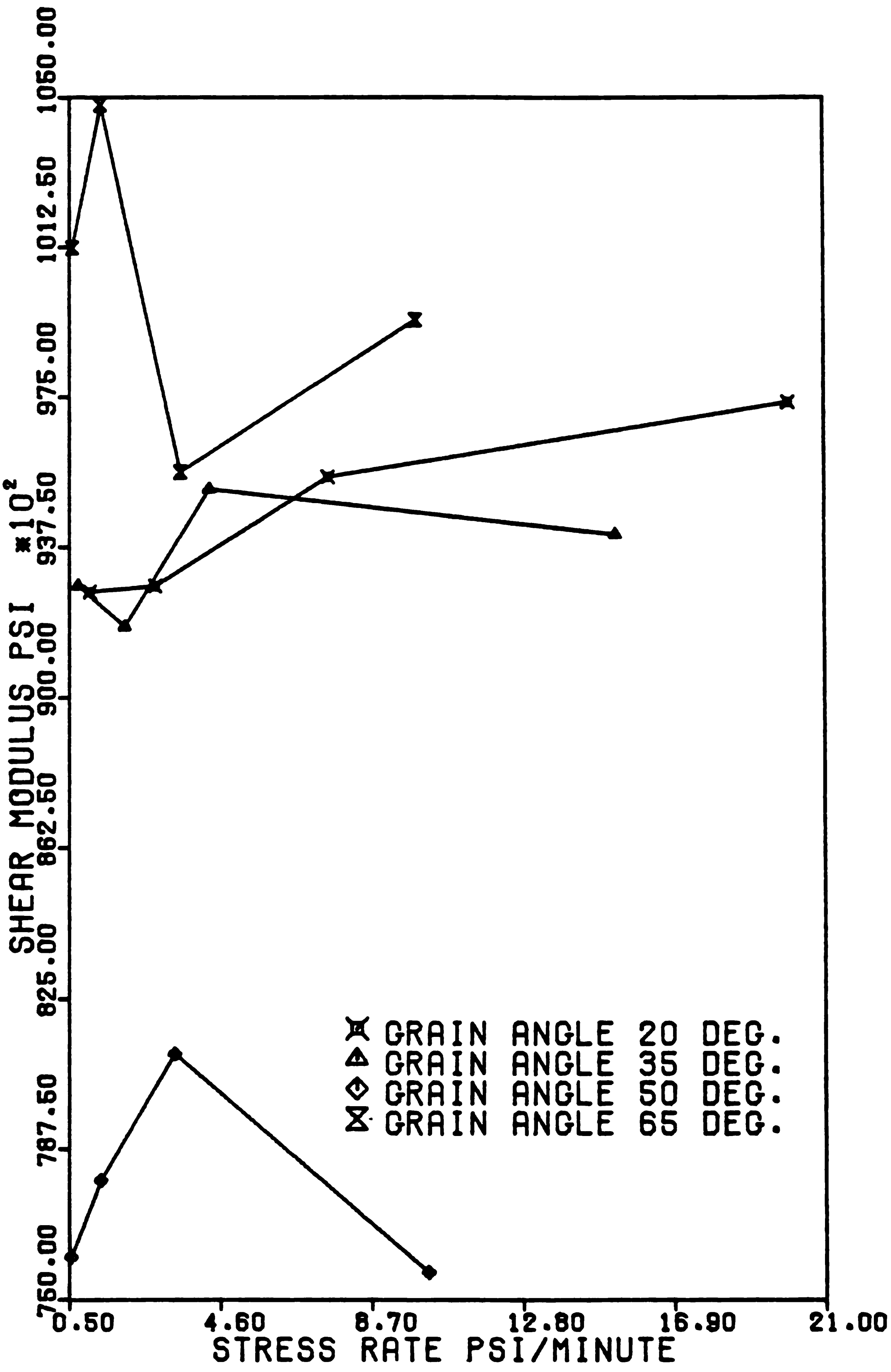


Fig. 12. Shear Modulus Versus Stress Rate for Basswood.

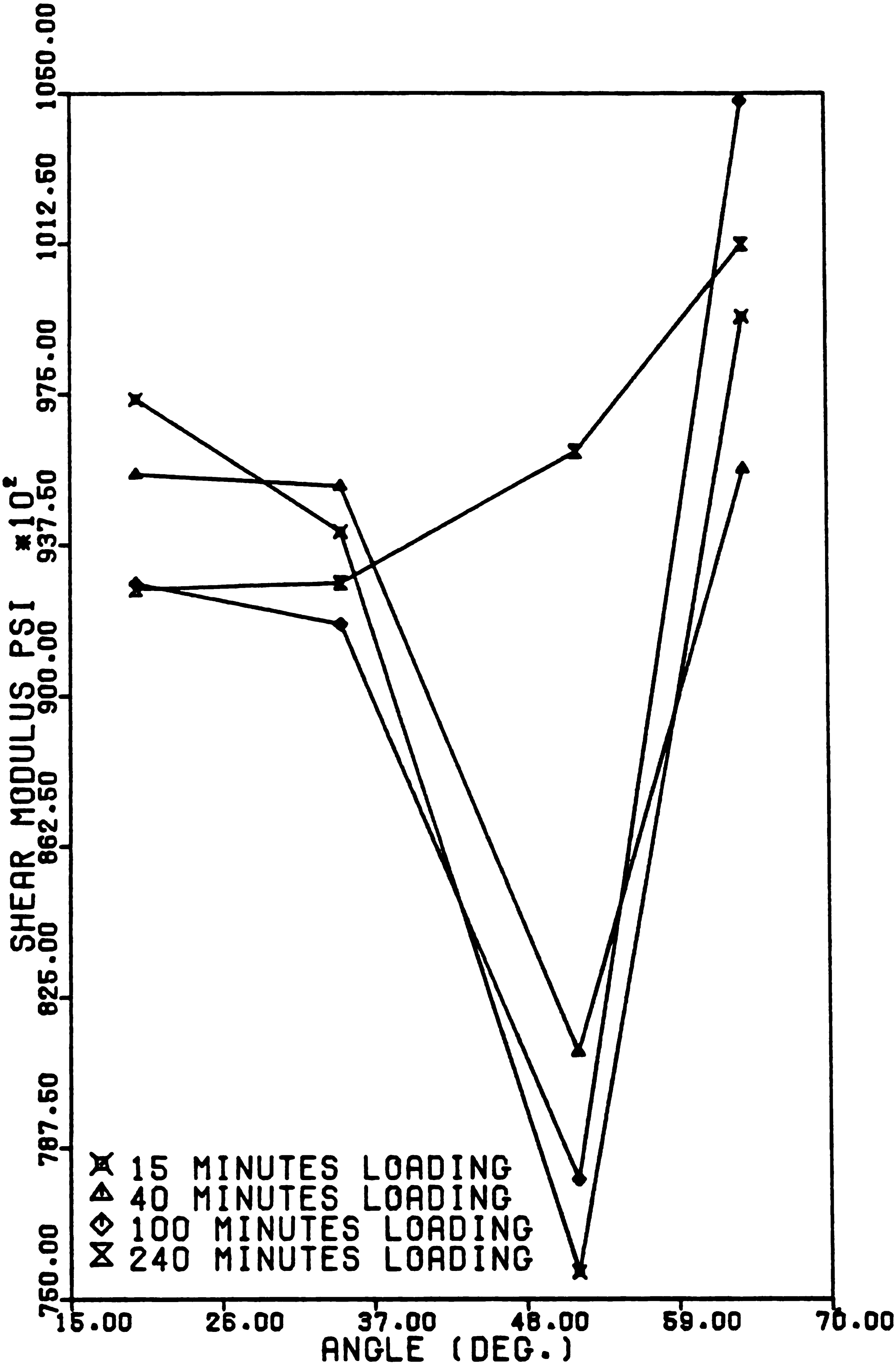


Fig. 13. Shear Modulus Versus Angle of Load to Grain for Basswood.

For yellow poplar samples the shear moduli ranged from 92 percent to 132 percent of the average from the plate shear test. There was little if any change of shear modulus with loading rate, but the shear modulus increased greatly with the angle of load to grain variable (Figure 14, 15). The average shear modulus for the specimen with the grain at 65 degrees to the load was 1.4 times that calculated for the specimen with the grain at 20 degrees to the load axis. The shear moduli from the 20-degree and the 35-degree tension specimens were closest to those from the plate shear test. They averaged 92 percent and 115 percent respectively of the shear moduli from the plate test.

For sugar pine samples, the shear moduli ranged from 69 percent to 361 percent of the average from the plate shear test. If the specimen with the load at 26-degree to the grain is ignored the range of values is reduced to 69 percent to 115 percent. There is little if any change of calculated shear moduli with either loading rate or angle of load to grain (Figure 16, 17). The shear moduli from the specimen with angle of load to grain of 32-degree were the closest to the average of the plate shear test. They were from 93 to 104 percent of this average. The large discrepancy of the shear moduli from the 26-degree specimen suggests a special problem. The one that comes to mind and the most obvious is the fact that the measurements were made on the longitudinal-tangential plane in the sugar pine specimens, and that in the 26-degree specimen the rosette is the least

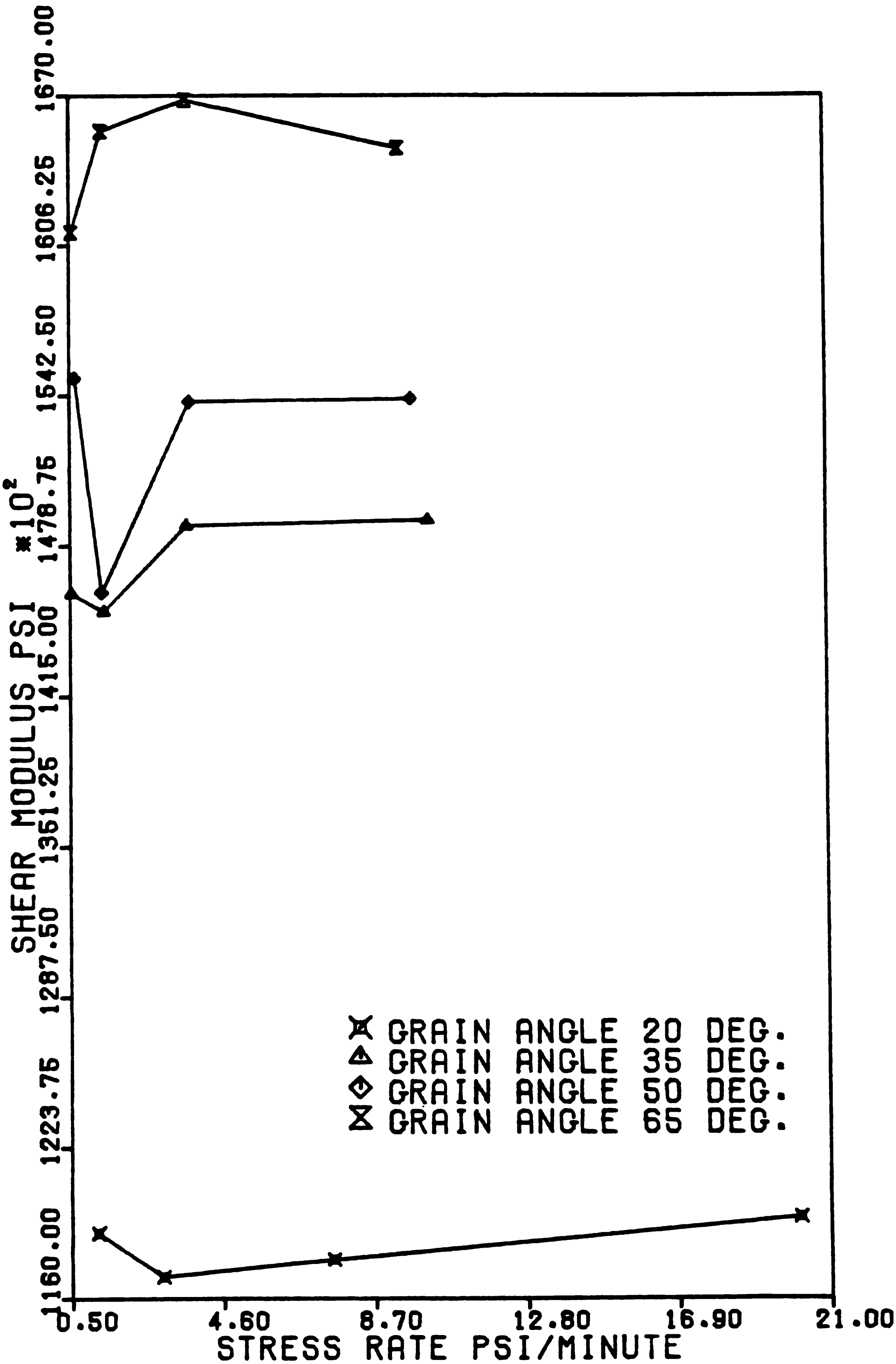


Fig. 14. Shear Modulus Versus Stress Rate for Yellow Poplar.

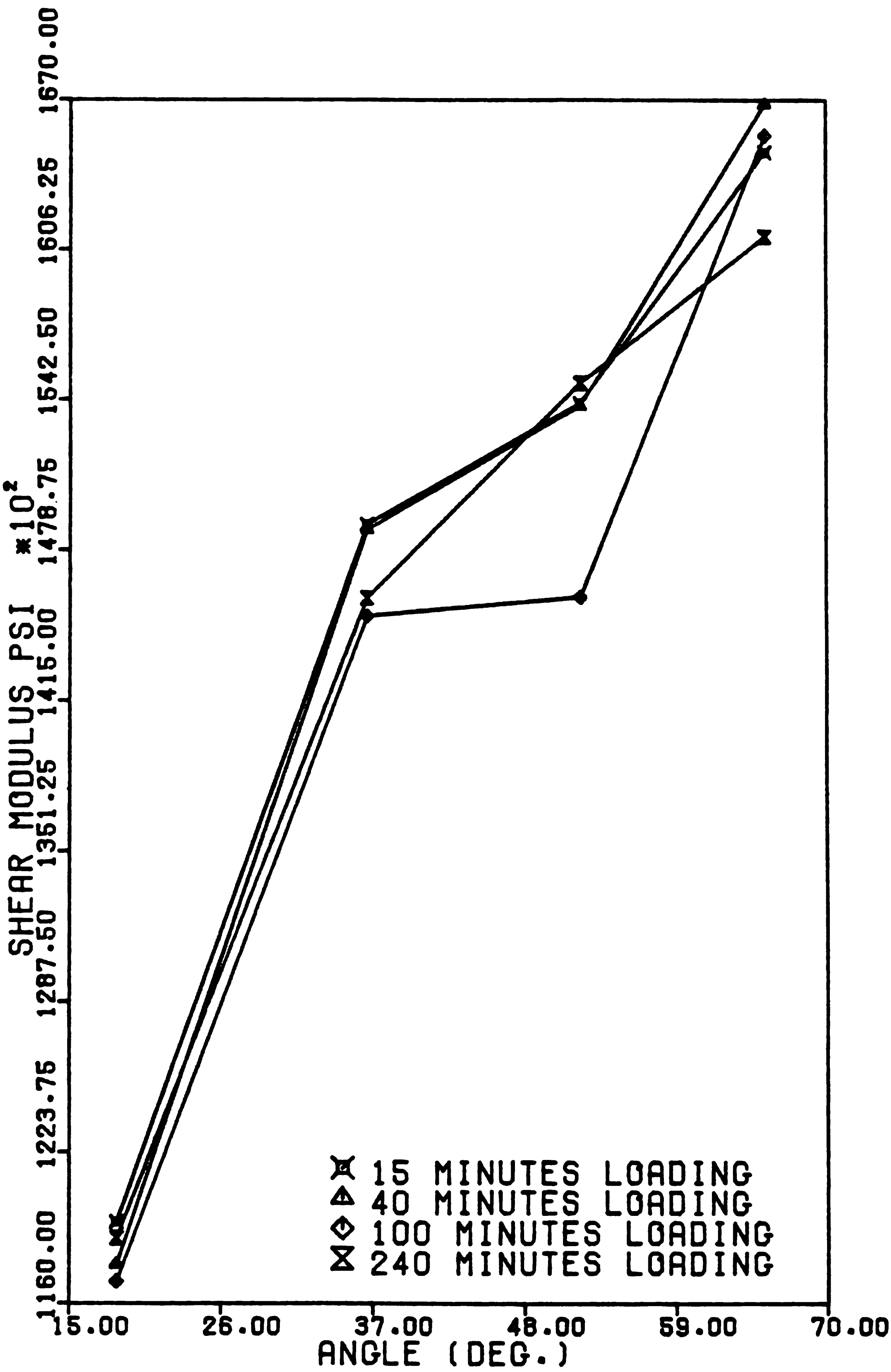


Fig. 15. Shear Modulus Versus Angle of Load to Grain for Yellow Poplar.

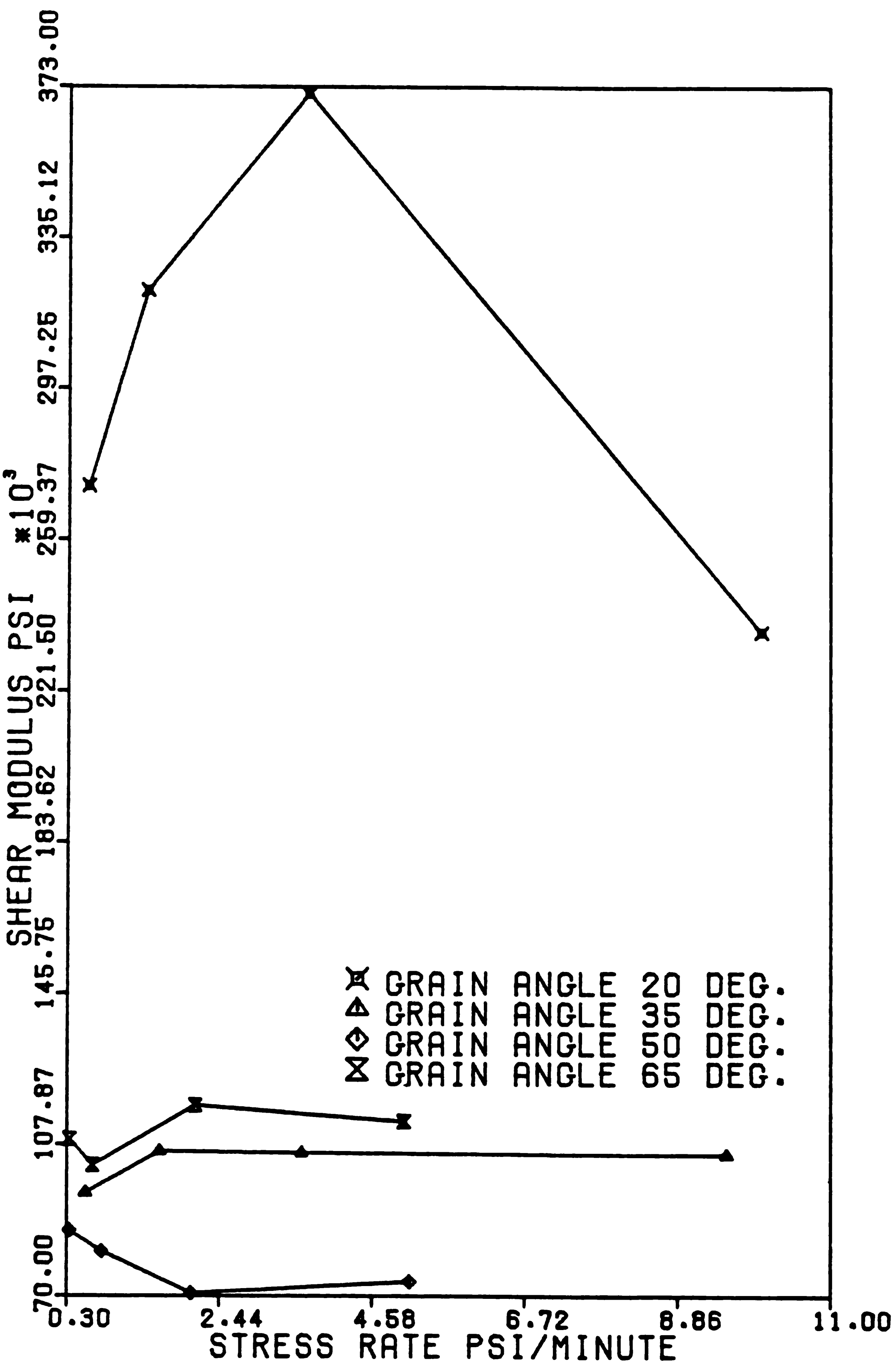


Fig. 16. Shear Modulus Versus Stress Rate for Sugar Pine.

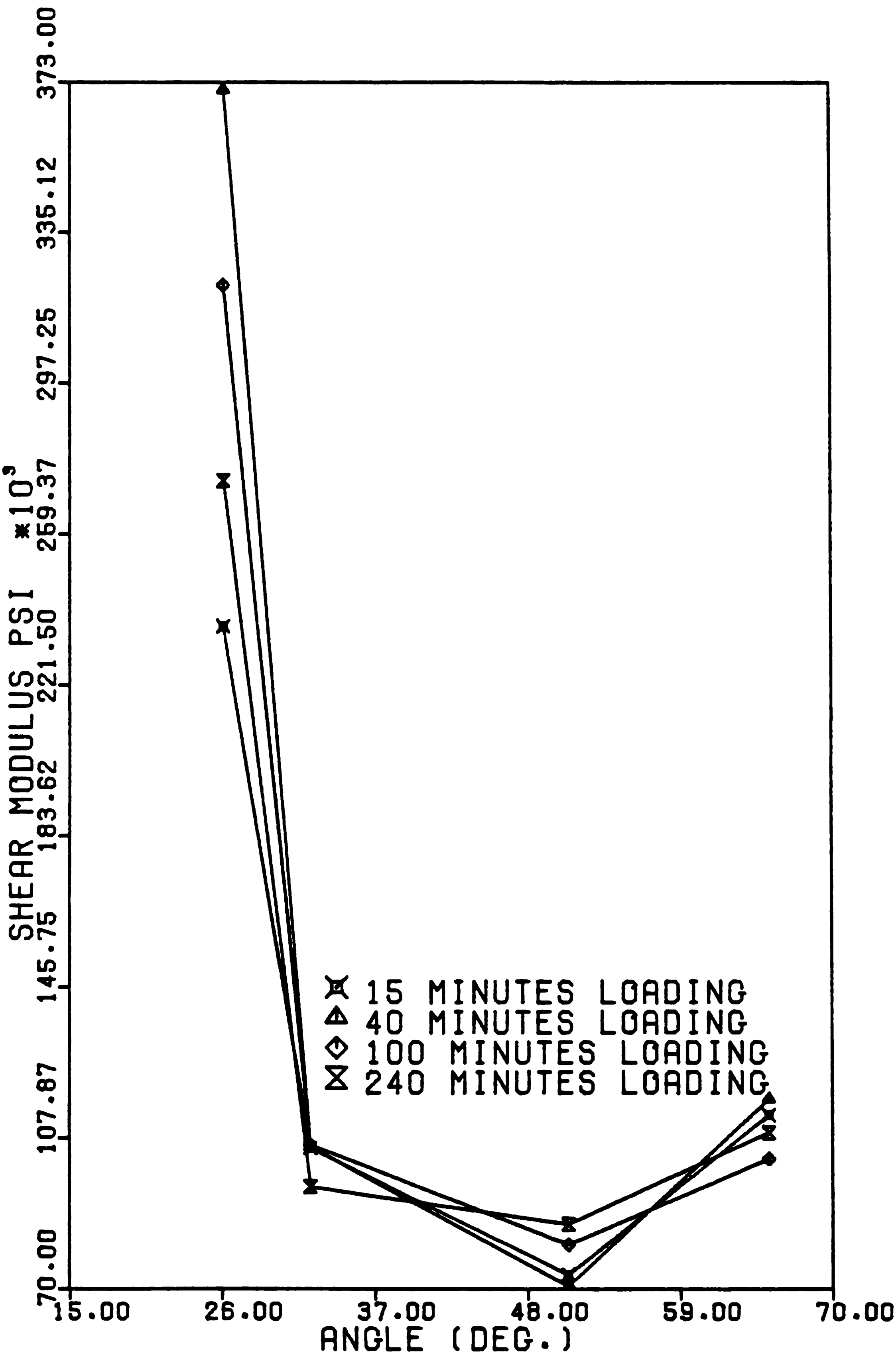


Fig. 17. Shear Modulus Versus Angle of Load to Grain for Sugar Pine.

likely to be in a true longitudinal-tangential plane. The reason for this latter observation is that there is only a small area on the specimen surface that very closely approximates a tangential surface and this area changes very rapidly from one side of the specimen to the other when the angle of load to the grain is small. It could be easily seen that some parts of the strain rosette on this particulr specimen were on locations that were distinctly different from a tangential-longitudinal plane. With greater angle this problem becomes less drastic.

For the redwood samples, the shear moduli ranged from 91 percent to 123 percent of the value from the plate shear test. If just the two lowest angles of loading to the grain (in this case 33-degree and 48-degree are considered) the shear moduli for the tension specimens were from 91 percent to 101 percent of that from the plate shear specimen. There is little if any change of shear modulus with loading rate but shear moduli increases as the angle between the load and the grain increases (Figure 18, 19).

When the data for all the shear tests are examined as a group, the shear moduli from all the tension tests (excluding one sugar pine specimen) were from 69 percent to 130 percent of the shear moduli from the plate shear tests. If specimens with angle of load to grain less than 37-degree only are considered (with the exception of the sugar pine with angle of 26 degrees) the shear moduli from the tension tests ranged from 93 percent to 117 percent of the average values from the shear plate tests. The shear moduli of the

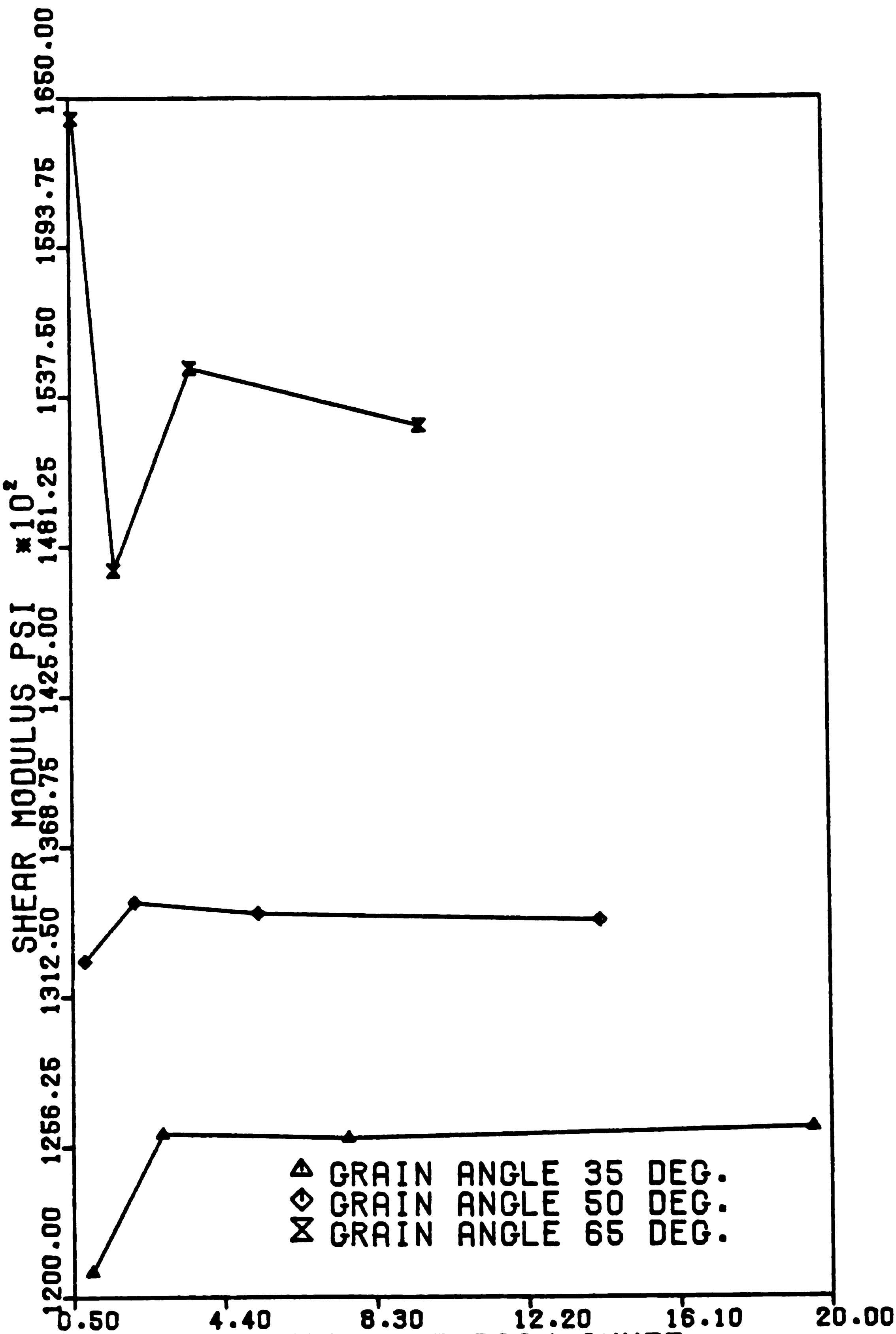


Fig. 18. Shear Modulus Versus Stress Rate for Redwood.

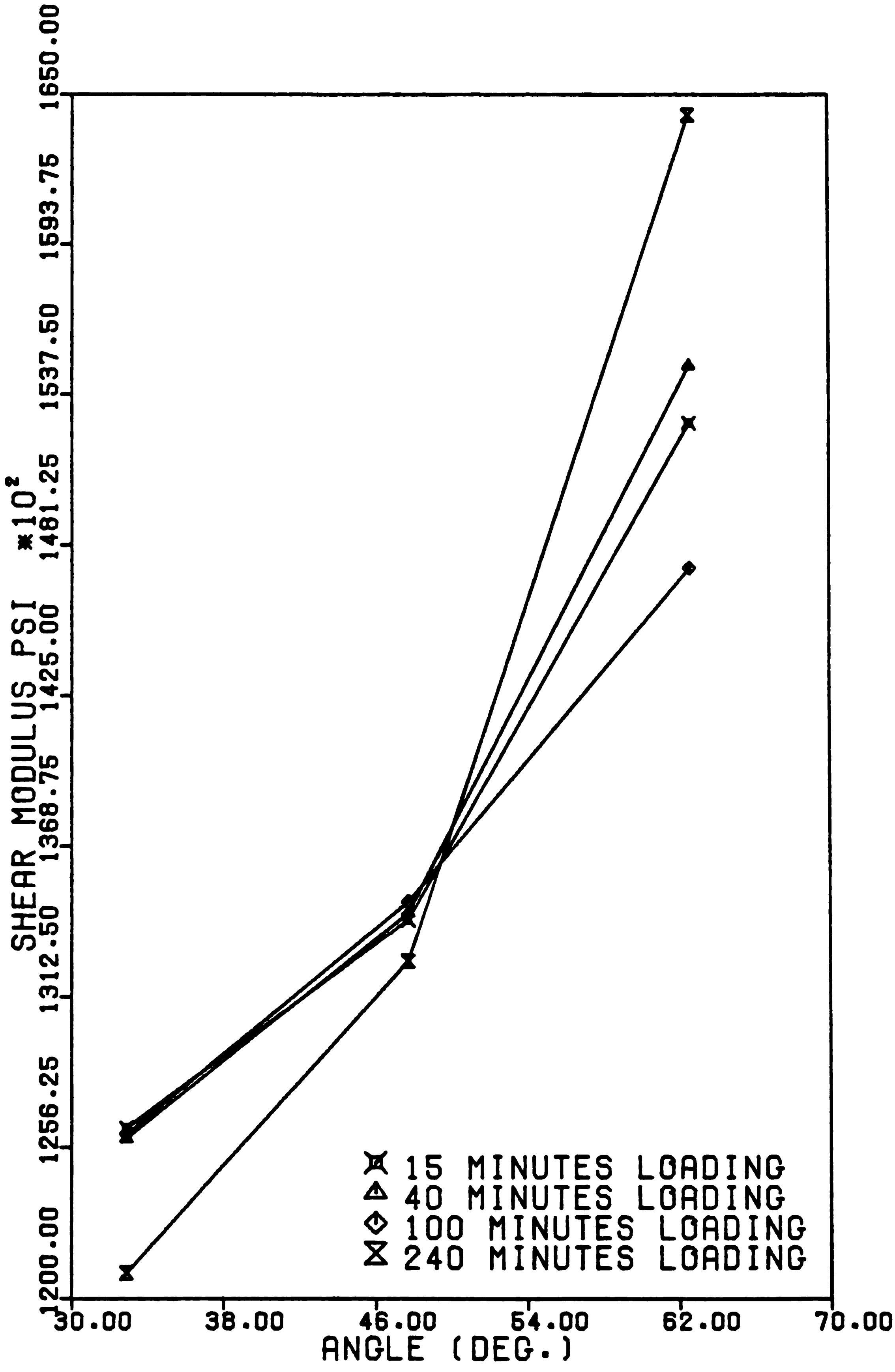


Fig. 19. Shear Modulus Versus Angle of Load to Grain for Redwood.

redwood and yellow poplar increased with the angle of load to the grain while that for the basswood and sugar pine did not. Also, Gresczuk [24] did not have any such change for his fiber glass laminates. A possible reason for the increase in shear modulus with the yellow poplar and the redwood is that they have a relatively large percentage of ray tissue oriented perpendicular to the grain direction: the volumetric percentages of ray tissue for these two species are 14 percent and 8 percent respectively [55]. The ray tissue might provide a reinforcement perpendicular to the grain. Basswood is listed as having 6 percent ray tissue, the sugar pine was tested in a plane where the ray tissue did not act as a reinforcement, and the fiber glass had no comparable structure.

It would seem with the experience with the sugar pine, that more care has to be taken with tension specimens made on a longitudinal-tangential plane than with those on a longitudinal-radial plane because of growth ring curvature. Larger angle between load and grain direction would seem to be best. A plus factor is that shear measurements on a tangential-longitudinal plane will not be influenced as much by the rays as those in radial plane.

Young's Moduli Parallel to the Grain.--Young's moduli parallel to the grain were calculated from the off-axis tensile specimens in two ways. The first of these presupposed a knowledge of μ_{LR} but then only required the data from one specimen to obtain E_L from Equation 12. μ_{LR} from the parallel to the grain tension samples was used for these calculations. If μ_{LR} was not known, data from two off-axis tensile specimens could be combined as per Equation 14. The results of the calculations for E_L by these two methods are given in Tables 15, 17 and in Tables 27-30, 31-34, Appendix A. In Gresczuk's tests [24], the largest percentage errors for any of the elastic constants occurred in the determination of E_L particularly at the larger angles E_L was more "sensitive" to error.

Determination of E_L using Equation 12 and the Poisson's ratio from the parallel to grain loading did not produce many numbers for Young's moduli that were very close to those found from testing the parallel to grain specimen. In fact the differences were mostly large. The E_L values for a given specimen at the four loading rates were averaged for comparison purposes. Of the fifteen such calculations made for the off-axis specimens for all species, only four differed from the expected E_L by less than 30 percent. These were for a basswood loading at 20-degree, yellow poplar loadings at 18-degrees and 52-degree, and a sugar pine loading at 65-degree. E_L from the two yellow poplar loadings mentioned were within 3 percent of the E_L value obtained from the parallel to grain loading.

Young's moduli obtained from the combining of the data from two off-axis tensile specimens in Equation 14 did not give much better results. Combinations where the calculated E_L differed from the E_L obtained from parallel to the grain testing by less than 30 percent were: basswood--20 and 35 degree specimens, 35 and 50 degree specimens; yellow poplar--20 and 35 degree specimens, 20 and 50 degree specimens, 20 and 65 degree specimens, 50 and 65 degree specimens; sugar pine--20 and 50 degree specimens; redwood--none. At this point it does not seem as though an off-axis tensile specimen would be very reliable in determining Young's modulus parallel to the grain for wood.

Young's Moduli Perpendicular to the Grain.--Young's moduli perpendicular to the grain were also calculated from the off-axis tensile specimens in two ways by equations either requiring one sample if μ_{LR} was known or two if it was not. See Equations 12 and 14. The results of the calculations for E_R by these two methods are given in Tables 16 and 18 and in Tables 27-30, 31-34 of Appendix A. In Gresczuk's tests, the moduli of elasticity calculated perpendicular to the fiber axis were within plus or minus 10 percent of the expected. The perpendicular modulus was expected to be "sensitive" to small errors when the angle of axis to loading was small.

Calculated Young's moduli perpendicular to the grain using Equation 13 and Poisson's ratios from parallel to grain loading were close to the values obtained from loading these species in tension at 90 degrees to the grain. If the average moduli calculated from the loadings of a given specimen are compared to the modulus obtained from the 90-degree specimen, all of the calculated values except two are within plus or minus 25 percent of the test value from the 90-degree specimen. For three of the four species, the calculated averages for the 65-degree samples are within 10 percent of the test value.

Young's moduli obtained from the combining of the data from two off-axis tensile specimens in Equations 14 gave even better results except for the redwood. Over one-half of the differences between calculated and test values were within plus or minus 10 percent of the test value. Except for the redwood, all of the combinations of 50-degree with 65-degree specimens and 35-degree with 65-degree specimens produced calculated moduli within plus or minus 10 percent of test value of the 90-degree specimen.

It could be concluded then that it is possible to make accurate calculations of modulus of elasticity perpendicular to the grain from off-axis tensile specimens. This is particularly true if the angle of load to grain direction is around 65 degrees. The presence of large errors in the values used for E_L in the calculation of E_R or E_T does not seem to affect the accuracy of E_R or E_T very much.

Poisson's Ratios.--Poisson'a ratios μ_{LR}, μ_{RL} from basswood, yellow poplar, redwood and μ_{LT} from sugar pine were computed from the off-axis tensiel samples through Equation 16. The results are compared with the average values of these constants measured by zero and 90-degree specimens (Table 25) for all four species. Some cases of combining off-axis specimens resulted in values for μ_{LR} and μ_{LT} that had less than 42 percent discrepancy from parallel to grain testing on zero-degree samples. These combinations were 20 and 35, 50 and 65-degree specimens of basswood; 20 and 35, 35 and 50-degree specimens of yellow poplar; 20 and 35, 20 and 50-degree samples of sugar pine, 35 and 50-degree samples of redwood. Almost all cases of off-axis data combinations for μ_{RL} and μ_{TL} resulted in values which differed by more than 60 percent from the corresponding values obtained from perpendicular to grain testing on 90-degree specimens. The exception was in combining data of 50 and 65-degree samples of basswood from which this difference was only 12 percent.

It is clear that Poisson's ratios are very sensitive to errors particularly μ_{RL} and μ_{TL}; transformed data from off-axis test practically could not provide the required accuracy.

Suggestions for Further Study

In view of the results obtained in this study, it is felt that investigation could be conducted in the following areas:

1. An analytical and experimental investigation on the effect of length and width of off-axis tensile samples and developing smaller samples which are convenient to construct and use.

Table 25.--Comparison for Poisson's Ratios Computed from Zero, 90-degree and Off-axis Specimens.

Species	Nominal Angle of Specimens (degree) (1)	$\bar{\mu}^*_{LR}$			$\bar{\mu}^*_{RL}$		
		Use of Equations 16 (2)	Zero** Degree Specimen (3)	Difference in % $\frac{2-3}{3}$ x 100	Use of Equations 16 (5)	90-degree** Specimen (6)	Differences in % $\frac{5-6}{6}$ x 100
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Basswood	20-35	0.579	0.431	34	0.062	0.0241	157
	20-50	0.990		129	-0.158		-755
	20-65	0.950		120	-0.057		-336
	35-50	0.031		-92	-0.144		-697
	35-65	-0.033		-107	-0.081		-436
	50-65	0.253		-41	-0.021		-187
Yellow Poplar	20-35	-0.242	0.396	-161	-0.182	0.0325	-660
	20-50	-0.056		-114	0.069		112
	20-65	0.170		-57	0.075		131
	35-50	0.300		-24	0.208		540
	35-65	0.887		124	0.091		180
	50-65	2.96		647	0.061		88
Sugar Pine	20-35	0.658	0.618	6	-0.070	0.0345	-303
	20-50	0.478		-22	-0.181		-624
	20-65	0.168		-73	0.057		65
	35-50	0.158		-74	-0.200		-679
	35-65	0.022		-96	0.064		85
	50-65	-0.167		-127	0.160		364
Redwood	35-50	0.517	0.425	21	0.216	0.0616	251
	35-65	0.132		-69	0.124		101
	50-65	-3.76		-984	0.107		74

* For Sugar Pine these constants are $\bar{\mu}_{LT}$ and $\bar{\mu}_{TL}$.

** Average of four readings from table 26 for Zero-degree sample and $\varepsilon_{min} \div \varepsilon_{max}$ from Table 14 for 90-degree specimen.

2. The interaction of loading time and angle of load to grain on specimens with investigated optimal length and width, along with a greater range of stress rate.
3. The uniformity of stress-strain field on off-axis tensile samples through experimental investigation.
4. The range of linear behavior of off-axis tensile specimens with optimal length and width.
5. Measurement of all elastic constants associated with a given plane, especially shear modulus, at large strain level.
6. Find out if there are any unusual elastic properties of basswood when loaded at 90 degrees to the grain.
7. Seeing if rays affect shear moduli determination in tensile specimens.

CHAPTER V

SUMMARY AND CONCLUSIONS

Shear moduli, moduli of elasticity and Poisson's ratios obtained from loading wood tension specimens at four angles to the grain were compared with elastic constants obtained from parallel and perpendicular to the grain tension loadings and from standard ASTM compression and shear plate tests. Measurements were made on a radial-longitudinal plane for basswood, yellow poplar and redwood, but on a tangential-longitudinal plane for sugar pine. Moisture contents of test materials were close to 12 percent. Tension specimens were so constructed that the angles between load axis and the grain direction were 0, 20, 35, 50, 65 and 90 degrees. Specially manufactured strain gauges were applied on each specimen in a rectangular rosette configuration with gauges parallel, perpendicular and at 45-degree to the load axis. Hardwood samples were loaded at most to 15 percent and softwood samples at most to 32 percent of their load carrying capacity at stress rates ranging from 0.3 to 20.0 psi per minute. At least seven days elapsed between successive loadings of a specimen to allow for recovery.

The findings of this study were:

1. Strains parallel, perpendicular and at 45-degree to the load axis were linear functions of stress. This indicates that specimens were loaded within their elastic limit.
2. The accuracy of the strain gauge rosettes was checked on the specimens loaded parallel to the grain and those loaded perpendicular to the grain by assuming the principal strains per unit stress and their directions were unknowns.
    a. For specimens loaded parallel to the grain, the magnitudes of computed principal strains per unit stress were within one standard error of measured ones.
    b. For specimens loaded perpendicular to the grain, the magnitudes of maximum computed strain per unit stress were within one standard error of the strains per unit stress measured parallel to the load for all species except basswood. This was also true for most of the minimum computed strain per unit stress and the strains per unit stress measured perpendicular to the load direction.
    c. For all the specimens loaded either parallel or perpendicular to the grain, the calculated angle between the load direction and the maximum strain was less than plus or minus five degrees except

for the basswood loaded perpendicular to the grain. The angle difference for the latter was about nine degrees.

d. The small calculated angular deviations between the load axis and the principal strains probably represent such things as imperfect grain alignment in the specimens, load not parallel to the specimen length, imperfect rosette construction, and non-homogeneity of wood.

e. Reasons for the basswood specimen loaded perpendicular to the grain being so different from the others is not known.

3. The average modulus of elasticity parallel to the grain computed from the tension specimens was greater than that from the ASTM compression tests by 0.4 percent for basswood, 5 percent for yellow poplar, 20 percent for sugar pine. It was 7 percent less for redwood. The large difference between the two test methods for E_L of sugar pine had no clear reason.

4. The average moduli of elasticity perpendicular to the grain computed from the tension specimens differed by minus 34 to plus 39 percent from the average values from the ASTM tests. The large coefficient of variation (from 4.4% to 20.7%) for the ASTM tests help to explain the differences. Of particular note is the non-linearity of the load-deflection curves in the

perpendicular to grain testing. Also, one might expect the ASTM test to produce a larger modulus value as a result of having been done at a faster loading rate.

5. Quotients of $(\mu_{RL} \div E_R) \div (\mu_{LR} \div E_L)$ ranged from 0.65 to 1.47 excluding basswood. This result compares very favorably with that of other researchers. Basswood fell into this range if the maximum and minimum strains computed from the rosette analysis were used instead of the strains measured parallel and perpendicular to the load direction.
6. Shear moduli calculated in the radial-longitudinal plane (all species except sugar pine) from the tension specimens were from 86 percent to 130 percent of the values calculated from the ASTM plate shear test.
7. When only specimens loaded at angles of 20 and 35-degree to the grain in the radial-longitudinal plane were considered, the shear moduli from the tension specimens were from 93 percent to 116 percent of those from the plate shear specimens.
8. Shear moduli calculated in the tangential-longitudinal plane for three of the four sugar pine specimens loaded at an angle to the grain were from 93 to 103 percent of the values calculated from the plate shear samples. The shear modulus calculated from the 26-degree tension specimen was about twice the plate

shear value. It was observed that the strain gauge rosette was not in a truly tangential-longitudinal plane for this specimen because of growth ring curvature and the rapid change of the curvature factor with specimen length.

9. Shear moduli increased the most with increasing angle of load to grain for the two species which had the greatest amount of ray tissue oriented parallel to the surface of the reference plane.

10. Young's moduli parallel to the grain were not accurately predicted by the equations used with the data from specimens loaded at an angle to the grain. In most instances the values calculated from these specimens differed by more than 30 percent from those determined from the parallel to grain specimens. The moduli obtained from combining the data of two specimens loaded at an angle to the grain were closer to the expected than were those obtained from the data of one sample and a known value of Poisson's ratio.

11. The Young's moduli perpendicular to the grain were predicted fairly closely by the equations used for the data from the specimens loaded at angle to the grain. When using the equation which took data from one specimen and a known Poisson's ratio, all calculated values were within ±25 percent of the values obtained from loading specimens at 90 degrees to the grain. The calculated average moduli from the

65-degree samples for all species were within 10 percent of the expected value except for redwood which was within 20 percent. The moduli obtained from combining data from two specimens were equally as good.

13. The effect of stress rate on the slope of stress-strain curves and elastic constants was a minor variable for the range of stress rates in the experiment.
    a. For specimens loaded parallel to the grain there were no consistent patterns of change of slope of strain-stress curves with stress rate.
    b. For specimens loaded perpendicular to the grain, there were slight increases in slopes of strain-stress curves with loading time. This was particularly true for the slopes of strain-stress data recorded at 45 degrees to the loaded axis.
    c. For specimens loaded at intermediate angles to the grain, about half of the slopes of the strain-stress curves showed consistent change with stress rate.
    d. There were few if any consistent patterns of change of moduli of elasticity parallel to the grain, of Poisson's ratios or of shear moduli with stress rate.

e. There were slight indications of decrease of moduli of elasticity perpendicular to the grain with decrease in stress rate.

14. Off-axis test was found to be productive for measuring shear modulus and modulus of elasticity perpendicular to the grain, but not accurate for determining Young's modulus parallel to the grain and Poisson's ratios.

LITERATURE CITED

LITERATURE CITED

1. American Society for Testing and Materials. 1978. ASTM Standards, part 22: Wood; Adhesives. Philadelphia, PA.

2. Anon. 1956. Stress-strain relations in wood and plywood considered as orthotropic materials. USDA Forest Service Report No. 1503. For. Prod. Lab, Madison, Wis.

3. Ashkenazi, E. K., M. V. Gershberg, and M. G. Kapustin. 1976. Impulse method of determining moduli of elasticity and the shear moduli of wood. Industrial Laboratory (Zavodskaya Lab.) 42(8):1291-1295.

4. Barkas, W. W. 1938. Recent work on the moisture in wood in relation to strength and shrinkage. Forest Products Research Special Report No. 4. London.

5. Beker, V. H. F. 1973. Measuring the moduli of rigidity of solid wood by torsional vibration test. Holz als Roh-und werkestoff 31:207-210.

6. Bell, E. R., E. C. Peck and N. T. Krueger. 1953. Modulus of elasticity of wood determined by dynamic method. USDA Forest Service Report No. 1977. For. Prod. Lab, Madison, Wis.

7. Biblis, E. J., W. C. Lee. 1976. Simplification on the experimental method for determining plate shear modulus of plywood and particleboard. For. Prod. J. 26(4):38-42.

8. Bodig, J. 1965. Initial stress-strain relationship. For. Prod. J. 15(5):197-202.

9. Bodig, J. and J. R. Goodman. 1973. Prediction of elastic parameters for wood. Wood Sci. 5(4): 249-264.

10. ________. 1969. A new apparatus for compression testing of wood. Wood and Fiber 1(2):146-153.

11. Brokaw, M. F. and G. W. Foster. 1945. Effect of rapid loading and duration of stress on the strength properties of wood tested in compression and flexure. USDA Forest Service Report No. 1518, For. Prod. Lab, Madison, Wis.

12. Carrington, M. 1921. The determination of values of Young's modulus and Poisson's ratio by the method of flexure. Philosophical Magazine 41:206-210.

13. _______. 1922. Young's modulus and Poisson's ratio for spruce. Philosophical Magazine 43:871-878.

14. Cave, J. D. and L. Hutt. 1968. The anisotropic elasticity of the plant cell wall. Wood Sci. and Tech. 2:268-278.

15. Chamis, C. C. and J. H. Sinclair. 1977. Ten-deg off-axis test for shear properties in fiber composite. Experimental Mechanics 17(9):339-346.

16. Chung, W. L. and E. J. Biblis. 1977. New approach for determination of elastic constants of orthotropic wood-base plates by strip bending and plate twisting. Wood Sci. 9(4):160-166.

17. Coker, E. C. and C. P. Coleman. 1930. Cleavage tests of timber proceeding of Royal Society, vol. 128: As quoted by Markwardt and Younquist.

18. Dove, R. C. and H. P. Adams. 1964. Experimental stress analysis and motion measurement. Charles E. Merrill Publishing Co., Columbus, OH. Bell and Howell Company.

19. Doyle, D. V., R. S. McBurney and J. T. Draw. 1946. The elastic properties of wood, Young's moduli, moduli of rigidity and Poisson's ratios. USDA Forest Service Report No. 1528 and supplement A-G. For. Prod. Lab, Madison, Wis.

20. Ellwood, L. E. 1954. Properties of American beech in tension and compression perpendicular to the grain and their relation to drying. Yale University, School of Forestry Bulletin No. 61.

21. Foye, R. L. 1967. Deflection limits on the plate-twisting test. J. of Composite Materials 1(2):194-198.

22. Goodman, J. R. and J. Bodig. 1971. Orthotropic strength of wood in compression. Wood Sci. 4(2):83-94.

23. Goodman, J. R. 1975. Orthotropic behavior of wood. ASCE Wood Structure (a design guide and commentary). Amer. Soc. of Civil Engineers, N.Y.

24. Greszczuk, L. B. 1966. New test technique for shear modulus and other elastic constants of filamentary composites. Douglas Paper No. 3670. Douglas Aircraft Company, Inc., Santa Monica, California.

25. ________. 1966. Theoretical and experimental studies on properties and behavior of filamentary composites. Proceeding of the 21st Annual Technical and Management Conference of the Society of Plastic Industry in Chicago. The Society of the Plastics Industry, Inc.

26. Gunnerson, R. A., J. R. Goodman and J. Bodig. 1973. Plate tests for determination of elastic parameters of wood. Wood Sci. 5(4):241-248.

27. Hearmon, R. F. S. 1948. The elasticity of wood and plywood. Forest Products Research Special Report No. 7. London.

28. ____________. 1958. The influence of shear and rotatory inertia on the free flexure vibration of wooden beams. British Journal of Applied Physics 9:381.

29. ____________. 1961. An introduction to applied anisotropic elasticity. Oxford University Press.

30. Hearmon, R. F. S. and E. H. Adams. 1952. The bending and twisting of anisotropic plate. British Journal of Applied Physics 3:150-156.

31. Hoyle, J. R. 1973. Wood technology in the design of structures. Mountain Press Publication Company, Missoula.

32. ________. 1975. Physical character of wood. ASCE Wood Structure (a design guide and commentary). Amer. Soc. of Civil Engineers. N.Y.

33. Ifju, G. and R. W. Kennedy. 1962. Some variables affecting microtensile strength of Douglas-Fir. For. Prod. J. 12:213-217.

34. Jane, B. A. and M. O. Hunt. 1969. Plane stress and plane strain in orthotropic and anisotropic media. Wood and Fiber 1(3):236-247.

35. Jane, B. A. 1962. Mechanical tests for wood proceeding of the conference on the mechanical behavior of wood, pp. 105-118. U. of California, Berkeley.

36. Kellog, R. M. 1958. Strain behavior of wood subjected to repetitive stressing in tension parallel to the grain. For. Prod. J. 8(10):301-307.

37. Kennedy, R. W. 1968. Wood in transverse compression. Influence of some anatomical variables and density on behavior. For. Prod. J. 18(3):36-40.

38. King, E. G. 1957. Creep and other strain behavior of wood in tension parallel to grain. For. Prod. J. 7(10):324-330.

39. ________. 1961. Time-dependent strain behavior of wood in tension parallel to grain. For. Prod. J. 11(3):156-165.

40. Kitazawa, G. 1950. Nondestructive testing for forest products. Proceeding of the national meeting. Forest Products Research Society.

41. Kollman, F. F. 1968. Principles of wood science and technology. vol. 1. Springer-Verlag Meidelberg. N.Y.

42. Kuenzi, E. W. 1952. Methods for determining the elastic constants of nonmetalic materials ASTM special technical publication 129:31-41. Philadelphia, PA.

43. Kunesh, R. H. 1961. Inelastic behavior of wood. For. Prod. J. 11(9):359-406.

44. Lee, I. D. G. 1959. Measuring the elasticity of timber. Timber Development Association Civil Engineering, London.

45. Love, A. E. H. 1944. The Mathematical Theory of Elasticity. 4th edition. Dover Publication. N.Y.

46. Madsen, B. 1975. Duration of load tests for dry lumber subjected to shear. For. Prod. J. 25(10):44-52.

47. Maghsood, J. 1970. Finite Element Analysis of Wood Beams. Ph.D. Thesis, Cornell University.

48. March, H. W., E. W. Kuenzi and W. J. Kommers. 1942. Method of measuring the shearing moduli in wood. USDA Forest Service Report No. 1301. For. Prod. Lab, Madison, Wis.

49. Mark, R. E., S. F. Adams, and R. C. Tang. 1970. Moduli of rigidity of virginia pine and tulip poplar related to moisture content. Wood Sci. 2(4):203-211.

50. Markwardt, L. J. and W. G. Younquist. 1956. Tension test method for wood, wood-base material and sandwich construction. USDA Forest Service Report No. 2055. For. Prod. Lab, Madison, Wis.

51. Myers, W. L. (undated). User's Guide for EZLS Regression Program. 2nd Revision. Michigan State University.

52. Newlin, J. A. and G. W. Trayer. 1956. Stress in wood members subjected to combined column end beam action. USDA Forest Service Report No. 1311. For. Prod. Lab, Madison, Wis.

53. Norris, C. B. 1962. Strength of orthotropic materials subjected to combined stress. USDA Forest Service Report No. 1816. For. Prod. Lab, Madison, Wis.

54. Pagano, N. J. and J. C. Halpin. 1968. Influence of end constraint in the testing of anisotropic bodies. J. of Composite Materials 2(1):18-31.

55. Panshin, A. J. and C. D. Zeeuw. 1970. Textbook for Wood Technology. 3rd edition. vol. 1. McGraw-Hill Book Company, N.Y.

56. Perry, C. C. and H. R. Lissner. 1962. The Strain Gauge Primer. 2nd edition. McGraw-Hill Book Company, N.Y.

57. Popov, E. P. 1968. Introduction to Mechanic of Solids. Prentice-Hall, Inc., Englewood Cliffs, N.J.

58. Radcliffe, B. M. 1953. Shear deflection in timber beams and method for determination of shear moduli. Purdue Univ. Agr. Expt. Sta. Bul. 589.

59. ________. 1953. Proposed new methods for determination of the stiffness of timber beams and the strength of wood columns. Purdue Univ. Agr. Expt. Sta. Bul. 596.

60. Richards, G. L., T. P. Airhart and J. E. Ashton. 1969. Off-axis tensile coupon testing. J. of Composite Materials 3(3);586-589.

61. Rizzo, R. R. 1969. More on the influence of end constraints on off-axis tensile tests. J. of Composite Materials 3(2):202-219.

62. Schniewind, A. P. 1959. Transverse anisotropy of wood. For. Prod. J. 9(1):350-359.

63. Schuldt, J. P. 1972. Unified testing procedure for determining the elastic parameters of wood. Ph.D. Thesis. Colorado State University.

64. Sliker, A. 1967. Making bonded wire electrical resistance strain gauges for use on wood. For. Prod. J. 17(4):53-55.

65. ________. 1971. Resistance strain gauges and adhesives for wood. For. Prod. J. 21(12):40-43.

66. ________. 1972. Measuring Poisson's ratios in wood. Experimental Mechanics 12(5):239-242.

67. ________. 1973. Young's modulus parallel to the grain in wood as a function of strain rate, stress level and mode of loading. Wood and Fiber 4(4):325-333.

68. ________. 1975. Young's modulus of wood as affected by strain rate, grain angle, and stress level. Wood Sci. 7(3):223-231.

69. ________. 1978. Strain as a function of stress, stress rate and time at 90° to the grain in sugar pine. Wood Sci. 10(4):208-219.

70. Tang, R. C., S. F. Adams and R. E. Mark. 1971. Moduli of rigidity and torsional strength of scarlet oak related to moisture content. Wood Sci. 3(4):238-244.

71. Timber Engineering Company. 1956. Timber design and construction handbook.

72. Timoshenko, S. P. and J. N. Goodier. 1969. Theory of elasticity. McGraw-Hill Book Company, N.Y.

73. Tsai, S. W. 1965. Experimental determination of the elastic behavior of orthotropic plates. Journal of Engineering for Industry 87(3):315-318.

74. U.S. Forest Products Laboratory. 1974 wood handbook wood as an engineering material (USDA Agr. Handb. 72, rev.) Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

75. Vafai, A., M. Farshad, and A. Ahmadieh. 1976. Determination of modulus of elasticity of wood from vibration reed measurements. Fiber Sci. and Technology 9(1):1-10.

76. Walker, J. N. and A. C. Dale. 1963. Interpretation and measurement of strain in wood. Transactions of ASAE 6(1):68-72.

77. Wang, C. T. Sc.D. 1953. Applied elasticity. McGraw-Hill Book Company, N.Y.

78. Wen/Nuri, P. R. and N. Mohsenin. 1970. Application of pulse technique for determination of elastic modulus of yellow poplar. Material and Research and Standard, pp. 25-27.

79. Witt, R. K., W. H. Hoffman and R. S. Buxbaum. 1953. Determination of elastic constants of orthotropic materials with special reference to Laminates ASTM Bulletin 194:53-57.

80. Wu, E. M. and T. L. Rodvey. 1968. Off-axis test of a composite. J. of Composite Materials 2(4):523-526.

81. Young, R. L. 1957. The perpendicular-to-grain mechanical properties of red oak as related to temperature, moisture content and time. USDA Forest Service Report No. 2079. For. Prod. Lab, Madison, Wis.

APPENDICES

APPENDIX A

Table 26.--Poisson's Ratios Computed From Slope of Strain Perpendicular to Load as a Function of Strain Parallel to Load: $\varepsilon_{\perp} = \mu\,\varepsilon_{\parallel} + b$.

Species	Loading Time (minute)	Zero-degree Specimen $\mu=\mu^*_{LR}$	Standard Error	Average μ^*_{LR}	b	Standard Error	90-degree Specimen $\mu=\mu^*_{RL}$	Standard Error	Average μ^*_{RL}	b	Standard Error
Basswood	15	0.464	0.005		0.221	0.573	0.645×10^{-5}	0.297×10^{-6}		-6.72	0.471
	40	0.454	0.003	0.431	-3.36	0.321	0.247×10^{-4}	0.120×10^{-5}	0.00245	-3.99	0.404
	100	0.424	0.004		-1.04	0.479	0.693×10^{-5}	0.180×10^{-6}		-2.86	0.295
	240	0.384	0.005		-4.58	0.529	0.979×10^{-2}	0.010		-1.29	9.41
Yellow Poplar	15	0.395	0.004		0.855	0.468	0.029	0.001		-5.99	0.666
	40	0.424	0.003	0.396	-5.04	0.348	0.030	0.001	0.0295	-5.56	0.707
	100	0.402	0.003		0.766	0.353	0.029	0.001		-3.93	0.541
	240	0.361	0.005		1.00	0.523	0.030	0.0008		-1.02	0.640
Sugar Pine	15	0.624	0.004		-0.085	0.615	0.027	0.001		-2.60	0.697
	40	0.634	0.008	0.618	4.46	1.23	0.028	0.0005	0.0305	-1.21	0.334
	100	0.641	0.009		2.32	1.43	0.032	0.0001		-1.15	0.487
	240	0.571	0.003		-2.35	0.479	0.035	0.001		-2.48	0.947
Redwood	15	0.405	0.003		-1.80	0.436	0.063	0.0007		-1.61	0.218
	40	0.406	0.004	0.425	-3.46	0.551	0.063	0.001	0.0612	-1.07	0.37
	100	0.440	0.004		-1.20	0.526	0.063	0.001		2.65	0.48
	240	0.447	0.001		5.83	0.542	0.056	0.001		-1.04	0.416

*For Sugar Pine these are μ_{LT} and μ_{TL}.

Table 27.--Computed Values of Elastic Moduli of Basswood by Tension Test.

Angle of Load to Grain θ (degree)	E_L^* (Psi)						E_R^{**} (Psi)					
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation
0	1,660,000	1,650,000	1,570,000	1,620,000	1,625,000	40,400						
19.8	1,940,000	2,040,000	1,900,000	2,040,000	1,980,000	71,200	99,400	95,700	94,900	95,100	96,300	2,110
34.7	3,960,000	2,410,000	5,890,000	3,660,000	3,980,000	1,439,400	94,100	94,500	91,600	89,000	92,300	2,500
51.8	90,300	146,000	154,000	161,000	137,800	32,300	73,100	80,400	79,900	81,200	78,700	3,700
63.9	1,190,000	817,000	226,000	318,000	637,700	450,500	88,500	85,000	90,300	82,400	86,600	3,500
90							84,100	82,600	81,100	81,300	82,300	1,400

* Computed by equation 12 for off-angle specimens.

** Computed by equation 13 for off-angle specimens.

Table 28.--Computed Values of Elastic Moduli of Yellow Poplar by Tension Test.

Angle of Load to Grain θ (degree)	E_L^* (Psi)						E_R^{**} (Psi)					
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation
0	1,600,000	1,620,000	1,610,000	1,650,000	1,620,000	21,600						
18.4	1,570,000	1,640,000	1,700,000	1,450,000	1,590,000	107,400	131,000	124,000	128,000	125,000	127,000	3,200
36.6	770,000	791,000	803,000	778,000	785,500	14,500	180,000	177,000	174,000	177,000	177,000	2,400
52.1	1,240,000	977,000	3,460,000	974,000	1,663,000	1,204,600	201,000	203,000	193,000	189,000	196,500	6,600
65.6	519,000	596,000	521,000	680,000	579,000	76,300	150,000	150,000	143,000	150,000	148,000	3,500
90							166,000	161,000	168,000	119,000	153,500	23,200

* Computed by equation 12 for off-angle specimens.

** Computed by equation 13 for off-angle specimens.

Table 29.--Computed Values of Elastic Moduli of Sugar Pine by Tension Tests.

Angle of Load to Grain θ (degree)	E_L * (Psi)						E_T ** (Psi)					
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation
0	1,190,000	1,250,000	1,210,000	1,110,000	1,190,000	58,900						
26.1	690,000	457,000	510,000	504,000	540,000	102,600	68,800	58,300	62,100	64,500	63,400	4,400
32.4	515,000	478,000	470,000	288,000	437,700	101,700	65,800	64,800	64,100	59,100	63,500	3,000
50.9	5,710	5,290	5,130	39,100	13,800	16,900	11,600	10,900	10,500	44,700	19,400	16,800
65.4	160,000	1,120,000	2,670,000	1,030,000	1,495,000	785,200	85,300	85,400	84,000	81,000	83,900	2,051
90							80,400	84,000	77,500	83,200	81,000	2,900

* Computed by equation 12 for off-angle specimens.

** Computed by equation 13 for off-angle specimens.

Table 30.--Computed Values of Elastic Moduli of Redwood by Tension Tests.

Angle of Load to Grain θ (degree)	E_L* (Psi)						E_R** (Psi)					
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation
0	1,410,000	1,440,000	1,450,000	1,450,000	1,437,500	18,900						
32.9	969,000	984,000	860,000	1,080,000	973,000	90,101	172,000	168,000	165,000	160,000	166,300	5,100
47.7	33,700,000	6,170,000	3,380,000	3,750,000	8,829,000	16,580,000	169,000	167,000	171,000	171,000	169,500	1,900
62.6	497,000	498,000	679,000	438,000	528,000	104,501	189,000	188,000	183,000	172,000	183,000	7,800
90							156,000	153,000	150,000	150,000	152,200	2,900

* Computed by equation 12 for off-axis specimens.

** Computed by equation 13 for off-axis specimens.

Table 31.--Computed Values of Elastic Moduli of Basswood by Combining Off-axis Specimens.

Nominal Angle of Specimens (degree)	Modulus of Elasticity											
	E_L^* (Psi)						E_R^* (Psi)					
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation
0	1,660,000	1,650,000	1,570,000	1,620,000	1,625,000	40,400						
20-35	1,690,000	1,890,000	1,650,000	1,760,000	1,747,500	105,300	90,000	93,800	88,800	86,200	89,700	3,200
20-50	3,700,000	3,480,000	3,450,000	4,550,000	3,795,000	515,500	94,400	94,500	92,200	92,200	93,300	1,300
20-65	2,020,000	3,740,000	2,450,000	2,390,000	2,650,000	751,100	88,200	89,200	86,400	85,300	87,300	1,800
35-50	1,630,000	2,460,000	2,180,000	1,070,000	1,835,000	615,600	98,000	96,100	95,800	95,100	96,000	1,200
35-65	4,730,000	1,590,000	2,220,000	2,420,000	2,740,000	1,373,000	88,700	88,800	87,800	85,200	87,600	1,700
50-65	183,000	336,000	240,000	313,000	268,000	69,900	85,000	85,900	83,300	81,500	83,900	1,900
90							84,100	82,600	81,100	81,300	82,300	1,400

* These values of elastic moduli were computed by Equation 14.

Table 32.--Computed Values of Elastic Moduli of Yellow Poplar by Combining Off-axis Specimens.

Nominal Angle of Specimens (degree)	Modulus of Elasticity											
	E_L^* (Psi)						E_R^* (Psi)					
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation
0	1,600,000	1,620,000	1,610,000	1,650,000	1,620,000	21,600						
20-35	1,920,000	2,040,000	2,130,000	1,730,000	1,955,000	172,900	226,000	229,000	215,000	223,000	223,000	6,000
20-50	1,480,000	1,530,000	1,620,000	1,350,000	1,495,000	112,700	194,000	194,000	190,000	182,000	190,000	57,000
20-65	1,500,000	1,550,000	1,610,000	1,420,000	1,520,000	80,400	153,000	154,000	146,000	153,000	151,500	3,700
35-50	628,000	617,000	669,000	587,000	625,000	33,900	184,000	183,000	181,000	170,000	179,500	6,400
35-65	758,000	758,000	765,000	784,000	766,000	12,300	148,000	149,000	142,000	148,000	147,000	3,200
50-65	1,800,000	2,140,000	1,280,000	2,510,000	1,932,500	522,800	139,000	140,000	132,000	142,000	138,000	4,400
90							166,000	161,000	168,000	119,000	153,500	23,200

* These values of elastic moduli were computed by Equation 14.

Table 33.--Computed Values of Elastic Moduli of Sugar Pine by Combining Off-axis Specimens.

Nominal Angle of Specimens (degree)	Modulus of Elasticity											
	E_L^* (Psi)						E_T^* (Psi)					
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation
0	1,190,000	1,250,000	1,210,000	1,110,000	1,190,000	58,900						
20-35	1,070,000	458,000	560,000	1,080,000	792,000	329,400	70,300	74,900	71,100	70,000	71,600	2,300
20-50	1,510,000	982,000	800,000	738,000	1,007,500	350,600	80,700	81,500	81,000	71,600	78,700	4,700
20-65	647,000	530,000	552,000	545,000	568,500	53,100	86,700	87,500	84,900	82,000	85,300	2,400
35-50	4,940,000	303,000	1,790,000	363,000	1,849,000	2,172,200	82,600	82,200	79,800	77,400	80,500	2,400
35-65	573,000	528,000	575,000	305,000	495,000	128,700	87,400	87,900	81,500	82,500	84,800	3,300
50-65	117,000	114,000	159,000	177,000	141,800	31,200	89,200	90,100	86,500	84,600	87,600	2,500
90							80,400	84,000	77,500	83,200	81,000	3,000

* These values of elastic moduli were computed by Equation 14.

Table 34.--Computed Values of Elastic Moduli of Redwood by Combining Off-axis Specimens.

Nominal Angle of Specimens (degree)	Modulus of Elasticity											
	E_L^* (Psi)						E_R^* (Psi)					
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation
0	1,410,000	1,440,000	1,450,000	1,450,000	1,437,500	18,900						
35-50	606,000	688,000	659,000	682,000	658,800	37,300	147,000	152,000	152,000	154,000	151,300	3,000
35-65	879,000	900,000	82,000	872,000	867,800	3,400	196,000	196,000	187,000	182,000	190,300	7,000
50-65	3,760,000	1,970,000	2,760,000	1,500,000	2,497,500	989,300	219,000	219,000	206,000	203,000	211,800	8,400
90							156,000	153,000	150,000	150,000	152,200	2,900

* These values of elastic moduli were computed by Equation 14.

Table 35.--E_θ Computed by Hankinson Formula and Directly from Off-axis Specimens.

Species	Angle of Inclination θ degree	Psi E_θ (calculated directly from off-axis specimens)						Psi E_θ (calculated by Hankinson's formula)					
		15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	Average	Standard Deviation
Basswood	19.80	653,600	649,400	625,000	632,900	640,225	13,521	527,000	519,300	505,400	510,800	515,625	9,499
	34.65	285,700	284,900	280,100	277,000	281,925	4,110	235,200	231,300	226,400	227,600	230,125	3,974
	51.76	133,000	139,300	134,400	132,100	134,700	3,209	132,200	130,000	127,400	127,800	129,350	2,217
	63.91	112,200	109,300	109.800	109,000	110,075	1,454	103,000	101,200	99,300	99,600	100,775	1,701
Yellow Poplar	18.43	769,200	775,200	781,250	741,000	766,662	17,801	858,600	850,000	86,700	721,800	629,275	367,086
	36.57	393,700	395,300	386,100	384,600	389,925	5,358	393,500	384,200	397,800	296,400	367,975	48,053
	52.08	287,400	286,500	275,500	278,600	282,000	5,865	251,000	250,000	253,900	183,200	234,525	34,256
	65.55	189,800	190,100	182,500	187,600	187,500	3,514	196,100	190,400	198,500	141,500	181,625	26,964
Sugar Pine	26.12	537,600	487,800	507,600	478,500	502,875	26,137	323,800	338,700	315,700	327,200	326,350	9,542
	32.38	272,500	268,800	268,100	223,200	258,150	23,379	240,000	251,000	233,100	244,500	242,150	7,535
	50.96	117,200	113,900	123,500	125,800	120,100	5,504	127,600	133,300	123,300	131,400	128,900	4,421
	65.43	109,400	110,200	105,600	104,000	107,300	2,977	95,800	100,200	92,500	99,000	96,875	3,457
Redwood	32.91	401,600	400,000	393,700	392,200	396,875	4,619	418,000	413,400	407,500	407,500	411,600	5,093
	47.72	276,300	275,500	278,600	276,200	276,650	1,347	261,100	25,700	252,400	252,400	197,900	114,873
	62.62	238,700	238,100	228,800	230,400	234,000	5,128	192,100	188,700	185,100	185,100	187,750	3,360

Table 36.--Computed Poisson's Ratios for Basswood by Combining Off-axis Test Equation 16.

Nominal Angle of Specimens (degree)	Poisson's Ratios							
	μ_{LR}				μ_{RL}			
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading
20-35	0.666	0.495	0.542	0.614	0.073	0.044	0.071	0.058
20-50	1.130	0.835	0.901	1.094	-0.169	-0.133	-0.154	-0.176
20-65	0.812	1.239	0.880	0.871	0.010	-0.144	-0.053	-0.039
35-50	0.095	-0.365	0.206	0.186	-0.128	-0.128	-0.111	-0.210
35-65	2.247	-0.848	-0.865	-0.667	-0.001	-0.161	-0.116	-0.047
50-65	0.396	-0.720	0.514	0.824	0.102	-0.174	-0.00051	-0.013

Table 37.--Computed Poisson's Ratios for Yellow Poplar by Combining Off-axis Test Equation 16.

Nominal Angle of Specimens (degree)	Poisson's Ratios							
	μ_{LR}				μ_{RL}			
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading
20-35	-0.186	-0.299	-0.243	-0.240	-0.179	-0.192	-0.186	-0.170
20-50	-0.026	-0.088	-0.073	-0.037	0.115	0.122	-0.088	0.127
20-65	0.209	0.142	0.203	0.125	0.082	0.082	0.076	0.060
35-50	0.284	0.288	0.242	0.371	0.212	0.222	0.182	0.218
35-65	0.899	0.872	0.915	0.864	0.098	0.099	0.093	0.075
50-65	6.126	6.951	4.815	-6.044	0.070	0.067	0.072	0.034

Table 38.--Computed Poisson's Ratios for Sugar Pine by Combining Off-axis Test Equation 16.

Nominal Angle of Specimens (degree)	Poisson's Ratios							
	μ_{LT}				μ_{TL}			
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading
20-35	0.940	0.241	0.433	1.020	-0.113	0.110	0.041	-0.317
20-50	0.768	0.241	0.267	0.637	-0.244	-0.236	-0.150	-0.093
20-65	0.195	0.024	0.108	0.347	0.059	0.064	0.042	0.064
35-50	0.353	0.235	-0.147	0.191	-0.281	-0.281	-0.211	-0.028
35-65	-0.106	-0.122	0.011	0.061	0.063	0.064	0.042	0.087
50-65	-0.150	-0.175	-0.137	-0.205	0.191	0.194	0.123	0.131

Table 39.--Computed Poisson's Ratios for Redwood by Combining Off-axis Test Equation 16.

Nominal Angle of Specimens (degree)	Poisson's Ratios							
	μ_{LR}				μ_{RL}			
	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading	15 Minutes Loading	40 Minutes Loading	100 Minutes Loading	240 Minutes Loading
35-50	0.563	0.546	0.519	0.441	0.236	0.195	0.221	0.212
35-65	0.120	0.088	0.204	0.116	0.118	0.117	0.113	0.149
50-65	-6.511	-3.238	-3.476	-1.835	0.095	0.103	0.087	0.142

APPENDIX B

LIST OF RAW DATA

LIST OF RAW DATA OF ZERO-DEGREE SPECIMEN(BASSWOOD)

σ	$d\sigma/dt$	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	$\varepsilon 45$	$\frac{d\varepsilon 45}{dt}$	card control
15 MINUTES LOADING									
31.17	20.58	1.50	18	12.00	-9	-4.66	7	4.66	15B03-17-78
46.35	19.97	2.25	27	12.66	-12	-5.33	11	4.66	15B03-17-78
61.12	19.90	3.00	37	13.33	-17	-5.33	14	4.00	15B03-17-78
76.20	20.10	3.75	47	11.33	-20	-4.00	17	4.66	15B03-17-78
91.28	19.90	4.50	54	11.33	-26	-6.00	21	4.66	15B03-17-78
106.05	19.82	5.25	64	13.33	-29	-4.66	24	3.33	15B03-17-78
121.02	19.96	6.00	74	12.66	-33	-6.66	26	3.33	15B03-17-78
136.00	19.90	6.75	83	10.66	-37	-7.33	29	6.00	15B03-17-78
150.87	19.76	7.50	90	10.66	-44	-6.00	34	6.66	15B03-17-78
165.64	19.62	8.25	99	12.66	-46	-4.00	38	4.00	15B03-17-78
180.30	20.10	9.00	109	11.33	-50	-5.33	40	4.00	15B03-17-78
195.79	19.76	9.75	116	11.33	-54	-5.33	44	5.33	15B03-17-78
209.94	19.55	10.50	126	12.00	-58	-5.33	48	4.00	15B03-17-78
225.12	19.83	11.25	134	12.00	-62	-6.66	50	2.66	15B03-17-78
239.69	19.69	12.00	144	13.33	-68	-6.66	52	4.00	15B03-17-78
254.66	19.82	12.75	154	12.00	-72	-4.00	56	5.33	15B03-17-78
269.43	19.83	13.50	162	12.00	-74	-4.00	60	5.33	15B03-17-78
284.41	19.82	14.25	172	12.00	-78	-6.66	64	5.33	15B03-17-78
299.17	19.82	15.00	180	12.00	-84	-6.66	68	5.33	15B03-17-78
40 MINUTES LOADING									
24.30	6.10	4.00	14	3.25	-9	-1.75	4	1.00	40B03-9-78
36.61	6.02	6.00	20	3.25	-12	-1.75	7	1.25	40B03-9-78
48.41	6.00	8.00	27	3.75	-16	-2.00	9	1.25	40B03-9-78
60.61	6.10	10.00	35	3.50	-20	-1.50	12	1.25	40B03-9-78
72.82	6.05	12.00	41	3.75	-22	-1.50	14	1.25	40B03-9-78
84.82	6.02	14.00	50	4.00	-26	-2.00	17	1.25	40B03-9-78
96.92	6.02	16.00	57	3.50	-30	-1.50	19	1.00	40B03-9-78
108.92	6.02	18.00	64	3.75	-32	-1.50	21	1.25	40B03-9-78
121.02	6.02	20.00	72	3.50	-36	-2.00	24	1.50	40B03-9-78
133.02	6.05	22.00	78	3.25	-40	-1.50	27	1.50	40B03-9-78
145.23	6.02	24.00	85	3.75	-42	-1.50	30	1.50	40B03-9-78
157.12	6.05	26.00	93	3.75	-46	-1.50	33	1.25	40B03-9-78
169.43	6.05	28.00	100	3.75	-48	-1.50	35	1.25	40B03-9-78
181.33	5.95	30.00	108	3.50	-52	-1.75	38	1.25	40B03-9-78
193.23	6.07	32.00	114	3.50	-55	-1.50	40	1.50	40B03-9-78
205.64	6.07	34.00	122	4.00	-58	-1.75	44	1.50	40B03-9-78
217.53	6.05	36.00	130	4.00	-62	-2.00	46	1.00	40B03-9-78
229.84	6.05	38.00	138	3.50	-66	-2.00	48	1.00	40B03-9-78
241.74	6.05	40.00	144	3.50	-70	-2.00	50	1.00	40B03-9-78
100 MINUTES LOADING									
29.43	2.96	10.00	19	1.80	-9	-0.70	6	0.60	100B03-25-78
44.30	2.92	15.00	27	1.80	-12	-0.90	10	0.80	100B03-25-78
56.66	2.94	20.00	37	1.60	-18	-0.80	14	0.70	100B03-25-78
73.74	2.97	25.00	43	1.50	-20	-0.60	17	0.60	100B03-25-78
88.41	2.89	30.00	52	2.00	-24	-0.80	20	0.70	100B03-25-78
102.66	2.87	35.00	63	2.00	-28	-0.80	24	0.70	100B03-25-78
117.12	2.90	40.00	72	1.90	-32	-0.70	27	0.60	100B03-25-78
131.69	2.92	45.00	82	1.90	-35	-0.80	30	0.70	100B03-25-78
146.35	2.90	50.00	91	1.90	-40	-0.80	34	0.70	100B03-25-78
160.71	2.86	55.00	101	1.90	-43	-0.70	37	0.60	100B03-25-78
174.97	2.87	60.00	110	1.70	-47	-0.70	40	0.70	100B03-25-78
189.43	2.92	65.00	118	1.60	-50	-0.70	44	0.80	100B03-25-78
204.20	2.91	70.00	126	2.00	-54	-0.80	48	0.80	100B03-25-78
218.56	2.85	75.00	138	2.00	-58	-0.80	52	0.60	100B03-25-78
232.71	2.89	80.00	146	1.80	-62	-1.00	54	0.40	100B03-25-78
247.48	2.91	85.00	156	1.80	-68	-1.00	56	0.60	100B03-25-78
261.84	2.87	90.00	164	1.80	-72	-0.80	60	0.80	100B03-25-78
276.20	2.87	95.00	174	2.00	-76	-0.80	64	0.80	100B03-25-78
290.56	2.87	100.00	184	2.00	-80	- .80	68	0.80	100B03-25-78
240 MINUTES LOADING									
25.84	1.06	24.00	17	0.58	-10	-0.29	4	0.25	240B02-27-78
38.56	1.07	36.00	22	0.62	-13	-0.33	7	0.25	240B02-27-78
51.69	1.08	48.00	32	0.75	-18	-0.29	10	0.25	240B02-27-78
64.51	1.06	60.00	40	0.62	-20	-0.16	13	0.25	240B02-27-78
77.33	1.06	72.00	47	0.54	-22	-0.12	16	0.25	240B02-27-78
90.05	1.05	84.00	53	0.66	-23	-0.29	19	0.29	240B02-27-78
102.66	1.05	96.00	63	0.75	-29	-0.37	23	0.16	240B02-27-78
115.38	1.07	108.00	71	0.50	-32	-0.25	23	0.16	240B02-27-78
128.51	1.06	120.00	75	0.58	-35	-0.25	27	0.29	240B02-27-78
140.82	1.03	132.00	85	0.79	-38	-0.33	30	0.12	240B02-27-78
153.43	1.05	144.00	94	0.70	-43	-0.25	35	0.33	240B02-27-78
166.05	1.04	156.00	102	0.62	-44	-0.16	38	0.25	240B02-27-78
178.56	1.03	168.00	109	0.66	-47	-0.20	41	0.29	240B02-27-78
190.97	1.04	180.00	118	0.70	-49	-0.20	45	0.29	240B02-27-78
203.58	1.04	192.00	126	0.66	-52	-0.29	48	0.29	240B02-27-78
216.10	1.05	204.00	134	0.58	-56	-0.25	52	0.25	240B02-27-78
228.82	1.05	216.00	140	0.58	-58	-0.25	54	0.16	240B02-27-78
241.33	1.04	228.00	148	0.66	-62	-0.25	60	0.25	240B02-27-78
253.84	1.04	240.00	156	0.66	-64	-0.25	60	0.25	240B02-27-78

LIST OF RAW DATA OF 20-DEGREE SPECIMEN (BASSWOOD)

σ	dσ/dt	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε_{45}	$\frac{d\varepsilon_{45}}{dt}$	card control
15 MINUTES LOADING									
30.00	20.26	1.50	46	30.66	-6	-2.66	64	42.00	15B203-17-78
45.40	20.06	2.25	69	30.66	-8	-3.33	96	42.00	15B203-17-78
60.10	19.93	3.00	92	31.33	-11	-3.33	127	42.00	15B203-17-78
75.30	20.47	3.75	116	30.00	-13	-3.33	159	42.00	15B203-17-78
90.81	20.14	4.50	137	30.00	-16	-3.33	190	41.33	15B203-17-78
105.51	19.86	5.25	161	30.66	-18	-3.33	221	42.00	15B203-17-78
120.61	20.00	6.00	183	30.00	-21	-3.33	253	42.00	15B203-17-78
135.51	19.93	6.75	206	30.66	-23	-3.33	284	41.33	15B203-17-78
150.51	20.06	7.50	229	31.33	-26	-4.00	315	42.00	15B203-17-78
165.61	19.79	8.25	253	30.00	-29	-2.66	347	41.33	15B203-17-78
180.20	19.79	9.00	274	30.00	-30	-2.66	377	41.33	15B203-17-78
195.30	20.61	9.75	298	32.00	-33	-2.00	409	43.33	15B203-17-78
211.12	19.93	10.50	322	30.65	-36	-3.33	442	42.00	15B203-17-78
225.20	19.45	11.25	344	30.66	-38	-2.66	472	41.33	15B203-17-78
240.30	20.13	12.00	368	30.66	-40	-2.66	504	44.00	15B203-17-78
255.40	20.14	12.75	390	30.66	-42	-2.66	538	44.00	15B203-17-78
270.51	20.54	13.50	414	32.00	-44	-2.66	570	45.33	15B203-17-78
286.22	20.00	14.25	438	30.66	-46	-2.66	606	45.33	15B203-17-78
300.51	20.00	15.00	460	30.66	-48	-2.66	638	45.33	15B203-17-78
40 MINUTES LOADING									
30.10	7.50	4.00	44	11.25	-6	-1.00	64	16.00	40B203-9-78
45.00	7.52	6.00	68	11.50	-8	-1.00	96	16.00	40B203-9-78
60.20	7.55	8.00	90	11.50	-10	-0.75	128	16.25	40B203-9-78
75.20	7.52	10.00	114	11.75	-11	-0.75	161	16.50	40B203-9-78
90.30	7.57	12.00	137	11.50	-13	-1.00	194	16.25	40B203-9-78
105.51	7.55	14.00	160	11.50	-15	-1.00	226	16.25	40B203-9-78
120.51	7.47	16.00	183	11.50	-17	-0.75	259	16.25	40B203-9-78
135.40	7.50	18.00	206	11.50	-18	-0.75	291	16.25	40B203-9-78
150.51	7.55	20.00	229	11.50	-20	-1.00	324	16.25	40B203-9-78
165.61	7.52	22.00	252	11.50	-22	-1.00	356	16.25	40B203-9-78
180.61	7.50	24.00	275	12.00	-24	-0.50	389	16.50	40B203-9-78
195.61	7.50	26.00	300	11.75	-24	-1.00	422	16.25	40B203-9-78
210.61	7.52	28.00	322	11.50	-28	-1.50	454	16.50	40B203-9-78
225.71	7.50	30.00	346	11.50	-30	-1.00	488	17.00	40B203-9-78
240.61	7.55	32.00	368	11.50	-32	-1.00	522	16.50	40B203-9-78
255.91	7.50	34.00	392	11.50	-34	-1.00	554	16.50	40B203-9-78
270.61	7.45	36.00	414	11.50	-36	-1.00	588	17.00	40B203-9-78
285.71	7.50	38.00	438	12.00	-38	-1.00	622	17.00	40B203-9-78
300.61	7.50	40.00	462	12.00	-40	-1.00	656	17.00	40B203-9-78
100 MINUTES LOADING									
28.57	2.91	10.00	41	4.20	-2	-0.50	61	6.20	100B203-25-78
43.26	2.84	15.00	64	4.50	-5	-0.40	92	6.30	100B203-25-78
57.04	2.80	20.00	86	4.40	-6	-0.30	124	6.40	100B203-25-78
71.32	2.84	25.00	108	4.60	-8	-0.60	156	6.20	100B203-25-78
85.51	2.83	30.00	132	4.60	-12	-0.50	186	6.20	100B203-25-78
99.69	2.86	35.00	154	4.20	-13	-0.20	218	6.20	100B203-25-78
114.18	2.97	40.00	174	4.80	-14	-0.30	248	6.40	100B203-25-78
125.48	2.80	45.00	202	4.70	-16	-0.40	282	6.30	100B203-25-78
142.24	2.68	50.00	221	4.30	-18	-0.30	311	6.00	100B203-25-78
156.32	2.81	55.00	245	4.50	-19	-0.30	342	6.20	100B203-25-78
170.40	2.82	60.00	266	4.50	-21	-0.50	373	6.20	100B203-25-78
184.59	2.89	65.00	290	4.60	-24	-0.50	404	6.30	100B203-25-78
199.38	2.86	70.00	312	4.60	-26	-0.30	436	6.40	100B203-25-78
213.26	2.77	75.00	336	4.40	-27	-0.40	468	6.40	100B203-25-78
227.14	2.79	80.00	356	4.40	-30	-0.60	500	6.60	100B203-25-78
241.22	2.83	85.00	380	4.40	-34	-0.60	534	6.80	100B203-25-78
255.51	2.81	90.00	400	4.60	-36	-0.40	568	6.60	100B203-25-78
269.38	2.75	95.00	426	4.80	-38	-0.40	600	5.60	100B203-25-78
283.06	2.75	100.00	448	4.80	-40	-0.40	624	5.60	100B203-25-78
240 MINUTES LOADING									
25.10	1.05	24.00	37	1.62	-5	-0.12	53	2.29	240B202-27-78
37.65	1.05	36.00	58	1.58	-6	-0.08	81	2.33	240B202-27-78
50.40	1.04	48.00	75	1.58	-7	-0.16	109	2.29	240B202-27-78
62.65	1.03	60.00	96	1.62	-10	-0.08	136	2.29	240B202-27-78
75.30	1.04	72.00	114	1.62	-9	-0.04	164	2.33	240B202-27-78
87.65	1.02	84.00	135	1.75	-11	-0.12	192	2.33	240B202-27-78
99.89	1.03	96.00	156	1.70	-12	-0.12	220	2.29	240B202-27-78
112.55	1.05	108.00	176	1.62	-14	-0.20	247	2.29	240B202-27-78
125.30	1.05	120.00	195	1.58	-17	-0.12	275	2.33	240B202-27-78
137.95	1.05	132.00	214	1.70	-17	-0.12	303	2.41	240B202-27-78
150.71	1.05	144.00	236	1.54	-20	-0.20	333	2.50	240B202-27-78
163.36	1.06	156.00	251	1.79	-22	-0.08	363	2.41	240B202-27-78
176.32	1.06	168.00	279	1.87	-22	-0.12	391	2.33	240B202-27-78
188.97	1.05	180.00	296	1.45	-25	-0.25	419	2.29	240B202-27-78
201.53	1.06	192.00	314	1.66	-28	-0.12	446	2.37	240B202-27-78
214.48	1.04	204.00	336	1.66	-28	-0.08	476	2.41	240B202-27-78
226.53	1.01	216.00	354	1.58	-30	-0.08	504	2.41	240B202-27-78
238.57	1.01	228.00	374	1.58	-30	-0.16	534	2.41	240B202-27-78
250.80	1.01	240.00	392	1.58	-34	-0.16	562	2.41	240B202-27-78

LIST OF RAW DATA OF35-DEGREE SPECIMEN(BASSWOOD)

σ	$d\sigma/dt$	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	$\varepsilon 45$	$\frac{d\varepsilon 45}{dt}$	card control
15 MINUTES LOADING									
32.98	15.36	2.14	110	53.27	-3		128	59.81	15B353-26-78
49.38	15.36	3.21	169	54.20	-3	-0.46	193	60.74	15B353-26-78
65.87	15.27	4.28	226	52.80	-4	-0.46	258	61.21	15B353-26-78
82.06	15.31	5.35	282	52.80	-4	-0.46	324	62.14	15B353-26-78
98.65	15.41	6.42	339	53.73	-5	-0.46	391	62.61	15B353-26-78
115.05	15.41	7.5	397	54.20	-5		458	63.08	15B353-26-78
131.64	15.21	8.57	455	54.20	-5		525	63.55	15B353-26-78
147.62	15.17	9.64	513	53.27	-5		593	63.55	15B353-26-78
164.12	15.46	10.71	569	53.27	-5		661	64.01	15B353-26-78
180.72	15.22	11.78	627	54.20	-5	0.46	729	66.82	15B353-26-78
196.70	15.50	12.85	685	54.67	-4	-0.46	798	68.22	15B353-26-78
213.91	15.56	13.92	744	53.73	-6	-0.93	872	68.22	15B353-26-78
230.00	15.56	15.00	800	53.73	-6	-0.93	944	68.22	15B353-26-78
40 MINUTES LOADING									
25.36	4.35	5.71	83	14.71	-3	-0.17	99	17.33	40B353-1-78
37.73	4.42	8.57	127	15.58	-4	-0.17	149	17.51	40B353-1-78
50.61	4.47	11.42	172	15.58	-4	0.17	199	17.51	40B353-1-78
63.29	4.33	14.28	216	15.23	-3		249	17.68	40B353-1-78
75.36	4.24	17.14	259	14.88	-4	-0.17	300	17.51	40B353-1-78
87.52	4.29	20.00	301	14.71	-4		349	17.16	40B353-1-78
99.89	4.26	22.85	343	15.06	-3		398	17.33	40B353-1-78
111.85	4.24	25.71	387	15.06	-4	0.17	448	17.51	40B353-1-78
124.12	4.29	28.57	429	15.06	-3		498	17.51	40B353-1-78
136.39	4.35	31.42	473	15.23	-3		548	17.68	40B353-1-78
148.96	4.29	34.28	516	15.23	-3		599	17.51	40B353-1-78
160.92	4.26	37.14	560	15.23	-3		648	17.33	40B353-1-78
173.29	4.26	40.00	603	15.23	-3		698	17.33	40B353-1-78
100 MINUTES LOADING									
31.44	2.20	14.28	111	7.70	-4	-0.14	120	8.68	100B353-18-78
47.11	2.08	21.42	166	7.42	-5		182	8.40	100B353-18-78
61.23	1.99	28.57	217	7.14	-4	0.07	240	8.26	100B353-18-78
75.56	2.01	35.71	268	7.07	-4	0.07	300	8.33	100B353-18-78
90.00	2.00	42.85	318	7.07	-5		359	8.33	100B353-18-78
104.12	1.99	50.00	369	7.14	-4	0.07	419	8.54	100B353-18-78
118.45	2.00	57.14	420	7.14	-4		481	8.61	100B353-18-78
132.68	2.00	64.28	471	7.14	-4	0.07	542	8.54	100B353-18-78
147.01	1.99	71.42	522	7.07	-3	0.07	603	8.61	100B353-18-78
161.13	1.99	78.57	572	7.21	-3	0.07	665	8.89	100B353-18-78
175.46	1.96	85.71	625	7.21	-2	0.07	730	8.75	100B353-18-78
189.17	1.98	92.85	675	7.07	-2	0.14	790	8.68	100B353-18-78
203.71	1.98	100.00	726	7.07		0.14	854	8.68	100B353-18-78
240 MINUTES LOADING									
25.56	0.73	34.28	87	2.50		0.08	95	3.15	240B353-8-78
38.04	0.73	51.42	134	2.68		0.08	154	3.20	240B353-8-78
50.72	0.63	68.57	179	2.24	3	0.11	209	2.74	240B353-8-78
59.69	0.73	85.71	211	2.65	4	0.05	248	3.17	240B353-8-78
75.97	0.84	102.85	270	3.00	5	0.02	318	3.61	240B353-8-78
88.65	0.74	120.00	314	2.62	5	0.05	372	3.15	240B353-8-78
101.34	0.73	137.14	360	2.65	7	0.11	426	3.17	240B353-8-78
113.60	0.72	154.28	405	2.62	9	0.08	481	3.20	240B353-8-78
126.08	0.73	171.42	450	2.62	10		536	3.17	240B353-8-78
138.65	0.73	188.57	495	2.65	9	0.05	590	3.15	240B353-8-78
151.03	0.72	205.71	541	2.65	12	0.14	644	3.15	240B353-8-78
163.40	0.72	222.85	586	2.59	14	0.05	698	3.17	240B353-8-78
175.77	0.72	240.00	630	2.59	14	0.05	753	3.17	240B353-8-78

LIST OF RAW DATA OF 50-DEGREE SPECIMEN(BASSWOOD)

σ	dσ/dt	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε45	$\frac{d\varepsilon 45}{dt}$	card control
15 MINUTES LOADING									
15.33	10.29	1.50	107	70.00	2	2.00	84	56.66	15B503-26-78
23.31	10.50	2.25	158	68.00	3	1.33	127	56.66	15B503-26-78
31.08	10.29	3.00	209	66.00	4	0.66	169	56.66	15B503-26-78
38.75	10.16	3.75	257	64.66	4		212	56.66	15B503-26-78
46.32	10.29	4.50	306	65.33	4	0.66	254	56.66	15B503-26-78
54.19	10.36	5.25	355	66.00	5	2.00	297	58.00	15B503-26-78
61.86	10.29	6.00	405	66.00	7	2.66	341	58.00	15B503-26-78
69.63	10.15	6.75	454	67.33	9	2.00	384	58.00	15B503-26-78
77.09	10.16	7.50	506	68.66	10	1.33	428	57.33	15B503-26-78
84.87	10.29	8.25	557	73.33	11	0.66	470	58.00	15B503-26-78
92.53	10.36	9.00	616	82.66	11	0.66	515	58.66	15B503-26-78
100.41	10.16	9.75	681	88.00	12	2.66	558	58.00	15B503-26-78
107.77	10.22	10.50	748	85.33	15	2.66	602	58.66	15B503-26-78
115.75	10.29	11.25	809	85.00	16	2.00	646	57.33	15B503-26-78
123.21	10.08	12.00	877	86.00	18	2.00	688	58.00	15B503-26-78
130.88	10.15	12.75	953	95.33	19	2.00	733	53.33	15B503-26-78
138.44	10.22	13.50	1020	88.00	21	4.00	768	58.66	15B503-26-78
146.21	10.22	14.25	1085	88.00	25	3.33	821	64.66	15B503-26-78
153.76	10.22	15.00	1152	88.00	26	3.33	865	64.66	15B503-26-78
40 MINUTES LOADING									
14.81	3.62	4.00	101	24.00	3	0.75	83	20.00	40B503-10-78
21.76	3.49	6.00	146	21.75	5	0.50	121	19.00	40B503-10-78
28.80	3.44	8.00	188	23.00	5		159	19.25	40B503-10-78
35.54	3.36	10.00	238	24.75	5	0.50	198	19.25	40B503-10-78
42.27	3.39	12.00	287	24.75	7	1.00	236	19.00	40B503-10-78
49.11	3.29	14.00	337	25.50	9	1.00	274	19.00	40B503-10-78
55.44	3.31	16.00	385	25.75	11	0.75	312	19.00	40B503-10-78
62.38	3.44	18.00	440	23.50	12	0.50	350	19.25	40B503-10-78
69.22	3.31	20.00	483	21.75	13	0.75	389	19.00	40B503-10-78
75.64	3.31	22.00	527	21.50	15	0.75	426	18.75	40B503-10-78
82.48	3.42	24.00	569	20.50	16	0.75	464	18.75	40B503-10-78
89.32	3.39	26.00	609	20.50	18	1.00	503	19.50	40B503-10-78
96.06	3.34	28.00	651	22.25	20	1.00	542	19.50	40B503-10-78
36.02	3.52	10.00	321	33.50	4	0.75	238	24.25	40B653-10-78
102.69	3.39	30.00	698	24.25	22	1.25	581	19.25	40B503-10-78
109.63	3.31	32.00	748	29.00	25	1.25	619	19.25	40B503-10-78
115.95	3.24	34.00	814	31.50	27	1.00	658	19.25	40B503-10-78
122.59	3.37	36.00	874	29.25	29	1.50	696	19.25	40B503-10-78
129.43	3.41	38.00	931	29.50	33	1.75	735	19.25	40B503-10-78
136.26	3.41	40.00	592	29.50	36	1.75	773	19.25	40B503-10-78
100 MINUTES LOADING									
16.78	1.50	10.00	119	10.80	-1	0.10	92	8.40	100503-18-78
23.73	1.39	15.00	170	9.80	1	0.20	133	8.00	100503-18-78
30.77	1.37	20.00	217	9.30	3	0.30	172	7.80	100503-18-78
37.51	1.36	25.00	263	9.20	4	0.10	211	7.90	100503-18-78
44.45	1.38	30.00	309	9.00	4	0.10	251	7.90	100503-18-78
51.39	1.37	35.00	353	8.70	5	0.20	290	7.90	100503-18-78
58.23	1.36	40.00	396	8.60	6	0.40	330	8.10	100503-18-78
65.07	1.36	45.00	439	8.80	9	0.60	371	8.10	100503-18-78
71.91	1.37	50.00	484	8.80	12	0.50	411	7.90	100503-18-78
78.86	1.35	55.00	527	9.50	14	0.30	450	7.90	100503-18-78
85.49	1.33	60.00	579	10.50	15	0.50	490	7.90	100503-18-78
92.22	1.34	65.00	632	10.80	19	0.60	529	7.80	100503-18-78
98.96	1.35	70.00	687	11.70	21	0.50	568	7.90	100503-18-78
105.80	1.32	75.00	749	12.50	24	0.70	608	8.00	100503-18-78
112.22	1.32	80.00	812	12.60	28	0.70	648	8.00	100503-18-78
118.96	1.35	85.00	875	11.90	31	0.70	688	7.90	100503-18-78
125.80	1.33	90.00	931	10.50	35	0.80	727	7.80	100B50-10-78
132.33	1.31	95.00	980	9.90	39	0.60	766	8.00	100B-3-10-76
138.86	1.31	100.00	1030	9.90	41	0.60	807	8.00	100B-3-10-78
240 MINUTES LOADING									
14.50	0.60	24.00	100	4.25	3	0.08	81	3.41	240B503-2-78
21.86	0.60	36.00	150	4.16	3		122	3.41	240B503-2-78
28.91	0.58	48.00	200	4.33	3		163	3.41	240B503-2-78
35.95	0.58	60.00	254	4.37	3	0.04	204	3.45	240B503-2-78
42.90	0.58	72.00	305	4.33	4	0.04	246	3.45	240B503-2-78
49.84	0.57	84.00	358	4.33	4	0.25	287	3.37	240B503-2-78
56.68	0.57	96.00	409	4.00	10	0.29	327	3.25	240B503-2-78
63.41	0.56	108.00	454	3.62	11	0.12	365	3.20	240B503-2-78
70.05	0.55	120.00	496	3.58	13	0.25	404	3.25	240B503-2-78
76.58	0.57	132.00	540	4.25	17	0.25	443	3.37	240B503-2-78
83.73	0.55	144.00	598	4.45	19	0.37	485	3.12	240B503-2-78
89.74	0.51	156.00	647	4.62	26	0.66	518	2.91	240B503-2-78
95.95	0.52	168.00	709	5.12	35	0.37	555	3.00	240B503-2-78
102.27	0.52	180.00	770	4.50	35	0.04	590	3.08	240B503-2-78
108.49	0.52	192.00	817	3.45	36	0.12	629	3.16	240B503-2-78
114.71	0.52	204.00	853	3.16	38	0.16	666	3.00	240B503-2-78
120.93	0.52	216.00	893	3.62	40	0.29	701	3.04	240B503-2-78
127.15	0.51	228.00	940	4.08	45	0.45	739	3.08	240B503-2-78
133.05	0.51	240.00	991	4.08	51	0.45	775	3.08	240B503-2-78

LIST OF RAW DATA OF 65-DEGREE SPECIMEN(BASSWOOD)

σ	dσ/dt	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε45	$\frac{d\varepsilon 45}{dt}$	card control
15 MINUTES LOADING									
14.89	10.00	1.50	129	86.00	3	3.33	100	66.00	15B653-26-78
22.44	9.86	2.25	193	86.00	4	4.00	150	66.66	15B653-26-78
29.69	9.80	3.00	258	86.	9	6.00	200	66.66	15B653-26-78
37.14	9.93	3.75	322	86.00	13	4.00	250	66.66	15B653-26-78
44.59	9.86	4.50	387	85.33	15	2.00	300	67.33	15B653-26-78
51.93	9.86	5.25	450	86.66	16	0.66	351	68.00	15B653-26-78
59.39	9.93	6.00	517	87.33	16	1.33	402	67.33	15B653-26-78
66.83	9.79	6.75	581	87.33	18	2.00	452	68.00	15B653-26-78
74.08	9.86	7.50	648	94.66	19	0.66	504	68.00	15B653-26-78
81.63	10.13	8.25	723	90.00	19	0.66	554	70.00	15B653-26-78
89.28	9.93	9.00	783	85.33	20	2.00	609	70.00	15B653-26-78
96.53	9.86	9.75	851	89.33	22	2.00	659	68.66	15B653-26-78
104.08	9.86	10.50	917	64.66	23	1.33	712	58.00	15B653-26-78
111.32	9.86	11.25	984	90.00	24	2.00	764	68.66	15B653-26-78
118.87	10.06	12.00	1052	90.66	26	2.00	815	69.33	15B653-26-78
126.42	9.80	12.75	1120	86.66	27	1.33	868	69.33	15B653-26-78
133.57	9.80	13.5	1182	86.00	28	1.33	919	70.00	15B653-26-78
141.12	10.00	14.25	1249	89.33	29	0.66	973	70.00	15B653-26-78
148.58	10.00	15.00	1316	89.33	29	0.66	1024	70.00	15B653-26-78
40 MINUTES LOADING									
42.85	3.49	12.00	387	32.25	6	0.75	287	24.50	40B653-10-78
50.00	3.54	14.00	450	31.75	7	1.50	336	24.75	40B653-10-78
57.04	3.54	16.00	514	31.75	12	2.50	386	24.50	40B653-10-78
64.18	3.72	18.00	577	34.25	17	3.25	434	23.50	40B653-10-78
71.93	3.49	20.00	651	32.00	25	4.75	480	24.75	40B653-10-78
78.16	3.29	22.00	705	29.75	36	6.75	533	25.75	40B653-10-78
85.10	3.52	24.00	770	32.25	52	8.75	583	24.50	40B653-10-78
92.24	3.52	26.00	834	31.75	71	9.75	631	24.50	40B653-10-78
99.18	3.47	28.00	897	31.75	91	8.75	681	25.25	40B653-10-78
106.12	3.57	30.00	961	32.25	106	8.50	732	25.25	40B653-10-78
113.46	3.54	32.00	1026	34.00	125	8.50	782	25.25	40B653-10-78
120.30	3.47	34.00	1097	33.75	140	8.00	833	25.00	40B653-10-78
127.34	3.57	36.00	1161	32.25	157	6.75	882	25.00	40B653-10-78
100 MINUTES LOADING									
13.46	1.34	10.00	117	10.70	3	0.4	94	9.50	100B653-18-78
20.20	1.34	15.00	176	12.00	6	1.20	142	9.60	100B653-18-78
26.93	1.34	20.00	237	12.20	15	1.90	190	9.60	100B653-18-78
33.67	1.35	25.00	298	12.00	25	2.30	238	9.50	100B653-18-78
40.51	1.35	30.00	357	11.80	38	2.60	285	9.50	100B653-18-78
47.24	1.33	35.00	416	11.80	51	3.80	333	9.70	100B653-18-78
53.87	1.34	40.00	475	11.90	76	2.90	382	9.70	100B653-18-78
60.71	1.36	45.00	535	12.30	80	2.00	430	9.70	100B653-18-78
67.55	1.33	50.00	598	12.50	86	1.20	479	9.60	100B653-18-78
74.08	1.33	55.00	660	12.40	92	0.70	526	9.60	100B653-18-78
80.91	1.34	60.00	722	12.40	93	0.20	575	9.70	100B653-18-78
87.55	1.32	65.00	784	12.50	94	0.30	623	9.80	100B653-18-78
94.18	1.32	70.00	847	12.50	95	0.20	673	10.00	100B653-18-78
100.81	1.34	75.00	909	12.20	96	0.20	723	9.80	100B653-18-78
107.65	1.35	80.00	969	12.40	97	0.00	771	9.70	100B653-18-78
114.38	1.32	85.00	1033	12.60	96	0.10	820	9.90	100B653-18-78
120.91	1.34	90.00	1095	12.10	98	0.40	870	10.00	100B653-18-78
127.85	1.37	95.00	1154	12.40	100	0.40	920	9.90	100B653-18-78
134.69	1.37	100.00	1219	12.40	102	0.40	969	9.90	100B653-18-78
240 MINUTES LOADING									
15.61	0.63	24.00	142	5.79	3	0.16	113	4.58	240B653-2-78
23.16	0.62	36.00	211	5.79	5	0.12	168	4.54	240B653-2-78
30.61	0.61	48.00	281	5.75	6	0.08	222	4.45	240B653-2-78
37.85	0.61	60.00	349	5.62	7	0.16	275	4.41	240B653-2-78
45.30	0.60	72.00	416	5.66	10	0.33	328	4.37	240B653-2-78
52.24	0.57	84.00	485	5.37	15	0.50	380	4.29	240B653-2-78
59.18	0.58	96.00	545	5.00	22	0.58	431	4.20	240B653-2-78
66.22	0.56	108.00	605	5.08	29	0.50	481	4.12	240B653-2-78
72.85	0.55	120.00	667	5.16	34	0.50	530	4.08	240B653-2-78
79.48	0.55	132.00	727	5.00	41	0.58	579	4.04	240B653-2-78
86.22	0.55	144.00	787	4.95	49	0.70	627	4.00	240B653-2-78
92.75	0.53	156.00	848	5.04	58	0.83	675	3.96	240B653-2-78
99.08	0.51	168.00	908	5.08	69	0.95	722	3.96	240B653-2-78
105.20	0.51	180.00	970	5.04	81	0.95	770	3.96	240B653-2-78

LIST OF RAW DATA 90-DEGREE SPECIMEN (BASSWOOD)

σ	$d\sigma/dt$	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	$\varepsilon 45$	$\frac{d\varepsilon 45}{dt}$	card control
15 MINUTES LOADING									
15.25	10.17	1.50	176	118.66	-4	-2.00	119	78.00	15B903-27-78
23.09	10.31	2.25	266	119.33	-6	-2.66	176	78.00	15B903-27-78
30.72	10.24	3.00	355	120.66	-8	-2.00	236	78.00	15B903-27-78
38.45	10.30	3.75	447	121.33	-9	-1.33	293	76.66	15B903-27-78
46.18	10.30	4.50	537	118.66	-10	-1.33	351	78.66	15B903-27-78
53.91	10.10	5.25	625	118.66	-11	-1.33	411	80.00	15B903-27-78
61.34	10.92	6.00	716	132.00	-12		471	86.66	15B903-27-78
70.30	10.24	6.75	823	122.00	-11		541	78.66	15B903-27-78
76.70	9.28	7.50	899	109.33	-12	-1.33	589	71.33	15B903-27-78
84.22	10.10	8.25	987	118.66	-13	-1.33	648	78.66	15B903-27-78
91.85	10.17	9.00	1077	122.00	-14	-0.66	707	80.00	15B903-27-78
99.48	10.17	9.75	1170	122.66	-14	-1.33	768	80.00	15B903-27-78
107.11	10.10	10.50	1261	120.66	-16	-2.66	827	78.66	15B903-27-78
114.63	10.10	11.25	1351	120.00	-18	-2.00	886	79.33	15B903-27-78
122.26	10.17	12.00	1441	119.33	-19	-2.66	946	80.00	15B903-27-78
129.89	10.10	12.75	1530	122.00	-22	-4.00	1006	80.00	15B903-27-78
137.42	10.10	13.50	1624	123.33	-25	-3.33	1066	81.33	15B903-27-78
145.05	10.17	14.25	1715	120.66	-27	-1.33	1128	81.33	15B903-27-78
152.68	10.17	15.00	1805	120.66	-27	-1.33	1188	81.33	15B903-27-78
40 MINUTES LOADING									
12.37	3.06	4.00	142	36.50	-4	-0.50	92	23.25	40B904-3-78
18.24	3.06	6.00	216	37.50	-5	-0.50	138	24.00	40B904-3-78
24.63	3.04	8.00	292	36.75	-6	-0.50	188	23.75	40B904-3-78
30.41	2.94	10.00	363	35.75	-7	-0.50	233	23.25	40B904-3-78
36.39	3.06	12.00	435	36.50	-8	-1.25	281	24.00	40B904-3-78
42.68	3.04	14.00	509	36.50	-12	-1.25	329	23.75	40B904-3-78
48.55	2.98	16.00	581	36.50	-13	-0.75	376	23.50	40B904-3-78
54.63	3.04	18.00	655	36.75	-15	-1.00	423	23.75	40B904-3-78
60.72	3.01	20.00	728	36.75	-17	-1.00	471	24.00	40B904-3-78
66.70	3.01	22.00	802	36.75	-19	-1.00	519	24.00	40B904-3-78
100 MINUTES LOADING									
14.12	1.49	10.00	168	18.00	-1	0.40	111	11.70	100B903-19-78
21.64	1.51	15.00	260	18.20	-2	-0.30	170	11.90	100B903-19-78
29.27	1.52	20.00	350	18.20	-4	-0.20	230	12.00	100B903-19-78
36.90	1.50	25.00	442	18.50	-4	-0.20	290	12.00	100B903-19-78
44.32	1.50	30.00	535	18.50	-5	-0.20	350	12.10	100B903-19-78
51.95	1.51	35.00	627	18.50	-6	-0.20	411	12.10	100B903-19-78
59.48	1.50	40.00	720	20.30	-7	-0.20	471	12.10	100B903-19-78
67.01	1.50	45.00	630	18.40	-8	-0.20	532	12.20	100B903-19-78
74.53	1.50	50.00	904	16.80	-9	-0.20	593	12.20	100B903-19-78
82.06	1.50	55.00	998	18.50	-10	-0.30	654	12.20	100B903-19-78
89.58	1.49	60.00	1089	18.30	-12	-0.30	715	12.10	100B903-19-78
97.01	1.49	65.00	1181	18.70	-13	-0.30	775	12.20	100B903-19-78
104.53	1.49	70.00	1276	18.80	-15	-0.30	837	12.40	100B903-19-78
111.58	1.50	75.00	1369	18.50	-16	-0.30	899	12.30	100B903-19-78
119.58	1.50	80.00	1461	18.60	-18	-0.40	960	12.40	100B903-19-78
127.01	1.45	85.00	1555	18.80	-20	-0.40	1023	12.40	100B903-19-78
134.53	1.49	90.00	1649	18.60	-22	-0.30	1084	12.30	100B903-19-78
141.95	1.47	95.00	1741	18.70	-23	-0.30	1146	12.50	100B903-19-78
149.27	1.47	100.00	1836	18.70	-25	-0.30	1209	12.50	100B903-19-78
240 MINUTES LOADING									
12.37	0.51	24.00	152	6.50	-4	-0.29	101	4.12	240B904-27-78
18.55	0.51	36.00	228	6.29	-8	-0.37	150	4.12	240B904-27-78
24.84	0.52	48.00	303	6.04	-13	-0.29	200	4.12	240B904-27-78
31.03	0.50	60.00	373	6.20	-15	0.04	249	3.83	240B904-27-78
37.01	0.51	72.00	452	6.29	-12	0.58	292	4.33	240B904-27-78
43.40	0.51	84.00	524	5.83	-1	0.58	353	4.62	240B904-27-78
49.48	0.51	96.00	592	6.12	2	0.58	403	4.04	240B904-27-78
55.67	0.50	108.00	671	6.50	13	1.12	450	4.12	240B904-27-78
61.64	0.47	120.00	748	6.29	29	0.79	502	4.25	240B904-27-78
67.01	0.48	132.00	822	6.20	32	0.41	552	4.04	240B904-27-78
73.19	0.53	144.00	897	6.33	39	0.08	599	4.08	240B904-27-78
79.79	0.52	156.00	974	6.37	34	-0.41	650	4.25	240B904-27-78
85.87	0.50	168.00	1050	6.25	29	-0.45	701	4.25	240B904-27-78
91.95	0.50	180.00	1124	6.33	23	-1.12	752	4.20	240B904-27-78
97.93	0.50	192.00	1202	6.16	2	-1.04	802	4.16	240B904-27-78
104.02	0.51	204.00	1272	6.29	-2	-0.33	852	4.25	240B904-27-78
110.30	0.51	216.00	1353	6.41	-10	-0.25	904	6.25	240B904-27-78
116.28	0.50	228.00	1426	6.25	-8	0.37	1002	4.20	240B904-27-78
122.37	0.50	240.00	1503	6.25	-1	0.37	1005	4.20	240B904-27-78

LIST OF RAW DATA OF ZERO-DEGREE SPECIMEN(YELLOW POPLAR)

σ	$d\sigma/dt$	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	$\varepsilon 45$	$\frac{d\varepsilon 45}{dt}$	card control
15 MINUTES LOADING									
30.00	19.93	1.50	19	11.33	-7	-4.66	7	4.00	15Y03-17-78
44.84	19.79	2.25	28	13.33	-11	-5.33	10	4.00	15Y03-17-78
59.69	19.93	3.00	39	12.66	-15	-4.66	13	4.00	15Y03-17-78
74.74	19.86	3.75	47	11.33	-18	-4.00	16	4.00	15Y03-17-78
89.49	20.74	4.50	56	11.33	-22	-4.00	19	4.00	15Y03-17-78
105.85	19.52	5.25	64	13.33	-24	-5.33	22	4.66	15Y03-17-78
118.78	18.32	6.00	76	14.00	-28	-6.00	26	2.66	15Y03-17-78
133.33	19.66	6.75	85	11.33	-32	-4.66	26	2.66	15Y03-17-78
148.28	19.72	7.50	93	12.00	-37	-4.00	30	5.33	15Y03-17-78
162.92	19.46	8.25	103	13.33	-39	-4.66	34	5.33	15Y03-17-78
177.47	19.86	9.00	113	12.66	-43	-4.66	38	5.33	15Y03-17-78
192.72	20.00	9.75	122	11.33	-46	-5.33	42	4.00	15Y03-17-78
207.47	19.66	10.50	130	12.00	-50	-5.33	44	4.00	15Y03-17-78
222.22	19.80	11.25	140	12.00	-54	-5.33	48	4.00	15Y03-17-78
237.17	19.93	12.00	148	10.66	-58	-5.33	50	2.66	15Y03-17-78
252.12	19.79	12.75	156	12.00	-62	-5.33	52	4.00	15Y03-17-78
266.86	18.85	13.50	166	13.33	-66	-5.33	56	6.66	15Y03-17-78
280.40	19.66	14.25	176	13.33	-70	-4.00	62	5.33	15Y03-17-78
296.36	19.96	15.00	186	13.33	-72	-4.00	64	5.33	15Y03-17-78
40 MINUTES LOADING									
29.99	7.32	4.00	15	4.50	-11	-1.75	5	1.25	40Y03-9-78
43.93	7.37	6.00	25	4.75	-14	-2.00	8	1.50	40Y03-9-78
59.19	7.47	8.00	34	4.25	-19	-2.25	11	1.25	40Y03-9-78
73.83	7.32	10.00	42	3.75	-23	-2.00	13	1.25	40Y03-9-78
88.48	7.40	12.00	49	4.25	-27	-2.00	16	1.25	40Y03-9-78
103.43	7.32	14.00	59	5.00	-31	-1.75	18	1.50	40Y03-9-78
117.77	7.37	16.00	69	4.50	-34	-1.75	22	1.75	40Y03-9-78
132.92	7.42	18.00	77	4.25	-38	-2.00	25	1.75	40Y03-9-78
147.47	7.32	20.00	86	5.00	-42	-2.25	29	2.00	40Y03-9-78
162.22	7.32	22.00	97	5.00	-47	-2.00	33	1.50	40Y03-9-78
176.76	7.30	24.00	106	4.25	-50	-1.75	35	1.50	40Y03-9-78
191.41	7.40	26.00	114	4.50	-54	-2.00	39	2.25	40Y03-9-78
206.36	7.22	28.00	124	5.00	-58	-2.00	44	1.75	40Y03-9-78
220.30	7.32	30.00	134	4.50	-62	-2.00	46	2.00	40Y03-9-78
235.65	7.57	32.00	142	4.00	-66	-1.50	52	2.50	40Y03-9-76
250.60	7.42	34.00	150	4.00	-68	-1.50	56	3.00	4CY03-9-78
265.35	7.22	36.00	158	4.50	-72	-2.00	64	2.50	40Y03-9-78
279.49	7.42	38.00	168	5.00	-76	-2.00	66	2.00	40Y03-9-78
295.05	7.42	40.00	178	5.00	-80	-2.00	72	2.00	40Y03-9-78
100 MINUTES LOADING									
30.00	2.96	10.00	18	1.80	-7	-0.60	7	0.70	100Y03-25-78
44.74	2.98	15.00	28	1.80	-10	-0.80	11	0.70	100Y03-25-78
59.89	2.99	20.00	36	1.80	-15	-0.70	14	0.60	100Y03-25-78
74.64	2.98	25.00	46	1.90	-17	-0.70	17	0.60	100Y03-25-78
89.69	2.98	30.00	55	1.80	-22	-0.80	20	0.60	100Y03-25-78
104.44	2.97	35.00	64	1.90	-25	-0.70	23	0.60	100Y03-25-78
119.39	2.96	40.00	74	1.90	-29	-0.70	26	0.50	100Y03-25-78
134.04	2.97	45.00	83	1.70	-32	-0.70	28	0.50	100Y03-25-78
149.09	2.98	50.00	91	1.80	-36	-0.80	31	0.70	100Y03-25-78
163.93	2.93	55.00	101	2.00	-40	-0.70	35	0.80	100Y03-25-78
176.48	2.66	60.00	111	1.90	-43	-0.80	39	0.70	100Y03-25-78
190.60	2.99	65.00	120	1.70	-48	-0.70	42	0.70	100Y03-25-78
208.38	3.25	70.00	128	1.80	-50	-0.60	46	0.60	100Y03-25-78
223.13	2.92	75.00	138	2.00	-54	-0.80	48	0.60	100Y03-25-78
237.67	2.93	80.00	148	1.80	-58	-0.80	52	0.70	100Y03-25-78
252.52	2.97	85.00	156	1.60	-62	-0.80	55	0.60	100Y03-25-78
267.37	2.96	90.00	164	1.80	-66	-0.80	58	0.70	100Y03-25-78
282.12	2.92	95.00	174	2.00	-70	-0.80	62	0.60	100Y03-25-78
296.66	2.92	100.00	184	2.00	-74	-0.80	64	0.60	100Y03-25-78
240 MINUTES LOADING									
24.84	1.03	24.00	13	0.54	-4	-0.16	6	0.20	240Y02-28-78
37.27	1.02	36.00	21	0.70	-7	-0.29	9	0.25	240Y02-28-78
49.49	1.02	48.00	30	0.66	-11	-0.25	12	0.16	240Y02-28-78
61.81	1.02	60.00	37	0.58	-13	-0.12	13	0.16	240Y02-28-78
74.14	1.02	72.00	44	0.58	-14	-0.20	16	0.20	240Y02-28-78
86.46	1.02	84.00	51	0.58	-18	-0.29	18	0.20	240Y02-28-78
98.68	1.01	96.00	58	0.62	-21	-0.16	21	0.20	240Y02-28-78
110.90	1.00	108.00	66	0.62	-22	-0.12	23	0.20	240Y02-28-78
122.82	0.97	120.00	73	0.58	-24	-0.16	26	0.25	240Y02-28-78
134.34	0.93	132.00	80	0.54	-27	-0.25	29	0.16	240Y02-28-78
145.15	0.90	144.00	86	0.58	-30	-0.20	30	0.16	240Y02-28-78
156.06	0.94	156.00	94	0.62	-32	-0.16	33	0.25	240Y02-28-78
167.87	0.98	168.00	101	0.58	-34	-0.20	36	0.25	240Y02-28-78
179.69	1.01	180.00	108	0.58	-37	-0.25	39	0.29	240Y02-28-78
192.22	0.99	192.00	115	0.58	-40	-0.29	43	0.29	240Y02-28-78
203.63	0.97	204.00	122	0.62	-44	-0.25	46	0.29	240Y02-28-78
215.55	1.00	216.00	130	0.58	-46	-0.25	50	0.29	240Y02-28-78
227.67	1.00	228.00	136	0.58	-50	-0.25	53	0.29	240Y02-28-78
239.59	1.00	240.00	144	0.58	-52	-0.25	57	0.29	240Y02-28-78

LIST OF RAW DATA OF 20-DEGREE SPECIMEN(YELLOW POPLAR)

σ	dσ/dt	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε45	$\frac{d\varepsilon 45}{dt}$	card control
15 MINUTES LOADING									
30.41	20.20	1.50	39	26.00	-9	-4.66	46	30.00	15Y203-17-78
45.77	20.34	2.25	58	27.33	-12	-3.33	69	30.66	15Y203-17-78
60.92	20.41	3.00	80	26.66	-14	-4.00	92	31.33	15Y203-17-78
76.39	20.55	3.75	98	26.66	-18	-4.66	116	31.33	15Y203-17-78
91.75	20.20	4.50	120	26.66	-21	-4.66	139	30.66	15Y203-17-78
106.70	20.27	5.25	138	26.00	-25	-4.66	163	31.33	15Y203-17-78
122.16	20.48	6.00	159	26.66	-28	-4.00	186	31.33	15Y203-17-78
137.42	20.48	6.75	178	26.66	-31	-4.66	210	31.33	15Y203-17-78
152.88	20.27	7.50	199	27.33	-35	-4.66	233	30.66	15Y203-17-78
167.83	20.00	8.25	219	26.00	-38	-4.66	256	31.33	15Y203-17-78
182.88	20.20	9.00	238	26.00	-42	-4.00	280	31.33	15Y203-17-78
198.14	20.06	9.75	258	25.33	-44	-4.66	303	31.33	15Y203-17-78
212.98	19.93	10.50	276	25.33	-49	-5.33	327	31.33	15Y203-17-78
228.04	19.93	11.25	296	26.66	-52	-4.65	350	31.33	15Y203-17-78
242.88	20.06	12.00	316	26.66	-56	-4.00	374	30.66	15Y203-17-78
258.14	20.34	12.75	336	25.33	-58	-4.00	396	30.66	15Y203-17-78
273.40	19.93	13.50	354	26.00	-62	-4.00	420	31.33	15Y203-17-78
288.04	19.92	14.25	375	26.66	-64	-4.00	443	31.33	15Y203-17-78
303.29	19.92	15.00	394	26.66	-68	-4.00	467	31.33	15Y203-17-78
40 MINUTES LOADING									
30.51	7.57	4.00	38	9.75	-6	-1.25	45	11.75	40Y203-9-78
45.46	7.55	6.00	59	10.00	-8	-1.25	69	12.00	40Y203-9-78
60.72	7.62	8.00	78	9.75	-11	-1.50	93	12.00	40Y203-9-78
75.97	7.65	10.00	98	9.75	-14	-1.25	117	11.75	40Y203-9-78
91.34	7.65	12.00	117	9.75	-16	-1.50	140	11.75	40Y203-9-78
106.59	7.65	14.00	137	10.00	-20	-1.50	164	11.75	40Y203-9-78
121.95	7.45	16.00	157	9.75	-22	-1.25	187	11.75	40Y203-9-78
136.39	7.37	18.00	176	9.75	-25	-1.50	211	12.00	40Y203-9-78
151.44	7.88	20.00	196	9.75	-28	-1.50	235	12.00	40Y203-9-78
167.93	7.75	22.00	215	9.25	-31	-1.75	259	12.00	40Y203-9-78
182.47	7.37	24.00	233	9.25	-35	-1.50	283	11.75	40Y203-9-78
197.42	7.55	26.00	252	9.75	-37	-1.25	306	11.75	40Y203-9-78
212.68	7.57	28.00	272	10.50	-40	-1.75	330	12.50	40Y203-9-78
227.73	7.52	30.00	294	10.00	-44	-1.50	356	12.50	40Y203-9-78
242.78	7.57	32.00	312	9.50	-46	-1.50	380	12.00	40Y203-9-78
258.04	7.57	34.00	332	10.00	-50	-1.50	404	12.00	40Y203-9-78
273.09	7.57	36.00	352	9.50	-52	-1.50	428	12.00	40Y203-9-78
288.35	7.52	38.00	370	9.50	-56	-2.00	452	11.50	40Y203-9-78
303.19	7.52	40.00	390	9.50	-60	-2.00	474	11.50	40Y203-9-78
100 MINUTES LOADING									
29.79	2.96	10.00	40	3.80	-5	-0.50	46	4.60	100Y203-25-78
44.84	2.99	15.00	59	3.70	-8	-0.50	69	4.60	100Y203-25-78
59.65	2.94	20.00	77	3.70	-10	-0.70	92	4.80	100Y203-25-78
74.32	3.00	25.00	96	3.90	-15	-0.70	117	4.80	100Y203-25-78
89.69	2.99	30.00	116	3.90	-17	-0.50	140	4.60	100Y203-25-78
104.22	2.95	35.00	135	3.70	-20	-0.60	163	4.60	100Y203-25-78
119.27	3.00	40.00	153	3.70	-23	-0.60	186	4.70	100Y203-25-78
134.22	2.98	45.00	172	3.80	-28	-0.80	210	4.70	100Y203-25-78
149.07	3.01	50.00	191	4.00	-31	-0.40	233	4.70	100Y203-25-78
164.32	2.94	55.00	212	4.00	-32	-0.50	257	4.70	100Y203-25-78
178.55	2.94	60.00	231	3.80	-36	-0.70	280	4.80	100Y203-25-78
193.81	3.00	65.00	250	3.70	-39	-0.60	305	4.80	100Y203-25-78
208.55	2.95	70.00	268	3.80	-42	-0.70	328	4.70	100Y203-25-78
223.40	2.99	75.00	288	3.40	-46	-0.60	352	4.80	100Y203-25-78
238.45	2.96	80.00	302	3.60	-48	-0.60	376	4.80	100Y203-25-78
253.09	2.99	85.00	324	4.00	-52	-0.60	400	4.60	100Y203-25-78
268.35	2.98	90.00	342	3.80	-54	-0.60	422	4.60	100Y203-25-78
282.98	2.98	95.00	362	4.20	-58	-0.80	446	4.80	100Y203-25-78
298.24	2.98	100.00	384	4.20	-62	-0.80	470	4.80	100Y203-25-78
240 MINUTES LOADING									
29.89	1.25	24.00	39	1.25	-5	-0.12	44	1.95	240Y202-28-78
44.74	1.24	36.00	59	1.66	-6	-0.16	68	1.91	240Y202-28-78
59.69	1.23	48.00	79	1.66	-9	-0.29	90	1.91	240Y202-28-78
74.32	1.23	60.00	99	1.62	-13	-0.20	114	1.95	240Y202-28-78
89.27	1.23	72.00	118	1.58	-14	-0.20	137	1.91	240Y202-28-78
104.02	1.23	84.00	137	1.54	-18	-0.25	160	1.91	240Y202-28-78
118.86	1.22	96.00	155	1.66	-20	-0.12	183	1.95	240Y202-28-78
133.29	1.20	108.00	177	1.75	-21	-0.25	207	1.95	240Y202-28-78
147.73	1.21	120.00	197	1.62	-26	-0.29	230	1.91	240Y202-28-78
162.37	1.21	132.00	216	1.54	-28	-0.25	253	1.83	240Y202-28-78
176.90	1.20	144.00	234	1.62	-31	-0.20	274	1.87	240Y202-28-78
191.23	1.20	156.00	255	1.66	-33	-0.20	298	2.00	240Y202-28-78
205.67	1.21	168.00	274	1.70	-36	-0.20	322	1.91	240Y202-28-78
220.30	1.21	180.00	296	1.66	-38	-0.16	344	1.91	240Y202-28-78
234.74	1.18	192.00	314	1.58	-40	-0.16	368	2.00	240Y202-28-78
248.76	1.19	204.00	334	1.66	-42	-0.25	392	1.91	240Y202-28-78
263.40	1.22	216.00	354	1.50	-46	-0.25	414	1.83	240Y202-28-78
278.24	1.20	228.00	370	1.58	-48	-0.25	436	1.91	240Y202-28-78
292.26	1.20	240.00	392	1.58	-52	-0.25	460	1.91	240Y202-28-78

LIST OF RAW DATA OF 35-DEGREE SPECIMEN(YELLOW POPLAR)

σ	$d\sigma/dt$	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε_{45}	$\frac{d\varepsilon_{45}}{dt}$	card control
15 MINUTES LOADING									
15.32	10.22	1.50	37	25.33	-8	-3.33	32	21.33	15Y353-20-78
23.14	10.43	2.25	56	25.33	-9	-1.33	48	20.66	15Y353-20-78
30.97	10.36	3.00	75	25.33	-10	-3.33	63	20.66	15Y353-20-78
38.68	10.08	3.75	94	24.00	-14	-2.66	79	21.33	15Y353-20-78
46.09	10.08	4.50	111	26.00	-14	-2.00	95	21.33	15Y353-20-78
53.80	10.22	5.25	133	26.00	-17	-3.33	111	21.33	15Y353-20-78
61.42	10.96	6.00	150	24.66	-19	-1.33	127	23.33	15Y353-20-78
70.25	10.42	6.75	170	26.00	-19	-2.00	146	21.33	15Y353-20-78
77.05	9.47	7.50	189	26.66	-22	-3.33	159	20.00	15Y353-20-78
84.46	10.08	8.25	210	26.66	-24	-4.66	176	21.33	15Y353-20-78
92.18	10.22	9.00	229	26.00	-29	-2.66	191	20.66	15Y353-20-78
99.79	10.28	9.75	249	26.00	-28	-0.66	207	20.00	15Y353-20-78
107.61	10.15	10.50	268	26.00	-30	-2.66	221	20.66	15Y353-20-78
115.02	9.94	11.25	288	26.66	-32	-2.66	238	22.00	15Y353-20-78
122.53	10.28	12.00	308	24.66	-34	-3.33	254	20.66	15Y353-20-78
130.45	10.36	12.75	325	25.33	-37	-2.66	269	21.33	15Y353-20-76
138.07	9.95	13.50	346	27.33	-38	-2.00	286	22.66	15Y353-20-78
145.38	9.94	14.25	366	26.66	-40	-2.66	303	22.00	15Y353-20-78
152.99	9.94	15.00	386	26.66	-42	-2.66	319	22.00	15Y353-20-78
40 MINUTES LOADING									
14.72	3.75	4.00	37	9.25	-8	-1.25	29	7.25	40Y353-11-78
22.33	3.73	6.00	55	8.75	-8	-0.50	44	7.50	40Y353-11-78
29.64	3.63	8.00	72	9.00	-10	-1.00	59	7.75	40Y353-11-78
36.85	3.65	10.00	91	9.50	-12	-0.75	75	8.00	40Y353-11-78
44.26	3.75	12.00	110	9.00	-13	-0.75	91	7.75	40Y353-11-78
51.87	3.68	14.00	127	9.00	-15	-1.00	106	7.75	40Y353-11-78
58.98	3.63	16.00	146	9.25	-17	-0.75	122	7.75	40Y353-11-78
66.39	3.63	18.00	164	9.25	-18	-0.75	137	7.50	40Y353-11-78
73.50	3.63	20.00	183	9.50	-20	-1.00	152	7.75	40Y353-11-78
80.91	3.68	22.00	202	9.25	-22	-0.75	168	7.75	40Y353-11-78
88.22	3.63	24.00	220	9.25	-23	-1.25	183	7.75	40Y353-11-78
95.43	3.65	26.00	239	9.25	-27	-1.25	199	8.00	40Y353-11-78
102.84	3.68	28.00	257	9.25	-28	-0.50	215	7.75	40Y353-11-78
110.15	3.68	30.00	276	9.00	-29	-1.25	230	7.25	40Y353-11-78
117.56	3.65	32.00	293	9.25	-33	-1.00	244	7.25	40Y353-11-78
124.77	3.63	34.00	313	9.50	-33	-1.00	259	7.50	40Y353-11-78
132.08	3.65	36.00	331	9.25	-37	-1.00	274	7.75	40Y353-11-78
139.39	3.63	38.00	350	9.75	-37	-0.50	290	7.75	40Y353-11-78
146.59	3.63	40.00	370	9.75	-39	-1.50	305	7.75	40Y353-11-78
100 MINUTES LOADING									
13.09	1.30	10.00	30	3.20	-3	-0.10	29	2.80	100Y353-28-78
19.39	1.35	15.00	46	3.40	-3	-0.10	43	3.00	100Y353-28-78
26.59	1.41	20.00	64	3.60	-4	-0.20	59	3.10	100Y353-28-78
33.50	1.39	25.00	82	3.60	-5	-0.30	74	3.00	100Y353-28-78
40.50	1.41	30.00	100	3.70	-7	-0.50	89	3.10	100Y353-28-78
47.61	1.42	35.00	119	3.70	-10	-0.40	105	3.10	100Y353-28-78
54.72	1.42	40.00	137	3.70	-11	-0.30	120	3.10	100Y353-28-78
61.82	1.42	45.00	156	3.60	-13	-0.40	136	3.10	100Y353-28-78
68.93	1.47	50.00	173	3.70	-15	-0.60	151	3.00	100Y353-28-78
76.54	1.43	55.00	193	3.80	-19	-0.40	166	3.00	100Y353-28-78
83.24	1.37	60.00	211	3.60	-19	-0.10	181	3.10	100Y353-28-78
90.25	1.43	65.00	229	3.70	-20	-0.20	197	3.20	100Y353-28-78
97.56	1.39	70.00	248	3.70	-21	-0.30	213	3.10	100Y353-28-78
104.16	1.38	75.00	266	3.50	-23	-0.40	228	3.00	100Y353-28-78
111.37	1.42	80.00	283	3.60	-25	-0.50	243	3.00	100Y353-28-78
118.37	1.41	85.00	302	3.80	-28	-0.40	258	3.00	100Y353-28-78
125.48	1.42	90.00	321	3.80	-29	-0.30	273	3.00	100Y353-28-78
132.58	1.41	95.00	340	3.70	-31	-0.40	288	3.00	100Y353-28-78
139.59	1.41	100.00	358	3.70	-33	-0.40	303	3.00	100Y353-28-78
240 MINUTES LOADING									
12.99	0.53	24.00	32	1.37	-6	-0.12	26	1.08	240Y353-3-78
19.39	0.53	36.00	48	1.25	-7	-0.12	39	1.08	240Y353-3-78
25.88	0.53	48.00	62	1.33	-9	-0.16	52	1.12	240Y353-3-78
32.28	0.53	60.00	80	1.41	-11	-0.20	66	1.12	240Y353-3-78
38.68	0.53	72.00	96	1.33	-14	-0.12	79	1.16	240Y353-3-78
45.17	0.53	84.00	112	1.37	-14	-0.04	94	1.16	240Y353-3-78
51.47	0.53	96.00	129	1.41	-15	-0.16	107	1.12	240Y353-3-78
58.07	0.54	108.00	146	1.37	-18	-0.20	121	1.12	240Y353-3-78
64.46	0.53	120.00	162	1.37	-20	-0.12	134	1.16	240Y353-3-78
70.76	0.53	132.00	179	1.41	-21	-0.12	149	1.16	240Y353-3-78
77.15	0.53	144.00	196	1.37	-23	-0.12	162	1.12	240Y353-3-78
83.65	0.53	156.00	212	1.37	-24	-0.08	176	1.16	240Y353-3-78
89.94	0.53	168.00	229	1.33	-25	-0.08	190	1.16	240Y353-3-78
96.54	0.53	180.00	244	1.45	-26	-0.12	204	1.16	240Y353-3-78
102.74	0.53	192.00	264	1.54	-28	-0.12	218	1.16	240Y353-3-78
109.23	0.53	204.00	281	1.37	-29	-0.16	232	1.12	240Y353-3-78
115.53	0.53	216.00	297	1.37	-32	-0.12	245	1.12	240Y353-3-78
121.82	0.54	228.00	314	1.41	-32	-0.12	259	1.16	240Y353-3-78
128.52	0.54	240.00	331	1.41	-35	-0.12	273	1.16	240Y353-3-78

LIST OF RAW DATA OF 50-DEGREE SPECIMEN(YELLOW POPLAR)

σ	$d\sigma/dt$	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	$\varepsilon 45$	$\frac{d\varepsilon 45}{dt}$	card control
15 MINUTES LOADING									
14.69	9.66	1.50	50	32.66	-7	-3.33	40	26.00	15Y503-20-78
21.73	9.66	2.25	74	31.33	-9	-2.66	60	26.00	15Y503-20-78
29.18	9.52	3.00	97	32.66	-11	-3.33	79	26.00	15Y503-20-78
36.02	9.25	3.75	123	32.66	-14	-4.00	99	26.66	15Y503-20-78
43.06	9.58	4.50	146	33.33	-17	-3.33	119	26.00	15Y503-20-78
50.40	9.45	5.25	173	32.66	-19	-3.33	138	26.00	15Y503-20-78
57.24	9.38	6.00	197	33.33	-22	-4.00	158	26.66	15Y503-20-78
64.48	9.59	6.75	223	33.33	-25	-4.00	178	26.00	15Y503-20-78
71.63	9.59	7.50	247	33.33	-28	-2.66	197	26.00	15Y503-20-78
78.87	9.45	8.25	273	32.66	-29	-3.33	217	26.00	15Y503-20-78
85.81	9.32	9.00	296	32.66	-33	-5.33	236	25.33	15Y503-20-78
92.85	9.66	9.75	322	32.66	-37	-4.00	255	26.66	15Y503-20-78
100.30	9.46	10.50	345	32.66	-39	-3.33	276	27.33	15Y503-20-78
107.04	9.18	11.25	371	33.33	-42	-2.66	296	26.00	15Y503-20-78
114.08	9.45	12.00	395	32.66	-43	-2.66	315	26.66	15Y503-20-78
121.22	9.52	12.75	420	32.66	-46	-4.66	336	26.00	15Y503-20-78
128.36	9.38	13.50	444	32.66	-50	-3.33	354	26.00	15Y503-20-78
135.30	9.32	14.25	469	32.66	-51	-2.66	375	26.66	15Y503-20-78
142.34	9.32	15.00	493	32.66	-54	-2.66	394	26.66	15Y503-20-78
40 MINUTES LOADING									
14.89	3.77	4.00	47	12.75	-5	-1.50	43	10.50	40Y503-12-78
22.55	3.80	6.00	72	12.50	-9	-1.75	64	10.50	40Y503-12-78
30.10	3.67	8.00	97	12.25	-12	-1.00	85	10.00	40Y503-12-78
37.24	3.44	10.00	121	12.00	-13	-1.00	104	9.50	40Y503-12-78
43.87	3.59	12.00	145	12.75	-16	-1.50	123	10.25	40Y503-12-78
51.63	3.80	14.00	172	12.75	-19	-1.75	145	10.50	40Y503-12-78
59.08	3.77	16.00	196	12.25	-23	-1.25	165	10.50	40Y503-12-78
66.73	3.75	18.00	221	13.00	-24	-1.	187	10.50	40Y503-12-78
74.08	3.75	20.00	248	13.25	-27	-1.75	207	10.00	40Y503-12-78
81.73	3.82	22.00	274	12.75	-31	-1.75	227	10.25	40Y503-12-78
89.38	3.77	24.00	299	13.25	-34	-1.25	248	10.75	40Y503-12-78
96.83	3.75	26.00	327	13.75	-36	-1.25	270	11.00	40Y503-12-78
104.38	3.77	28.00	354	12.75	-39	-1.75	292	11.00	40Y503-12-78
111.93	3.75	30.00	378	13.25	-43	-1.25	314	10.75	40Y503-12-78
119.38	3.75	32.00	407	14.00	-44	-1.25	335	10.50	40Y503-12-78
126.93	3.85	34.00	434	13.75	-48	-1.50	356	10.25	40Y503-12-78
134.79	3.77	36.00	462	13.75	-50	-1.25	376	10.25	40Y503-12-78
142.04	3.70	38.00	489	14.00	-53	-1.50	397	10.25	40Y503-12-78
149.59	3.70	40.00	518	14.00	-56	-1.50	417	10.25	40Y503-12-78
100 MINUTES LOADING									
12.55	1.31	10.00	48	4.50	-5	-0.50	38	3.80	100Y503-28-78
19.38	1.35	15.00	70	4.40	-8	-0.50	58	3.90	100Y503-28-78
26.12	1.35	20.00	92	4.50	-10	-0.40	77	3.90	100Y503-28-78
32.95	1.33	25.00	115	4.80	-12	-0.50	97	3.90	100Y503-28-78
39.48	1.34	30.00	140	4.90	-15	-0.60	116	3.80	100Y503-28-78
46.42	1.35	35.00	164	4.70	-18	-0.50	135	3.80	100Y503-28-78
53.06	1.33	40.00	187	4.70	-20	-0.50	154	3.90	100Y503-28-78
59.79	1.35	45.00	211	5.00	-23	-0.70	174	4.00	100Y503-28-78
66.63	1.34	50.00	237	5.00	-27	-0.80	194	3.90	100Y503-28-78
73.26	1.35	55.00	261	4.80	-28	-0.30	213	3.80	100Y503-28-78
80.20	1.37	60.00	285	5.00	-30	-0.70	232	3.60	100Y503-28-78
87.04	1.36	65.00	311	5.00	-35	-0.80	249	3.50	100Y503-28-78
93.87	1.44	70.00	335	5.40	-38	-0.50	267	3.90	100Y503-28-78
101.53	1.34	75.00	365	5.20	-40	-0.50	288	3.80	100Y503-28-78
107.34	1.26	80.00	387	4.80	-43	-0.40	305	3.70	100Y503-28-78
114.18	1.35	85.00	413	5.10	-44	-0.60	325	4.00	100Y503-28-78
120.91	1.28	90.00	438	4.80	-49	-0.70	345	3.60	100Y503-28-78
127.04	1.35	95.00	461	5.00	-51	-0.30	361	3.80	100Y503-28-78
134.48	1.35	100.00	488	5.00	-52	-0.30	383	3.80	100Y503-28-78
240 MINUTES LOADING									
12.95	0.57	24.00	46	2.04	-6	-0.16	38	1.70	240Y503-4-78
20.00	0.59	36.00	71	2.00	-8	-0.20	59	1.70	240Y503-4-78
27.14	0.59	48.00	94	2.08	-11	-0.12	79	1.70	240Y503-4-78
34.18	0.63	60.00	121	2.33	-11	-0.16	100	1.83	240Y503-4-78
42.44	0.68	72.00	150	2.41	-15	-0.33	123	1.95	240Y503-4-78
50.51	0.67	84.00	179	2.37	-19	-0.25	147	1.95	240Y503-4-78
58.57	0.68	96.00	207	2.41	-21	-0.25	170	1.95	240Y503-4-78
66.83	0.66	108.00	237	2.45	-25	-0.25	194	1.95	240Y503-4-78
74.59	0.65	120.00	266	2.29	-27	-0.29	217	1.87	240Y503-4-78
82.65	0.65	132.00	292	2.33	-32	-0.16	239	1.91	240Y503-4-78
90.20	0.64	144.00	322	2.41	-31	-0.16	263	2.00	240Y503-4-78
98.16	0.65	156.00	350	2.37	-36	-0.20	287	2.04	240Y503-4-78
106.02	0.65	168.00	379	2.37	-36	-0.16	312	2.00	240Y503-4-78
113.87	0.65	180.00	407	2.29	-38	-0.33	335	2.00	240Y503-4-78
121.83	0.65	192.00	434	2.29	-42	-0.20	360	2.00	240Y503-4-78
129.59	0.65	204.00	462	2.33	-43	-0.16	383	1.95	240Y503-4-78
137.55	0.65	216.00	490	2.41	-46	-0.20	407	2.04	240Y503-4-78
145.20	0.64	228.00	520	2.50	-48	-0.16	432	2.04	240Y503-4-78
152.85	0.64	240.00	550	2.50	-50	-0.16	456	2.04	240Y503-4-78

LIST OF RAW DATA OF 65-DEGREE SPECIMEN(YELLOW POPLAR)

σ	dσ/dt	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε_{45}	$\frac{d\varepsilon_{45}}{dt}$	card control
15 MINUTES LOADING									
14.38	9.38	1.50	74	49.33	-5	-2.66	57	36.66	15Y653-20-78
21.32	9.59	2.25	112	48.66	-7	-1.33	84	36.00	15Y653-20-78
28.77	9.52	3.00	147	48.66	-7	-1.33	111	36.66	15Y653-20-78
35.61	9.52	3.75	185	48.00	-9	-2.00	139	36.00	15Y653-20-78
43.06	9.52	4.50	219	50.00	-10	-2.00	165	36.66	15Y653-20-78
49.89	9.32	5.25	260	51.33	-12	-3.33	194	37.33	15Y653-20-78
57.04	9.46	6.00	296	54.00	-15	-2.00	221	36.66	15Y653-20-78
64.08	9.32	6.75	341	50.00	-15	-1.33	249	37.33	15Y653-20-78
71.02	9.38	7.50	371	44.00	-17	-2.00	277	36.66	15Y653-20-78
78.15	9.45	8.25	407	49.33	-18	-1.33	304	36.66	15Y653-20-78
85.20	9.38	9.00	445	50.66	-19	-1.33	332	37.33	15Y653-20-78
92.24	9.38	9.75	483	50.00	-20	-1.33	360	37.33	15Y653-20-78
99.28	9.52	10.50	520	50.00	-21	-1.33	388	38.66	15Y653-20-78
106.53	9.25	11.25	558	50.00	-22	-2.00	418	38.66	15Y653-20-78
113.16	9.32	12.00	595	50.00	-23	-2.00	446	38.66	15Y653-20-78
40 MINUTES LOADING									
14.59	3.72	4.00	70	18.50	-4	-0.25	56	14.25	40Y653-12-78
22.24	3.70	6.00	107	19.25	-5	-0.75	85	14.25	40Y653-12-78
29.38	3.62	6.00	147	19.50	-7	-0.75	113	14.25	40Y653-12-78
36.73	3.64	10.00	185	19.00	-8	-0.75	142	14.50	40Y653-12-78
43.97	3.62	12.00	223	19.25	-10	-1.00	171	14.50	40Y653-12-78
51.22	3.70	14.00	262	19.25	-12	-0.75	200	14.25	40Y653-12-78
58.77	3.67	16.00	300	19.25	-13	-0.75	228	14.50	40Y653-12-78
65.91	3.60	18.00	339	19.00	-15	-0.75	258	14.50	40Y653-12-78
73.16	3.67	20.00	376	19.00	-16	-0.50	286	14.00	40Y653-12-78
80.61	3.67	22.00	415	19.50	-17	-0.75	314	14.50	40Y653-12-78
87.85	3.95	24.00	454	19.25	-19	-0.50	344	15.00	40Y653-12-78
96.42	3.70	26.00	492	19.00	-19	-0.50	374	14.50	40Y653-12-78
102.65	3.36	28.00	530	19.25	-21	-0.75	402	13.75	40Y653-12-78
109.89	3.62	30.00	569	19.50	-22	-0.75	430	14.00	40Y653-12-78
117.14	3.62	32.00	608	19.50	-24	-0.50	458	14.25	40Y653-12-78
124.38	3.67	34.00	647	19.50	-24	-0.25	487	15.00	40Y653-12-78
131.83	3.64	36.00	686	19.25	-25	-0.50	518	14.75	40Y653-12-78
138.97	3.62	38.00	724	19.00	-26	-0.50	546	14.75	40Y653-12-78
146.32	3.62	40.00	762	19.00	-27	-0.50	577	14.75	40Y653-12-78
100 MINUTES LOADING									
13.83	1.38	10.00	75	7.40	-6	-0.30	53	5.40	100Y653-28-78
20.81	1.40	15.00	112	7.30	-7	-0.30	80	5.40	100Y653-28-78
27.85	1.37	20.00	148	7.40	-9	-0.30	107	5.50	100Y653-28-78
34.59	1.36	25.00	186	7.70	-10	-0.20	135	5.60	100Y653-28-78
41.53	1.38	30.00	225	7.70	-11	-0.30	163	5.60	100Y653-28-78
48.46	1.37	35.00	263	7.50	-13	-0.40	191	5.70	100Y653-28-78
55.30	1.36	40.00	300	7.50	-15	-0.40	220	5.60	100Y653-28-78
62.14	1.37	45.00	338	7.40	-17	-0.30	247	5.50	100Y653-28-78
69.08	1.37	50.00	374	7.50	-18	-0.10	275	5.60	100Y653-28-78
75.91	1.38	55.00	413	7.70	-18	-0.10	303	5.60	100Y653-28-78
82.95	1.36	60.00	451	7.40	-19	-0.20	331	5.60	100Y653-28-78
89.59	1.34	65.00	487	7.50	-20	-0.20	359	5.70	100Y653-28-78
96.42	1.35	70.00	526	7.60	-21	-0.10	388	6.00	100Y653-28-78
103.16	1.37	75.00	563	7.40	-21	-0.10	419	6.10	100Y653-28-78
110.20	1.37	80.00	600	7.60	-22	-0.20	449	6.00	100Y653-28-78
116.93	1.34	85.00	639	7.60	-23	-0.10	479	6.00	100Y653-28-78
123.67	1.36	90.00	676	7.40	-23	-0.10	509	5.90	100Y653-28-78
130.61	1.37	95.00	713	7.60	-24	-0.10	538	5.70	100Y653-28-78
137.44	1.37	100.00	752	7.60	-24	-0.10	566	5.70	100Y653-28-78
240 MINUTES LOADING									
12.05	0.51	24.00	64	2.66	-5	-0.08	44	1.87	240Y65-7-1-78
18.26	0.51	36.00	96	2.54	-6	-0.08	67	1.87	240Y65-7-1-78
24.18	0.54	48.00	125	2.75	-7	-0.12	89	2.04	240Y65-7-1-78
31.42	0.57	60.00	162	3.04	-9	-0.12	116	2.33	240Y65-7-1-78
37.95	0.57	72.00	198	3.04	-10		145	2.37	240Y65-7-1-78
45.20	0.57	84.00	235	3.04	-9		173	2.33	240Y65-7-1-78
51.83	0.56	96.00	271	3.08	-10	-0.08	201	2.29	240Y65-7-1-78
58.77	0.56	108.00	309	3.04	-11	-0.08	228	2.20	240Y65-7-1-78
65.40	0.56	120.00	344	2.95	-12	-0.04	254	2.20	240Y65-7-1-78
72.24	0.57	132.00	380	3.04	-12		281	2.20	240Y65-7-1-78
79.08	0.58	144.00	417	3.04	-12	-0.04	307	2.20	240Y65-7-1-78
86.22	0.56	156.00	453	3.00	-13	-0.04	334	2.25	240Y65-7-1-78
92.55	0.54	168.00	489	2.91	-13	-0.04	361	2.16	240Y65-7-1-78
99.18	0.55	180.00	523	3.00	-14	-0.08	386	2.16	240Y65-7-1-78
105.91	0.54	192.00	561	3.00	-15	-0.12	413	2.16	240Y65-7-1-78
112.34	0.54	204.00	595	2.95	-17	-0.16	438	2.16	240Y65-7-1-78
119.08	0.55	216.00	632	3.00	-19	-0.04	465	2.20	240Y65-7-1-78
125.71	0.54	228.00	667	2.95	-18		491	2.16	240Y65-7-1-78
132.04	0.54	240.00	703	2.95	-19		517	2.16	240Y65-7-1-78

LIST OF RAW DATA 90-DEGREE SPECIMEN (YELLOW POPLAR)

σ	dσ/dt	t	ε∥	dε∥/dt	ε⊥	dε⊥/dt	ε45	dε45/dt	card control
15 MINUTES LOADING									
14.89	9.92	1.50	92	61.33	-8	-4.00	46	30.66	15Y903-21-78
22.44	10.07	2.25	138	60.66	-10	-2.66	70	30.66	15Y903-21-78
30.00	9.66	3.00	183	63.33	-12	-2.00	92	30.66	15Y903-21-78
36.93	9.92	3.75	233	61.33	-13	-0.66	116	31.33	15Y903-21-78
44.89	10.34	4.50	275	57.33	-13	-0.66	139	30.66	15Y903-21-78
52.44	9.80	5.25	319	59.33	-14	-2.00	162	30.66	15Y903-21-78
59.59	9.86	6.00	364	58.66	-16	-2.00	185	30.00	15Y903-21-78
67.24	9.86	6.75	407	56.66	-17	-2.00	207	30.00	15Y903-21-78
74.38	9.72	7.50	449	60.00	-19	-4.00	230	30.66	15Y903-21-78
81.83	10.14	8.25	494	58.00	-23	-3.00	253	30.66	15Y903-21-78
89.59	9.86	9.00	536	58.00	-24	-0.66	276	30.00	15Y903-21-78
96.63	9.58	9.75	581	59.33	-24	-1.33	298	30.00	15Y903-21-78
103.97	10.06	10.50	625	59.33	-26	-1.33	321	31.33	15Y903-21-78
111.73	9.86	11.25	670	59.33	-26	-1.33	345	30.66	15Y903-21-78
118.77	9.72	12.00	714	60.66	-28	-2.00	367	30.66	15Y903-21-78
126.32	10.06	12.75	761	60.00	-29	-0.66	391	31.33	15Y903-21-78
133.87	9.80	13.50	804	60.66	-29		414	31.33	15Y903-21-78
141.02	8.57	14.25	852	60.66	-29	-1.33	438	60.66	15Y903-21-78
146.73	8.57	15.00	895	60.66	-31	-1.33	460	30.66	15Y903-21-78
40 MINUTES LOADING									
14.79	3.72	4.00	88	22.75	-7	-1.50	43	11.25	40Y903-13-78
22.24	3.75	6.00	133	22.75	-10	-0.75	66	11.50	40Y903-13-78
29.79	3.70	8.00	179	23.00	-10	-0.25	89	11.25	40Y903-13-78
37.04	3.67	10.00	225	23.00	-11	-0.75	111	11.50	40Y903-13-78
44.48	3.72	12.00	271	23.00	-13	-1.00	135	11.75	40Y903-13-78
51.93	3.72	14.00	317	22.75	-15	-1.00	158	11.25	40Y903-13-78
59.38	3.75	16.00	362	22.75	-17	-0.50	180	11.50	40Y903-13-78
66.93	3.70	18.00	408	22.75	-17	-0.75	204	11.75	40Y903-13-78
74.18	3.67	20.00	453	22.75	-20	-1.25	227	11.25	40Y903-13-78
81.63	3.75	22.00	499	22.50	-22	-0.75	249	11.25	40Y903-13-78
89.18	3.70	24.00	543	22.75	-23	-1.00	272	11.50	40Y903-13-78
96.42	3.65	26.00	590	23.25	-26	-1.00	295	11.50	40Y903-13-78
103.77	3.70	28.00	636	22.75	-27	-0.25	318	11.50	40Y903-13-78
111.22	3.70	30.00	681	23.25	-27	-0.25	341	11.50	40Y903-13-78
118.57	3.67	32.00	729	23.25	-28	-0.25	364	11.50	40Y903-13-78
125.91	3.70	34.00	774	22.50	-28	-0.25	387	11.50	40Y903-13-78
133.36	3.19	36.00	819	23.50	-29	-0.50	410	11.00	40Y903-13-78
138.67	3.70	38.00	868	23.50	-30	-0.50	431	11.50	40Y903-13-78
148.16	3.70	40.00	913	23.50	-31	-0.50	456	11.50	40Y903-13-78
100 MINUTES LOADING									
13.46	1.33	10.00	86	8.40	-5	-0.30	41	4.40	100Y903-29-78
20.30	1.39	15.00	127	8.40	-7	-0.30	63	4.40	100Y903-29-78
27.44	1.35	20.00	170	8.40	-8	-0.20	85	4.20	100Y903-29-78
33.87	1.31	25.00	211	8.10	-9	-0.40	105	4.20	100Y903-29-78
40.61	1.34	30.00	251	8.10	-12	-0.40	127	4.30	100Y903-29-78
47.34	1.35	35.00	292	8.30	-13	-0.30	148	4.20	100Y903-29-78
54.18	1.36	40.00	334	8.40	-15	-0.30	169	4.30	100Y903-29-78
61.02	1.34	45.00	376	8.10	-16	-0.20	191	4.40	100Y903-29-78
67.65	1.34	50.00	415	7.90	-17	-0.20	213	4.30	100Y903-29-78
74.48	1.36	55.00	455	8.00	-19	-0.30	234	4.20	100Y903-29-78
81.32	1.35	60.00	495	7.90	-20	-0.20	255	4.20	100Y903-29-78
88.06	1.34	65.00	534	7.80	-21	-0.20	276	4.30	100Y903-29-78
94.79	1.35	70.00	573	7.90	-22	-0.10	298	4.30	100Y903-29-78
101.63	1.35	75.00	613	8.00	-22	-0.10	319	4.30	100Y903-29-78
108.36	1.34	80.00	653	7.90	-23	-0.20	341	4.30	100Y903-29-78
115.10	1.34	85.00	692	8.00	-24	-0.20	362	4.40	100Y903-29-78
121.83	1.36	90.00	733	8.30	-25	-0.20	385	4.40	100Y903-29-78
128.77	1.37	95.00	775	8.30	-26	-0.20	406	4.20	100Y903-29-78
135.61	1.37	100.00	816	8.30	-27	-0.20	427	4.20	100Y903-29-78
240 MINUTES LOADING									
44.48	0.64	72.00	306	4.66	-11	-0.12	137	2.00	240Y903-5-78
52.44	0.63	84.00	363	4.70	-13	-0.12	161	2.00	240Y903-5-78
59.69	0.62	96.00	419	4.87	-14	-0.08	185	2.00	240Y903-5-78
67.34	0.62	108.00	480	5.25	-15	-0.08	209	2.00	240Y903-5-78
74.59	0.62	120.00	545	5.20	-16	-0.12	233	1.95	240Y903-5-78
82.14	0.62	132.00	605	5.33	-18	-0.20	256	1.95	240Y903-5-78
89.59	0.61	144.00	673	6.04	-21	-0.25	280	1.95	240Y903-5-78
96.83	0.61	156.00	750	5.83	-24	-0.20	303	1.95	240Y903-5-78
104.18	0.61	168.00	813	4.91	-26	-0.16	327	1.95	240Y903-5-78
111.63	0.61	180.00	868	4.79	-28	-0.12	350	1.91	240Y903-5-78
118.87	0.61	192.00	928	5.16	-29	-0.16	373	1.75	24CY903-5-78
126.42	0.61	204.00	992	4.91	-32	-0.12	392	1.91	240Y903-5-78
133.46	0.60	216.00	1042	4.37	-32	-0.12	419	2.08	240Y903-5-78
140.81	0.60	228.00	1097	4.29	-35	-0.12	442	1.95	240Y903-5-78
147.85	0.60	240.00	1149	4.29	-35	-0.12	466	1.95	240Y903-5-78

LIST OF RAW DATA OF ZERO-DEGREE SPECIMEN(SUGAR PINE)

σ	dσ/dt	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε45	$\frac{d\varepsilon 45}{dt}$	card control
15 MINUTES LOADING									
28.83	19.56	1.50	24	16.66	-16	-11.33	6	3.33	15P03-17-78
43.95	19.49	2.25	37	16.66	-25	-9.33	9	2.66	15P03-17-78
58.07	19.22	3.00	49	16.66	-30	-8.66	10	2.66	15P03-17-78
72.79	19.62	3.75	62	16.00	-38	-10.66	13	4.66	15P03-17-78
87.51	19.49	4.50	73	16.00	-46	-10.00	17	4.00	15P03-17-78
102.03	19.42	5.25	86	17.33	-53	-10.66	19	4.00	15P03-17-78
116.64	19.35	6.00	99	16.66	-62	-10.66	23	4.66	15P03-17-78
131.06	19.22	6.75	111	16.66	-69	-9.33	25	3.33	15P03-17-78
145.48	19.29	7.50	124	16.66	-76	-11.33	28	3.33	15P03-17-78
160.00	19.08	8.25	136	16.00	-86	-11.66	30	2.00	15P03-17-78
174.11	19.42	9.00	148	15.33	-92	-9.33	31	4.00	15P03-17-78
189.13	19.69	9.75	159	17.33	-100	-9.33	36	4.66	15P03-17-78
203.65	19.29	10.50	174	18.00	-106	-10.66	38	4.00	15P03-17-78
217.07	18.81	11.25	186	14.66	-116	-12.00	42	5.33	15P03-17-78
231.87	19.35	12.00	196	14.66	-124	-9.33	46	4.00	15P03-17-78
247.10	19.36	12.75	208	13.33	-130	-8.00	48	2.66	15P03-17-78
260.91	19.36	13.50	216	16.00	-136	-9.33	50	4.00	15P03-17-78
276.14	19.62	14.25	232	16.66	-144	-10.66	54	5.33	15P03-17-78
290.35	19.62	15.00	241	16.66	-152	-10.66	58	5.33	15P03-17-78
40 MINUTES LOADING									
29.84	7.46	4.00	26	6.75	-15	-3.50	7	1.25	40P03-9-78
44.67	7.46	6.00	40	6.50	-22	-4.00	10	1.50	40P03-9-78
59.69	7.51	8.00	52	6.25	-31	-4.00	13	1.50	40P03-9-78
74.72	7.48	10.00	65	6.50	-38	-3.75	16	1.75	40P03-9-78
89.64	7.38	12.00	78	6.75	-46	-3.75	20	1.50	40P03-9-78
104.26	7.43	14.00	92	7.00	-53	-3.75	22	1.50	40P03-9-78
119.39	7.48	16.00	106	6.75	-61	-3.75	26	1.75	40P03-9-78
134.21	7.38	18.00	119	6.50	-68	-3.75	29	1.25	40P03-9-78
148.93	7.48	20.00	132	6.00	-76	-3.75	31	1.25	40P03-9-78
164.16	7.46	22.00	143	5.75	-83	-3.75	34	1.50	40P03-9-78
178.78	7.36	24.00	155	5.75	-91	-4.00	37	1.50	40P03-9-78
193.60	7.43	26.00	166	4.75	-99	-3.75	40	1.75	40P03-9-78
208.52	7.48	28.00	174	5.00	-106	-3.75	44	1.50	40P03-9-78
223.55	7.41	30.00	186	5.50	-114	-4.00	46	1.50	40P03-9-78
238.17	7.31	32.00	196	5.50	-122	-3.50	50	2.00	40P03-9-78
252.79	7.41	34.00	208	5.50	-128	-3.50	54	1.50	40P03-9-78
267.81	7.46	36.00	218	5.00	-136	-4.00	56	1.00	40P03-9-78
282.63	7.31	38.00	228	6.00	-144	-3.50	58	1.50	40P03-9-78
297.05	7.31	40.00	242	6.00	-150	-3.50	62	1.50	40P03-9-78
100 MINUTES LOADING									
31.67	2.90	10.00	23	2.40	-16	-1.40	7	0.70	100P03-25-78
43.55	2.64	15.00	36	2.40	-22	-1.20	10	0.60	100P03-25-78
58.07	2.93	20.00	47	2.10	-28	-1.50	13	0.50	100P03-25-78
72.89	2.92	25.00	57	2.40	-37	-1.60	15	0.60	100P03-25-78
87.30	2.87	30.00	71	2.70	-44	-1.40	19	0.60	100P03-25-78
101.62	2.87	35.00	84	2.50	-51	-1.60	21	0.60	100P03-25-78
116.04	2.89	40.00	96	2.80	-60	-1.50	25	0.60	100P03-25-78
130.55	2.90	45.00	112	3.10	-66	-1.40	27	0.60	100P03-25-78
145.07	2.89	50.00	127	2.70	-74	-1.70	31	0.60	100P03-25-78
159.49	2.90	55.00	139	2.30	-83	-1.70	33	0.40	100P03-25-78
174.11	2.90	60.00	150	2.30	-91	-1.50	35	0.40	100P03-25-78
188.52	2.90	65.00	162	2.20	-98	-1.50	37	0.50	100P03-25-78
203.14	2.86	70.00	172	1.80	-106	-1.60	40	0.70	100P03-25-78
217.15	2.86	75.00	180	2.00	-114	-1.60	44	0.80	100P03-25-78
231.77	2.92	80.00	192	2.00	-122	-1.40	48	0.60	100P03-25-78
246.39	2.88	85.00	200	2.20	-128	-1.40	50	0.40	100P03-25-78
260.60	2.90	90.00	214	2.20	-136	-1.60	52	0.60	100P03-25-78
275.43	2.86	95.00	222	2.00	-144	-1.40	56	0.60	100P03-25-78
289.23	2.86	100.00	234	2.00	-150	-1.40	58	0.60	100P03-25-78
240 MINUTES LOADING									
26.90	1.10	24.00	20	0.95	-14	-0.58	5	0.20	240P03-1-78
40.00	1.09	36.00	34	0.95	-21	-0.58	8	0.16	240P03-1-78
53.09	1.09	48.00	43	0.91	-28	-0.58	9	0.12	240P03-1-78
66.19	1.07	60.00	56	0.95	-35	-0.54	11	0.20	240P03-1-78
78.78	1.05	72.00	66	0.91	-41	-0.45	14	0.25	240P03-1-78
91.47	1.04	84.00	78	0.95	-46	-0.54	17	0.20	240P03-1-78
103.95	1.03	96.00	89	0.95	-54	-0.54	19	0.16	240P03-1-78
116.34	1.03	108.00	101	0.91	-59	-0.50	21	0.29	240P03-1-78
128.73	1.01	120.00	111	0.95	-66	-0.50	26	0.29	240P03-1-78
140.71	1.01	132.00	124	0.95	-71	-0.54	28	0.12	240P03-1-78
152.99	1.02	144.00	134	0.87	-79	-0.54	29	0.16	240P03-1-78
165.17	1.02	156.00	145	0.83	-84	-0.50	32	0.12	240P03-1-78
177.56	1.02	168.00	154	0.83	-91	-0.50	32	0.08	240P03-1-78
189.64	1.01	180.00	165	0.95	-96	-0.54	34	0.25	240P03-1-78
201.92	1.02	192.00	177	0.95	-104	-0.58	38	0.25	240P03-1-78
214.11	1.01	204.00	188	0.95	-110	-0.50	40	0.16	240P03-1-78
226.09	1.01	216.00	200	0.95	-116	-0.58	42	0.16	240P03-1-78
238.27	1.01	228.00	211	0.95	-124	-0.58	44	0.25	240P03-1-78
250.45	1.01	240.00	223	0.95	-130	-0.58	48	0.25	240P03-1-78

LIST OF RAW DATA OF 20-DEGREE SPECIMEN(SUGAR PINE)

σ	dσ/dt	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε_{45}	$\frac{d\varepsilon_{45}}{dt}$	card control
15 MINUTES LOADING									
15.17	10.25	1.50	30	20.66	12	10.00	38	24.66	15P203-21-78
23.11	10.18	2.25	44	18.66	22	10.66	56	24.00	15P203-21-78
30.45	9.91	3.00	58	20.00	28	8.66	74	23.33	15P203-21-78
37.98	9.98	3.75	74	20.66	35	9.33	91	24.66	15P203-21-78
45.42	10.12	4.50	89	20.66	42	10.66	111	26.00	15P203-21-78
53.16	10.12	5.25	105	20.00	51	12.66	130	24.66	15P203-21-78
60.60	10.05	6.00	119	20.00	61	12.00	148	24.66	15P203-21-78
68.24	10.04	6.75	135	21.33	69	11.33	167	25.33	15P203-21-78
75.67	9.91	7.50	151	20.66	78	14.00	186	23.33	15P203-21-78
83.11	9.92	8.25	166	19.33	90	14.66	202	24.66	15P203-21-78
90.55	10.18	9.00	180	19.33	100	14.66	223	26.00	15P203-21-78
98.39	10.04	9.75	195	21.33	112	13.33	241	24.66	15P203-21-78
105.62	9.98	10.50	212	16.66	120	14.00	260	24.66	15P203-21-78
113.36	10.05	11.25	220	13.33	132	13.33	278	24.66	15P203-21-78
120.70	9.92	12.00	232	14.00	140	8.66	297	25.33	15P203-21-78
128.24	9.78	12.75	241	14.00	145	8.66	316	24.66	15P203-21-78
135.37	10.18	13.50	253	16.00	153	10.00	334	25.33	15P203-21-78
143.51	10.32	14.25	265	15.33	160	9.33	354	25.33	15P203-21-78
150.85	10.32	15.00	276	15.33	167	9.33	372	25.33	15P203-21-78
40 MINUTES LOADING									
14.67	3.69	4.00	30	7.50	16	4.75	36	8.75	40P203-13-78
22.21	3.71	6.00	44	7.00	27	5.50	53	8.50	40P203-13-78
29.54	3.66	8.00	58	7.25	38	6.00	70	9.00	40P203-13-78
36.88	3.62	10.00	73	7.75	51	6.00	89	9.25	40P203-13-78
44.02	3.64	12.00	89	7.25	62	6.00	107	9.25	40P203-13-78
51.45	3.66	14.00	102	7.25	75	7.00	126	9.00	40P203-13-78
58.69	3.69	16.00	118	7.50	90	6.25	143	9.00	40P203-13-78
66.23	3.71	18.00	132	7.25	100	6.00	162	9.25	40P203-13-78
73.56	3.66	20.00	147	7.00	114	6.25	180	8.75	40P203-13-78
80.90	3.62	22.00	160	6.75	125	5.50	197	8.50	40P203-13-78
88.04	3.66	24.00	174	7.00	136	6.00	214	9.00	40P203-13-78
95.57	3.66	26.00	188	7.50	149	6.25	233	9.25	40P203-13-78
102.71	3.62	28.00	204	8.00	161	6.00	251	8.75	40P203-13-78
110.05	3.69	30.00	220	8.25	173	5.75	268	9.00	40P203-13-78
117.48	3.66	32.00	237	8.25	184	6.00	287	8.50	40P203-13-78
124.72	3.64	34.00	253	7.75	197	6.75	302	9.00	40P203-13-78
132.06	3.62	36.00	268	8.50	211	5.50	323	9.50	40P203-13-78
139.19	3.59	38.00	287	8.75	219	3.25	340	8.75	40P203-13-78
146.43	3.59	40.00	303	8.75	224	3.25	358	8.75	40P203-13-78
100 MINUTES LOADING									
13.76	1.39	10.00	26	2.50	20	2.00	32	3.20	100P203-29-78
20.80	1.43	15.00	39	2.30	29	2.20	48	3.30	100P203-29-78
28.14	1.40	20.00	49	2.60	42	2.60	65	3.30	100P203-29-78
34.87	1.34	25.00	65	3.10	55	2.50	81	3.30	100P203-29-78
41.60	1.41	30.00	80	2.70	67	2.00	98	3.60	100P203-29-78
49.04	1.42	35.00	92	2.60	75	1.90	117	3.50	100P203-29-78
55.87	1.38	40.00	106	2.80	86	2.20	133	3.10	100P203-29-78
62.91	1.41	45.00	120	2.80	97	2.10	148	3.30	100P203-29-78
70.05	1.41	50.00	134	2.70	107	2.40	166	3.50	100P203-29-78
77.08	1.37	55.00	147	2.70	121	2.40	183	3.10	100P203-29-78
83.81	1.38	60.00	161	2.80	131	1.90	197	3.20	100P203-29-78
90.95	1.41	65.00	175	2.60	140	1.90	215	3.40	100P203-29-78
97.98	1.39	70.00	187	2.80	150	2.00	231	3.50	100P203-29-78
104.92	1.39	75.00	203	3.00	160	1.80	250	3.50	100P203-29-78
111.95	1.41	80.00	217	2.80	168	1.70	266	3.30	100P203-29-78
119.09	1.39	85.00	231	2.90	177	1.90	283	3.50	100P203-29-78
125.92	1.38	90.00	246	2.80	187	1.90	301	3.30	100P203-29-78
132.96	1.40	95.00	259	2.70	196	1.60	316	3.50	100P203-29-78
140.00	1.40	100.00	273	2.70	203	1.60	336	3.50	100P203-29-78
240 MINUTES LOADING									
14.17	0.59	24.00	32	1.20	7	0.41	27	1.20	240P203-5-78
21.20	0.59	36.00	47	1.20	14	0.54	42	1.25	240P203-5-78
28.34	0.59	48.00	61	1.20	20	0.50	57	1.29	240P203-5-78
35.37	0.58	60.00	76	1.20	26	0.54	73	1.29	240P203-5-78
42.31	0.58	72.00	90	1.20	33	0.70	88	1.37	240P203-5-78
49.34	0.59	84.00	105	1.16	43	0.79	106	1.41	240P203-5-78
56.46	0.58	96.00	118	1.16	52	0.75	122	1.41	240P203-5-78
63.41	0.59	108.00	133	1.12	61	0.87	140	1.45	240P203-5-78
70.65	0.58	120.00	145	1.20	73	0.91	157	1.45	240P203-5-78
77.38	0.57	132.00	162	1.20	83	0.79	175	1.41	240P203-5-78
84.42	0.57	144.00	174	1.16	92	0.75	191	1.41	240P203-5-78
91.25	0.57	156.00	190	1.29	101	0.83	209	1.50	240P203-5-78
98.19	0.58	168.00	205	1.12	112	0.91	227	1.45	240P203-5-78
105.22	0.57	180.00	218	1.20	123	0.83	244	1.41	240P203-5-78
111.96	0.57	192.00	234	1.29	132	0.87	261	1.50	240P203-5-78
118.89	0.57	204.00	249	1.29	144	0.91	280	1.45	240P203-5-78
125.82	0.57	216.00	265	1.29	154	0.87	296	1.45	240P203-5-78
132.56	0.57	228.00	280	1.29	165	0.87	315	1.50	240P203-5-78
139.49	0.57	240.00	296	1.29	175	0.87	332	1.50	240P203-5-78

LIST OF RAW DATA OF 35-DEGREE SPECIMEN(SUGAR PINE)

σ	$d\sigma/dt$	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε_{45}	$\frac{d\varepsilon_{45}}{dt}$	card control
15 MINUTES LOADING									
14.40	9.80	1.50	52	34.00	11	7.33	59	39.33	15P353-22-78
21.90	9.73	2.25	76	34.00	17	7.33	89	40.66	15P353-22-78
29.00	9.60	3.00	103	35.33	22	7.33	120	40.66	15P353-22-78
36.30	9.53	3.75	129	35.33	28	6.66	150	38.00	15P353-22-78
43.30	9.60	4.50	156	35.33	32	8.00	177	40.66	15P353-22-78
50.70	9.73	5.25	182	35.33	40	10.00	211	42.66	15P353-22-78
57.90	9.40	6.00	209	35.33	47	6.66	241	39.33	15P353-22-78
64.80	9.53	6.75	235	35.33	50	6.66	270	40.00	15P353-22-78
72.20	9.60	7.50	262	34.66	57	8.66	301	41.33	15P353-22-78
79.20	9.66	8.25	287	34.66	63	9.33	332	42.00	15P353-22-78
86.70	9.53	9.00	314	35.33	71	9.33	364	41.33	15P353-22-78
93.50	9.33	9.75	340	35.33	77	7.33	394	40.00	15P353-22-78
100.70	9.60	10.50	367	34.66	82	6.00	424	40.66	15P353-22-78
107.90	9.46	11.25	392	35.33	86	8.00	455	40.00	15P353-22-78
114.90	9.53	12.00	420	34.66	94	9.33	484	41.33	15P353-22-78
122.20	9.60	12.75	444	34.00	100	8.00	517	42.00	15P353-22-78
129.30	9.53	13.50	471	35.33	106	6.00	547	40.66	15P353-22-78
136.50	9.40	14.25	497	35.33	109	8.66	578	41.33	15P353-22-78
143.40	9.40	15.00	524	35.33	119	8.66	609	41.33	15P353-22-78
40 MINUTES LOADING									
14.30	3.70	4.00	53	12.50	14	2.50	59	14.25	40P353-14-78
21.80	3.65	6.00	79	13.75	19	3.00	88	15.00	40P353-14-78
28.90	3.57	8.00	108	13.50	26	3.25	119	15.00	40P353-14-78
36.10	3.60	10.00	133	13.25	32	3.00	148	14.50	40P353-14-78
43.30	3.57	12.00	161	13.75	38	3.00	177	15.75	40P353-14-78
50.40	3.62	14.00	188	13.00	44	2.75	211	16.25	40P353-14-78
57.80	3.62	16.00	213	13.25	49	2.75	242	15.25	40P353-14-78
64.90	3.60	18.00	241	13.75	55	3.25	272	15.25	40P353-14-78
72.20	3.62	20.00	268	13.25	62	3.25	303	15.50	40P353-14-78
79.40	3.60	22.00	294	13.25	68	3.25	334	15.25	40P353-14-78
86.60	3.57	24.00	321	13.50	75	3.00	364	15.50	40P353-14-78
93.70	3.57	26.00	348	13.50	80	3.25	396	15.50	40P353-14-78
100.90	3.60	28.00	375	13.75	88	3.50	426	14.75	40P353-14-78
108.10	3.62	30.00	403	13.00	94	2.75	455	15.00	40P353-14-78
115.40	3.60	32.00	427	13.00	99	3.00	486	16.00	40P353-14-78
122.50	3.60	34.00	455	13.50	106	3.50	519	15.75	40P353-14-78
129.80	3.60	36.00	481	13.25	113	3.00	549	15.50	40P353-14-78
136.90	3.55	38.00	508	13.75	118	2.75	581	16.00	40P353-14-78
144.00	3.55	40.00	536	13.75	124	2.75	613	16.00	40P353-14-78
100 MINUTES LOADING									
16.00	1.63	10.00	56	5.90	11	1.20	67	6.80	100P353-30-78
24.20	1.61	15.00	88	6.10	16	1.30	100	6.70	100P353-30-78
32.10	1.58	20.00	117	5.90	24	1.50	134	6.70	100P353-30-78
40.00	1.62	25.00	147	6.10	31	1.50	167	6.80	100P353-30-78
48.30	1.61	30.00	178	6.00	39	1.60	202	7.00	100P353-30-78
56.10	1.58	35.00	208	5.80	47	1.40	237	6.80	100P353-30-78
64.10	1.59	40.00	236	5.90	53	1.40	270	6.80	100P353-30-78
72.00	1.60	45.00	266	5.90	61	1.40	305	6.90	100P353-30-78
80.10	1.63	50.00	295	6.00	67	1.20	339	7.00	100P353-30-78
88.30	1.61	55.00	326	6.00	73	1.30	375	7.10	100P353-30-78
96.20	1.59	60.00	355	5.90	80	1.70	410	6.90	100P353-30-78
104.20	1.60	65.00	385	6.00	90	1.70	444	6.80	100P353-30-78
112.20	1.61	70.00	415	6.10	97	1.30	478	6.80	100P353-30-78
120.30	1.61	75.00	446	6.10	103	1.30	512	7.10	100P353-30-78
128.30	1.60	80.00	476	6.00	110	1.50	549	7.10	100P353-30-78
136.30	1.62	85.00	506	5.90	118	1.50	583	6.70	100P353-30-78
144.50	1.61	90.00	535	6.00	125	1.50	616	6.60	100P353-30-78
152.40	1.60	95.00	566	6.10	133	1.10	649	6.90	100P353-30-78
160.50	1.60	100.00	596	6.10	136	1.10	685	6.90	100P353-30-78
240 MINUTES LOADING									
13.90	0.58	24.00	54	2.16	10	0.33	57	2.45	240P353-6-78
20.90	0.58	36.00	80	2.12	12	0.25	87	2.50	240P353-6-78
28.00	0.57	48.00	105	2.20	16	0.29	117	2.45	240P353-6-78
34.70	0.57	60.00	133	2.25	19	0.33	146	2.41	240P353-6-78
41.80	0.57	72.00	159	2.41	24	0.45	145	2.37	240P353-6-78
48.40	0.57	84.00	191	2.62	30	0.50	203	2.37	240P353-6-78
55.50	0.55	96.00	222	2.70	36	0.45	232	2.54	240P353-6-78
61.70	0.55	108.00	256	3.20	41	0.41	264	2.50	240P353-6-78
68.90	0.58	120.00	299	3.33	46	0.50	292	2.37	240P353-6-78
75.70	0.56	132.00	336	3.00	53	0.62	321	2.50	240P353-6-78
82.40	0.56	144.00	371	2.70	61	0.58	352	2.50	240P353-6-78
89.30	0.56	156.00	401	2.29	67	0.54	381	2.41	240P353-6-78
95.90	0.56	168.00	426	2.20	74	0.50	410	2.45	240P353-6-78
102.70	0.56	180.00	454	2.20	79	0.45	440	2.45	240P353-6-78
109.30	0.56	192.00	479	2.04	85	0.50	469	2.37	240P353-6-78
116.10	0.55	204.00	503	2.08	91	0.58	497	2.33	240P353-6-78
122.60	0.55	216.00	529	2.08	99	0.54	525	2.50	240P353-6-78
129.20	0.55	228.00	553	2.00	104	0.45	557	2.54	240P353-6-78
136.00	0.55	240.00	577	2.00	110	0.45	586	2.54	240P353-6-78

LIST OF RAW DATA OF 50-DEGREE SPECIMEN(SUGAR PINE)

σ	dσ/dt	t	ε₍₁₁₎	dε₍₁₁₎/dt	ε⊥	dε⊥/dt	ε45	dε45/dt	card control
15 MINUTES LOADING									
13.20	5.20	2.50	98	40.00	12	5.20	83	33.60	15P503-24-78
19.70	5.20	3.75	150	43.60	19	5.20	126	34.00	15P503-24-78
26.20	5.20	5.00	207	46.40	25	4.80	168	33.60	15P503-24-78
32.70	5.00	6.25	266	48.00	31	5.20	210	33.60	15P503-24-78
38.70	5.16	7.50	327	42.80	38	4.80	252	33.60	15P503-24-78
45.60	5.24	8.75	373	38.80	43	4.80	294	33.20	15P503-24-78
51.80	5.04	10.00	424	40.00	50	5.20	335	32.80	15P503-24-78
58.20	5.08	11.25	473	44.00	56	4.80	376	34.40	15P503-24-78
64.50	5.04	12.50	534	46.40	62	4.80	421	34.40	15P503-24-78
70.80	5.04	13.75	589	45.60	68	5.20	462	33.20	15P503-24-78
77.10	5.04	15.00	648	45.60	75	5.20	504	33.20	15P503-24-78
40 MINUTES LOADING									
13.90	2.02	6.67	100	15.40	13	1.79	87	12.89	40P503-16-78
20.90	2.09	10.00	152	15.59	18	1.79	130	13.34	40P503-16-78
27.90	2.05	13.33	204	16.34	25	2.09	176	13.34	40P503-16-78
34.60	2.01	16.67	261	17.24	32	1.94	219	13.19	40P503-16-78
41.30	2.05	20.00	319	18.44	38	1.79	264	13.79	40P503-16-78
48.30	2.08	23.33	384	18.89	44	2.09	311	13.64	40P503-16-78
55.20	2.02	26.67	445	17.99	52	2.09	355	13.34	40P503-16-78
61.80	2.05	30.00	504	18.59	58	1.94	400	14.09	40P503-16-78
68.90	2.06	33.33	569	19.34	65	1.94	449	13.94	40P503-16-78
75.60	2.01	36.67	633	18.74	71	2.09	493	13.49	40P503-16-78
82.30	2.01	40.00	694	18.74	79	2.09	539	13.49	40P503-16-78
100 MINUTES LOADING									
13.40	0.79	16.67	96	5.93	11	0.71	85	4.85	100P504-1-78
19.90	0.79	25.00	146	6.05	18	0.83	122	5.20	100P504-1-78
26.60	0.80	33.33	197	6.41	25	0.83	172	5.51	100P504-1-78
33.30	0.80	41.67	253	6.95	32	0.83	214	5.27	100P504-1-78
40.00	0.78	50.00	313	6.89	39	0.83	260	5.39	100P504-1-78
46.40	0.78	58.33	368	6.17	46	0.83	304	5.21	100P504-1-78
53.00	0.80	66.67	416	6.23	53	0.71	347	5.33	100P504-1-78
59.80	0.77	75.00	472	6.53	58	0.71	393	5.33	100P504-1-78
66.00	0.76	83.33	525	6.11	65	0.83	436	5.15	100P504-1-78
72.50	0.77	91.66	574	5.63	72	0.83	479	5.27	100P504-1-78
79.00	0.77	100.00	619	5.63	79	0.83	524	5.27	100P504-1-78
240 MINUTES LOADING									
12.90	0.33	40.00	94	2.55	9	0.27	84	2.15	240P503-8-78
19.70	0.33	60.00	146	2.52	16	0.27	127	2.15	240P503-8-78
26.20	0.33	80.00	195	2.45	20	0.32	170	2.17	240P503-8-78
32.90	0.33	100.00	244	2.82	29	0.40	214	2.40	240P503-8-78
39.70	0.34	120.00	308	3.17	36	0.35	266	2.67	240P503-8-78
46.60	0.34	140.00	371	2.90	43	0.40	321	2.60	240P503-8-78
53.40	0.34	160.00	424	2.62	52	0.40	370	2.37	240P503-8-78
60.40	0.35	180.00	476	2.45	59	0.37	416	2.32	240P503-8-78
67.40	0.34	200.00	522	2.45	67	0.37	463	2.32	240P503-8-78
74.00	0.33	220.00	574	2.65	74	0.37	509	2.30	240P503-8-78
80.50	0.33	240.00	628	2.65	82	0.37	555	2.30	240P503-8-78

LIST OF RAW DATA OF 65-DEGREE SPECIMEN(SUGAR PINE)

σ	dσ/dt	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε45	$\frac{d\varepsilon 45}{dt}$	card control
15 MINUTES LOADING									
12.66	5.02	2.50	106	45.20	2	0.40	87	34.00	15P653-24-78
18.99	5.06	3.75	164	45.60	2	0.40	130	34.40	15P653-24-78
25.32	5.10	5.00	220	46.40	3	0.80	173	34.40	15P653-24-78
31.70	5.18	6.25	280	46.40	4	0.80	216	35.60	15P653-24-78
38.29	5.02	7.50	336	45.20	5	0.60	262	37.60	15P653-24-78
44.32	4.90	8.75	393	45.20	6	0.80	310	38.00	15P653-24-78
50.55	4.98	10.00	449	46.40	7	0.80	357	36.40	15P653-24-78
56.78	5.02	11.25	509	46.80	8	0.80	401	36.80	15P653-24-78
63.11	5.02	12.50	566	46.60	9	0.80	449	38.00	15P653-24-78
69.34	4.98	13.75	623	46.40	10	0.80	496	38.40	15P653-24-78
75.57	4.98	15.00	682	46.40	11	0.80	545	38.40	15P653-24-78
40 MINUTES LOADING									
13.96	2.07	6.67	117	18.20	4	0.59	95	14.39	40P653-16-78
20.80	2.11	10.00	178	18.29	5	0.29	142	14.24	40P653-16-78
28.04	2.12	13.33	239	18.59	6	0.29	190	14.69	40P653-16-78
34.97	2.09	16.67	302	19.04	7	0.29	240	15.14	40P653-16-78
42.01	2.10	20.00	366	19.34	8	0.29	291	16.19	40P653-16-78
49.04	2.09	23.33	431	19.19	9	0.59	348	16.64	40P653-16-78
55.97	2.07	26.67	494	18.89	12	0.44	402	15.59	40P653-16-78
62.91	2.09	30.00	557	19.34	12	0.29	452	14.69	40P653-16-78
69.94	2.10	33.33	623	19.49	14	0.59	500	14.84	40P653-16-78
76.98	2.11	36.67	687	19.19	16	0.29	551	15.44	40P653-16-78
84.02	2.11	40.00	751	19.19	16	0.29	603	15.44	40P653-16-78
100 MINUTES LOADING									
12.66	0.75	16.67	115	6.77	5	0.11	89	5.51	100P654-1-78
18.89	0.75	25.00	172	6.77	5	0.05	136	5.57	100P654-1-78
25.22	0.71	33.33	228	6.77	6	0.17	182	5.39	100P654-1-78
30.75	0.67	41.67	285	6.65	8	0.17	226	5.27	100P654-1-78
36.48	0.68	50.00	339	6.29	9	0.11	272	4.91	100P654-1-78
42.11	0.66	58.33	390	6.11	10	0.11	314	4.91	100P654-1-78
47.63	0.63	66.67	441	6.05	11	0.11	354	4.49	100P654-1-78
52.66	0.60	75.00	491	5.87	12	0.11	389	4.19	100P654-1-78
57.78	0.61	83.33	539	5.93	13	0.11	424	4.25	100P654-1-78
62.91	0.62	91.66	590	5.99	14	0.11	460	4.37	100P654-1-78
68.14	0.62	100.00	639	5.94	15	0.11	497	4.37	100P654-1-78
240 MINUTES LOADING									
13.66	0.34	40.00	123	2.85	-2	0.05	101	2.35	240653-8-78
20.70	0.34	60.00	179	3.02	-2	0.07	146	2.32	240653-8-78
27.33	0.33	80.00	244	3.27	1	0.10	194	2.45	240653-8-78
34.07	0.34	100.00	310	3.17	2	0.05	244	2.67	240653-8-78
41.10	0.33	120.00	371	3.20	3	0.05	301	2.85	240653-8-78
47.53	0.33	140.00	438	3.27	4	0.07	358	2.82	240653-8-78
54.57	0.33	160.00	502	3.12	6	0.07	414	2.62	240653-8-78
61.00	0.33	180.00	563	3.25	7	0.05	463	2.45	240653-8-78
67.93	0.35	200.00	632	3.57	8	0.07	512	2.60	240653-8-78
75.07	0.36	220.00	706	3.82	10	0.10	567	2.72	240653-8-78
82.51	0.36	240.00	785	3.82	12	0.10	621	2.72	240653-8-78

LIST OF RAW DATA OF 90-DEGREE SPECIMEN(SUGAR PINE)

σ	$d\sigma/dt$	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε_{45}	$\frac{d\varepsilon_{45}}{dt}$	card control
15 MINUTES LOADING									
11.87	5.08	2.50	143	60.80	-5	-1.60	76	32.40	15P903-24-78
18.95	5.46	3.75	227	65.20	-8	-2.80	120	34.80	15P903-24-78
25.52	5.25	5.00	306	63.60	-12	-2.80	163	34.00	15P903-24-78
32.08	5.04	6.25	386	63.60	-15	-1.60	205	33.20	15P903-24-78
38.12	5.24	7.50	465	65.60	-16	-1.20	246	34.80	15P903-24-78
45.20	5.12	8.75	550	62.40	-18	-1.20	292	33.60	15P903-24-78
50.93	4.87	10.00	621	60.00	-19	-1.60	330	32.40	15P903-24-78
57.39	5.08	11.25	700	64.00	-22	-2.00	373	34.00	15P903-24-78
63.64	5.04	12.50	781	64.80	-24	-1.60	415	33.60	15P903-24-78
70.00	4.96	13.75	862	64.00	-26	-1.60	457	32.40	15P903-24-78
76.04	4.96	15.00	941	64.00	-28	-1.60	496	32.40	15P903-24-78
40 MINUTES LOADING									
14.27	2.12	6.67	159	25.18	-6	-0.59	89	13.64	40P904-1-78
21.45	2.18	10.00	244	25.33	-8	-0.74	135	13.64	40P904-1-78
28.85	2.13	13.33	328	25.48	-11	-0.74	180	13.64	40P904-1-78
35.72	2.12	16.67	414	25.63	-13	-0.59	226	13.94	40P904-1-78
43.02	2.14	20.00	499	24.88	-15	-0.74	273	14.09	40P904-1-78
50.00	2.17	23.33	580	23.98	-18	-0.89	320	13.79	40P904-1-78
57.50	2.16	26.67	659	25.48	-21	-0.74	365	14.09	40P904-1-78
64.47	2.12	30.00	750	26.08	-23	-0.74	414	14.39	40P904-1-78
71.66	2.10	33.33	833	26.08	-26	-0.74	461	14.39	40P904-1-78
78.54	2.07	36.67	924	27.13	-28	-0.59	510	14.54	40P904-1-78
85.52	2.07	40.00	1014	27.13	-30	-0.59	558	14.54	40P904-1-78
100 MINUTES LOADING									
10.93	0.77	16.67	135	9.29	-6	-0.29	70	4.97	100F904-1-78
18.33	0.89	25.00	223	10.97	-9	-0.29	117	5.81	100P904-1-78
25.93	0.92	33.33	318	11.39	-11	-0.29	167	6.05	100F904-1-78
33.75	0.91	41.67	413	11.33	-14	-0.35	218	6.05	100P904-1-78
41.14	0.89	50.00	507	11.27	-17	-0.35	268	6.05	100P904-1-78
48.75	0.91	58.33	601	11.33	-20	-0.47	319	6.23	100P904-1-78
56.45	0.92	66.67	696	11.63	-25	-0.47	372	6.41	100P904-1-78
64.16	0.89	75.00	795	12.41	-28	-0.35	426	6.35	100F904-1-78
71.45	0.88	83.33	903	12.65	-31	-0.35	478	6.11	100P904-1-78
78.95	0.89	91.67	1006	12.71	-34	-0.35	528	6.29	100P904-1-78
86.45	0.89	100.00	1115	12.71	-37	-0.35	583	6.29	100P904-1-78
240 MINUTES LOADING									
15.93	0.38	40.00	202	4.92	-10	-0.17	108	2.70	240P903-8-78
23.54	0.38	60.00	303	4.85	-13	-0.20	162	2.67	240P903-8-78
31.45	0.39	80.00	396	4.65	-18	-0.15	215	2.67	240P903-8-78
39.37	0.39	100.00	489	4.52	-19	-0.15	269	2.70	240P903-8-78
47.29	0.38	120.00	577	4.47	-24	-0.15	323	2.67	240P903-8-78
54.89	0.38	140.00	668	4.67	-25	-0.07	376	2.65	240P903-8-78
62.60	0.39	160.00	764	4.67	-27	-0.22	429	2.60	240P903-8-78
70.62	0.39	180.00	855	4.65	-34	-0.17	480	2.57	240P903-8-78
78.54	0.39	200.00	950	4.95	-37	-0.15	532	2.67	240P903-8-78
86.25	0.39	220.00	1053	5.15	-40	-0.17	587	2.67	240P903-8-78
94.37	0.39	240.00	1156	5.15	-44	-0.17	639	2.67	240P903-8- 8

6LIST OF RAW DATA ZERO DEGREE SPECIMEN (REDWOOD)

σ	$d\sigma/dt$	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε_{45}	$\frac{d\varepsilon_{45}}{dt}$	card control
15 MINUTES LOADING									
28.88	19.52	1.50	17	12.66	-8	-6.00	8	5.33	15R03-17-78
43.63	19.60	2.25	27	12.66	-12	-6.66	12	4.66	15R03-17-78
58.28	19.73	3.00	36	14.00	-18	-5.33	15	5.33	15R03-17-78
73.23	19.52	3.75	48	14.66	-20	-5.33	20	6.00	15R03-17-78
87.57	19.32	4.50	58	13.33	-26	-6.00	24	5.33	15R03-17-78
102.22	19.39	5.25	68	13.33	-29	-5.33	28	4.66	15R03-17-78
116.66	19.26	6.00	78	13.33	-34	-6.00	31	4.66	15R03-17-78
131.11	19.39	6.75	88	14.00	-38	-6.00	35	6.00	15R03-17-78
145.75	19.46	7.50	99	14.00	-43	-5.33	40	6.66	15R03-17-78
160.30	19.06	8.25	109	13.33	-46	-4.66	45	5.33	15R03-17-78
174.34	19.26	9.00	119	14.00	-50	-6.00	48	4.66	15R03-17-78
189.19	19.59	9.75	130	14.00	-55	-5.33	52	6.66	15R03-17-78
203.73	19.52	10.50	140	13.33	-58	-4.66	58	5.33	15R03-17-78
218.48	19.53	11.25	150	13.33	-62	-5.33	60	4.00	15R03-17-78
233.03	19.52	12.00	160	14.66	-66	-5.33	64	5.33	15R03-17-78
247.77	19.79	12.75	172	13.33	-70	-6.66	68	5.33	15R03-17-78
262.72	19.53	13.50	180	13.33	-76	-6.66	72	6.66	15R03-17-78
277.07	19.39	14.25	192	14.66	-80	-5.33	78	6.66	15R03-17-78
291.81	19.39	15.00	202	14.66	-84	-5.33	82	6.66	15R03-17-78
40 MINUTES LOADING									
30.30	7.57	4.00	21	5.00	-10	-2.50	9	2.25	40R03-9-78
45.45	7.55	6.00	30	4.75	-16	-2.50	13	2.00	40R03-9-78
60.50	7.55	8.00	40	5.25	-20	-2.00	17	2.00	40R03-9-78
75.65	7.55	10.00	51	5.25	-24	-2.00	21	2.25	40R03-9-78
90.70	7.55	12.00	61	5.25	-28	-2.25	26	2.00	40R03-9-78
105.85	7.57	14.00	72	5.00	-33	-2.25	29	2.00	40R00978
121.01	7.50	16.00	81	5.00	-37	-2.25	34	2.50	40R03-9-78
135.85	7.52	18.00	92	5.50	-42	-2.00	39	2.25	40R03-9-78
151.11	7.55	20.00	103	5.25	-45	-1.75	43	2.00	40R03-9-78
166.06	7.47	22.00	113	5.00	-49	-2.25	47	2.00	40R03-9-78
181.01	7.52	24.00	123	5.25	-54	-2.25	51	2.25	40R03-9-78
196.16	7.57	26.00	134	5.75	-58	-2.50	58	2.25	40R03-9-78
211.31	7.52	28.00	146	5.50	-64	-2.50	60	1.50	40R03-9-78
226.26	7.52	30.00	156	4.50	-68	-2.00	64	2.00	40R03-9-78
241.41	7.52	32.00	164	5.00	-72	-1.50	68	2.50	40R03-9-78
256.36	7.47	34.00	176	5.50	-74	-2.00	74	2.50	40R03-9-78
271.31	7.52	36.00	186	5.50	-80	-2.00	78	2.00	40R03-9-78
286.46	7.57	38.00	198	5.00	-82	-1.50	82	2.00	40R03-9-78
301.61	7.57	40.00	206	5.00	-86	-1.50	86	2.00	40R03-9-78
100 MINUTES LOADING									
28.58	2.87	10.00	17	1.80	-9	-0.80	7	0.80	100R03-25-78
43.03	2.87	15.00	26	1.80	-13	-0.90	12	0.90	100R03-25-78
57.37	2.83	20.00	35	1.80	-18	-0.80	16	0.70	100R03-25-78
71.41	2.83	25.00	44	1.90	-21	-0.70	19	0.80	100R03-25-78
85.75	2.84	30.00	54	2.00	-25	-0.80	24	0.80	100R03-25-78
99.89	2.83	35.00	64	2.10	-29	-0.80	27	0.60	100R03-25-78
114.14	2.87	40.00	75	1.90	-33	-0.80	30	0.80	100R03-25-78
128.68	2.86	45.00	83	1.90	-37	-1.10	35	0.90	100R03-25-78
142.82	2.85	50.00	94	2.10	-44	-1.00	39	0.70	100R03-25-78
157.27	2.85	55.00	104	2.10	-47	-0.60	42	0.70	100R03-25-78
171.41	2.83	60.00	115	2.00	-50	-0.80	46	0.80	100R03-25-78
185.65	2.84	65.00	124	1.70	-55	-1.00	50	0.80	100R03-25-78
199.89	2.81	70.00	132	2.00	-60	-0.90	54	0.80	100R03-25-78
213.83	2.82	75.00	144	2.00	-64	-0.80	58	0.80	100R03-25-78
228.16	2.82	80.00	152	1.80	-68	-0.80	62	0.80	100R03-25-78
242.12	2.82	85.00	162	2.00	-72	-0.80	66	0.80	100R03-25-78
256.46	2.86	90.00	172	1.90	-76	-1.00	70	1.00	100R03-25-78
270.80	2.84	95.00	181	2.00	-82	-1.20	76	1.00	100R03-25-78
284.94	2.84	100.00	192	2.00	-88	-1.20	80	1.00	100R03-25-78
240 MINUTES LOADING									
24.94	1.02	24.00	18	0.66	-4	-0.12	5	0.25	240R03-1-78
36.96	1.02	36.00	28	0.75	-7	-0.29	9	0.33	240R03-1-78
49.49	1.03	48.00	36	0.66	-11	-0.25	13	0.33	240R03-1-78
61.71	1.02	60.00	44	0.75	-13	-0.25	17	0.33	240R03-1-78
74.14	1.02	72.00	54	0.70	-17	-0.33	21	0.29	240R03-1-78
86.26	1.02	84.00	61	0.66	-21	-0.37	24	0.33	240R03-1-78
98.68	1.03	96.00	70	0.79	-26	-0.29	29	0.33	240R03-1-78
111.01	1.03	108.00	80	0.75	-28	-0.29	32	0.25	240R03-1-78
123.43	1.02	120.00	88	0.66	-33	-0.41	35	0.25	240R03-1-78
135.55	1.01	132.00	96	0.66	-38	-0.29	38	0.29	240R03-1-78
147.77	1.02	144.00	104	0.70	-40	-0.25	42	0.33	240R03-1-78
160.10	1.03	156.00	113	0.58	-44	-0.33	46	0.33	240R03-1-78
172.62	1.06	168.00	118	0.70	-48	-0.41	50	0.29	240R03-1-78
185.65	1.01	180.00	130	0.83	-54	-0.33	53	0.33	240R03-1-78
196.76	0.98	192.00	138	0.66	-56	-0.25	58	0.29	240R03-1-78
209.09	1.02	204.00	146	0.66	-60	-0.33	60	0.16	240R03-1-78
221.21	1.01	216.00	154	0.66	-64	-0.25	62	0.25	240R03-1-78
233.33	1.01	228.00	162	0.66	-66	-0.25	66	0.25	240R03-1-78
245.54	1.01	240.00	170	0.66	-70	-0.25	68	0.25	240R03-1-78

LIST OF RAW DATA 35-DEGREE SPECIMEN (REDWOOD)

σ	$d\sigma/dt$	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε_{45}	$\frac{d\varepsilon_{45}}{dt}$	card control
15 MINUTES LOADING									
29.44	19.56	1.50	77	48.66	-16	-8.66	60	39.33	15R353-17-78
44.06	19.42	2.25	112	46.66	-22	-8.66	89	40.00	15R353-17-78
58.57	19.69	3.00	147	48.66	-29	-9.33	120	40.00	15R353-17-78
73.60	19.49	3.75	185	48.66	-36	-9.33	149	38.66	15R353-17-78
87.81	19.08	4.50	220	48.00	-43	-9.33	178	39.33	15R353-17-78
102.23	19.80	5.25	257	48.66	-50	-9.33	208	39.33	15R353-17-78
116.44	19.49	6.00	293	48.00	-57	-8.00	237	39.33	15R353-17-78
131.47	19.90	6.75	329	48.66	-62	-8.00	267	41.33	15R353-17-78
146.29	19.56	7.50	366	49.33	-69	-9.33	299	41.33	15R353-17-78
160.81	19.42	8.25	403	49.33	-76	-10.00	329	40.66	15R353-17-78
175.43	19.62	9.00	440	48.66	-84	-10.00	360	40.66	15R353-17-78
190.25	19.76	9.75	476	48.00	-91	-9.33	390	41.33	15R353-17-78
205.07	19.76	10.50	512	49.33	-98	-8.66	422	44.00	15R353-17-78
219.89	19.90	11.25	550	48.00	-104	-10.66	456	44.00	15R353-17-78
234.92	19.49	12.00	584	49.33	-114	-9.33	488	42.66	15R353-17-78
249.13	19.35	12.75	624	49.33	-118	-8.00	520	44.00	15R353-17-78
263.95	19.49	13.50	658	49.33	-126	-9.33	554	45.33	15R353-17-78
278.37	19.22	14.25	698	49.33	-132	-8.00	588	42.66	15R353-17-78
292.79	19.22	15.00	732	49.33	-138	-8.00	618	42.66	15R353-17-78
30.45	7.64	4.00	75	18.75	-14	-3.25	60	15.50	40R353-9-78
40 MINUTES LOADING									
45.78	7.61	6.00	111	18.75	-21	-3.75	92	15.50	40R353-9-78
60.91	7.61	8.00	150	19.00	-29	-3.50	122	15.25	40R353-9-78
76.24	7.64	10.00	187	18.75	-35	-3.25	153	16.00	40R353-9-78
91.47	7.61	12.00	225	18.75	-42	-3.50	186	16.25	40R353-9-78
106.70	7.58	14.00	262	19.00	-49	-3.50	218	15.75	40R353-9-78
121.82	7.51	16.00	301	19.25	-56	-3.75	249	16.00	40R353-9-78
136.75	7.56	18.00	339	19.00	-64	-3.50	282	16.25	40R353-9-78
152.08	7.66	20.00	377	19.00	-70	-3.00	314	16.00	40R353-9-78
167.41	7.61	22.00	415	18.50	-76	-3.50	346	16.25	40R353-9-78
182.53	7.58	24.00	451	18.75	-84	-3.50	379	16.50	40R353-9-78
197.76	7.56	26.00	490	19.25	-90	-3.50	412	17.25	40R353-9-78
212.79	7.56	28.00	528	19.00	-98	-3.50	448	17.00	40R353-9-78
228.02	7.56	30.00	566	19.00	-104	-3.00	480	16.50	40R353-9-78
243.04	7.56	32.00	604	19.00	-110	-3.50	514	16.50	40R353-9-78
258.27	7.61	34.00	642	19.00	-118	-3.50	546	16.50	40R353-9-78
273.50	7.51	36.00	680	19.50	-124	-3.50	580	17.00	40R353-9-78
288.32	7.56	38.00	720	19.50	-132	-3.50	614	17.00	40R353-9-78
303.75	7.56	40.00	756	19.00	-138	-3.50	648	17.00	40R353-9-78
100 MINUTES LOADING									
28.12	2.84	10.00	70	6.80	-15	-1.10	57	5.80	100R353-26-78
42.23	2.78	15.00	104	7.20	-20	-1.10	86	5.80	100R353-26-78
55.93	2.80	20.00	142	7.30	-26	-1.40	115	5.70	100R353-26-78
70.25	2.80	25.00	177	7.00	-34	-1.00	143	5.80	100R353-26-78
83.95	2.76	30.00	212	7.10	-39	-1.10	173	6.10	100R353-26-78
97.86	2.80	35.00	248	7.20	-45	-1.30	204	6.00	100R353-26-78
111.97	2.81	40.00	284	7.00	-52	-1.30	233	5.80	100R353-26-78
125.98	2.79	45.00	318	7.00	-58	-1.40	262	6.10	100R353-26-78
139.89	2.81	50.00	354	6.90	-66	-1.40	294	6.10	100R353-26-78
154.11	2.78	55.00	387	7.10	-72	-1.10	323	6.00	100R353-26-78
167.71	2.77	60.00	425	8.00	-77	-1.10	354	6.10	100R353-26-78
181.82	2.81	65.00	467	7.10	-83	-1.30	384	6.40	100R353-26-78
195.83	2.84	70.00	496	6.50	-90	-1.30	418	6.60	100R353-26-78
210.25	2.80	75.00	532	7.20	-96	-1.20	450	6.40	100R353-26-78
223.85	2.72	80.00	568	7.20	-102	-1.40	482	5.80	100R353-26-78
237.47	2.80	85.00	604	7.00	-110	-1.40	508	4.60	100R353-26-78
251.87	2.84	90.00	638	7.00	-116	-1.40	528	5.00	100R353-26-78
265.88	2.76	95.00	674	7.20	-124	-1.40	558	5.20	100R353-26-78
279.49	2.76	100.00	710	7.20	-130	-1.40	580	5.20	100R353-26-78
240 MINUTES LOADING									
24.26	1.01	24.00	60	2.54	-8	-0.29	48	2.12	240R353-2-78
36.24	0.99	36.00	91	2.54	-13	-0.45	74	2.16	240R353-2-78
48.22	1.00	48.00	121	2.54	-19	-0.50	100	2.12	240R353-2-78
60.40	1.01	60.00	152	2.58	-25	-0.45	125	2.08	240R353-2-78
72.58	1.01	72.00	183	2.50	-30	-0.45	150	2.12	240R353-2-78
84.67	1.01	84.00	212	2.54	-36	-0.45	176	2.29	240R353-2-78
96.85	1.00	96.00	244	2.54	-41	-0.50	205	2.33	240R353-2-78
108.83	0.99	108.00	273	2.54	-47	-0.54	232	2.33	240R353-2-78
120.71	0.99	120.00	305	2.54	-53	-0.45	261	2.45	240R353-2-78
132.69	0.98	132.00	334	2.45	-60	-0.41	291	2.41	240R353-2-78
144.26	0.97	144.00	364	2.50	-64	-0.41	319	2.25	240R353-2-78
155.93	0.96	156.00	394	2.41	-70	-0.41	345	2.20	240R353-2-78
167.41	0.96	168.00	422	2.41	-74	-0.45	372	2.16	240R353-2-78
178.98	0.96	180.00	452	2.50	-80	-0.50	397	2.16	240R353-2-78
190.55	0.98	192.00	482	2.58	-85	-.50	424	2.20	240R353-2-78
202.63	0.96	204.00	514	2.50	-92	-0.45	450	2.16	240R353-2-78
213.80	0.95	216.00	542	2.41	-96	-0.41	476	2.08	240R353-2-78
225.38	0.95	228.00	572	2.50	-102	-0.41	500	2.16	240R353-2-78
236.54	0.95	240.00	602	2.50	-106	0.41	528	2.16	240R353-2-78

LIST OF RAW DATA 50-DEGREE SPECIMEN (REDWOOD)

σ	$d\sigma/dt$	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε_{45}	$\frac{d\varepsilon_{45}}{dt}$	card control
15 MINUTES LOADING									
30.15	14.08	2.14	104	50.00	-14	-6.07	95	44.39	15R503-24-78
45.22	14.27	3.21	159	51.40	-21	-5.60	142	44.39	15R503-24-78
60.70	14.18	4.28	214	50.46	-26	-5.60	190	43.45	15R503-24-78
75.57	13.76	5.35	267	49.06	-33	-6.54	235	44.39	15R503-24-78
90.15	14.28	6.42	319	50.93	-40	-6.54	285	44.85	15R503-24-78
106.13	14.32	7.50	376	51.86	-47	-6.07	331	42.52	15R503-24-78
120.80	13.99	8.57	430	50.93	-53	-5.14	376	42.52	15R503-24-78
136.08	14.08	9.64	485	51.40	-58	-5.60	422	42.99	15R503-24-78
150.95	14.08	10.71	540	50.46	-65	-6.07	468	42.05	15R503-24-78
166.23	14.08	11.78	593	51.86	-71	-4.20	512	42.05	15R503-24-78
181.10	13.94	12.85	651	51.86	-74	-2.80	558	42.05	15R503-24-78
196.08	13.94	13.92	704	50.00	-77	-2.80	602	42.05	15R503-24-78
210.95	13.94	15.00	758	50.00	-80	-2.80	648	42.05	15R503-24-78
40 MINUTES LOADING									
30.25	5.28	5.71	102	18.56	-11	-2.10	91	16.11	40R503-16-78
45.38	5.31	8.57	156	18.56	-18	-2.10	137	16.28	40R503-16-78
60.60	5.28	11.43	208	18.91	-23	-1.92	184	16.11	40R503-16-78
75.53	5.33	14.29	264	19.43	-29	-2.10	229	15.93	40R503-16-78
91.06	5.31	17.14	319	19.08	-35	-2.27	275	16.28	40R503-16-78
105.88	5.21	20.00	373	19.08	-42	-2.10	322	16.46	40R503-16-78
120.81	5.26	22.86	428	19.26	-47	-1.92	369	15.93	40R503-16-78
135.93	5.28	25.71	483	19.08	-53	-1.92	413	15.76	40R503-16-78
150.96	5.26	28.57	537	19.26	-58	-1.40	459	16.11	40R503-16-78
165.98	5.29	31.43	593	19.61	-62	-1.57	505	15.93	40R503-16-78
181.21	5.29	34.29	649	19.43	-67	-1.75	550	15.93	40R503-16-78
196.24	5.29	37.14	704	19.08	-72	-1.75	596	16.46	40R503-16-78
211.47	5.29	40.00	758	19.08	-77	-1.75	644	16.46	40R503-16-78
100 MINUTES LOADING									
30.15	2.09	14.28	100	7.49	-17	-0.84	89	6.51	100R504-1-78
45.17	2.10	21.42	153	7.42	-23	-0.84	137	6.65	100R504-1-78
60.20	2.10	28.57	206	7.56	-29	-0.84	184	6.51	100R504-1-78
75.22	2.09	35.71	261	7.56	-35	-0.91	230	6.44	100R504-1-78
90.15	2.09	42.85	314	7.49	-42	-0.91	276	6.44	100R504-1-78
105.17	2.10	50.00	368	7.63	-48	-0.84	322	6.37	100R504-1-78
120.20	2.10	57.14	423	7.63	-54	-0.84	367	6.37	100R504-1-78
135.22	2.11	64.28	477	7.56	-60	-0.63	413	6.37	100R504-1-78
150.35	2.11	71.42	531	7.56	-63	-0.63	458	6.37	100R504-1-78
240 MINUTES LOADING									
28.32	0.84	34.28	97	3.03	-10	-0.29	86	2.59	240R503-7-78
42.33	0.84	51.42	148	3.00	-14	-0.29	130	2.62	240R503-7-78
57.15	0.81	68.57	200	2.94	-20	-0.32	176	2.50	240R503-7-78
70.35	0.78	85.71	249	2.88	-25	-0.32	216	2.42	240R503-7-78
84.16	0.81	102.85	299	2.85	-31	-0.29	259	2.50	240R503-7-78
98.07	0.81	120.00	347	2.82	-35	-0.35	302	2.47	240R503-7-78
112.78	0.81	137.14	396	2.94	-43	-0.46	344	2.47	240R503-7-78
125.78	0.80	154.29	448	3.03	-51	-0.43	387	2.45	240R503-7-78
139.69	0.81	171.43	500	3.00	-58	-0.35	428	2.42	240R503-7-78
153.50	0.80	188.57	551	2.94	-63	-0.20	470	2.45	240R503-7-78
167.30	0.80	205.71	601	2.94	-65	-0.20	512	2.45	240R503-7-78

LIST OF RAW DATA OF 65-DEGREE SPECIMEN(REDWOOD)

σ	$d\sigma/dt$	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε_{45}	$\frac{d\varepsilon_{45}}{dt}$	card control
15 MINUTES LOADING									
14.47	9.51	1.50	57	38.00	-7	-3.33	41	26.66	15R653-22-78
21.70	9.58	2.25	84	37.33	-9	-3.33	61	26.66	15R653-22-78
28.84	9.51	30.00	113	40.00	-12	-4.00	81	27.33	15R653-22-78
35.97	9.64	3.75	144	40.66	-15	-4.66	102	28.66	15R653-22-78
43.31	9.78	4.50	174	39.33	-19	-4.00	124	27.33	15R653-22-78
50.65	9.58	5.25	203	39.33	-21	-4.66	143	26.66	15R653-22-78
57.68	9.38	6.00	233	40.00	-26	-4.00	164	27.33	15R653-22-78
64.72	9.31	6.75	263	39.33	-27	-2.66	184	26.00	15R653-22-78
71.65	9.38	7.50	292	39.33	-30	-4.00	203	26.00	15R653-22-78
78.79	9.51	8.25	322	38.66	-33	-4.66	223	27.33	15R653-22-78
85.92	9.64	9.00	350	40.00	-37	-4.66	244	28.66	15R653-22-78
93.26	9.58	9.75	382	41.33	-40	-2.66	266	26.66	15R653-22-78
100.30	9.38	10.50	412	38.66	-41	-3.33	284	25.33	15R653-22-78
107.33	9.38	11.25	440	40.00	-45	-4.66	304	26.66	15R653-22-78
114.37	9.44	12.00	472	41.33	-48	-4.00	324	26.66	15R653-22-78
121.50	9.64	12.75	502	40.00	-51	-5.33	344	26.66	15R653-22-78
128.84	9.72	13.50	532	41.33	-55	-4.00	364	26.66	15R653-22-78
136.08	9.31	14.25	564	42.66	-57	-3.33	384	27.33	15R653-22-78
142.81	9.31	15.00	596	42.66	-60	-3.33	405	27.33	15R653-22-78
40 MINUTES LOADING									
14.27	3.66	4.00	56	14.25	-8	-1.50	39	10.00	40R653-14-78
21.80	3.61	6.00	84	14.50	-10	-1.25	59	10.00	40R653-14-78
28.74	3.57	8.00	114	15.00	-13	-1.50	79	10.25	40R653-14-78
36.08	3.64	10.00	144	15.00	-16	-1.50	100	10.25	40R653-14-78
43.31	3.57	12.00	174	15.00	-19	-1.25	120	10.25	40R653-14-78
50.35	3.57	14.00	204	15.25	-21	-1.50	141	10.25	40R653-14-78
57.58	3.57	16.00	235	15.25	-25	-1.50	161	10.50	40R653-14-78
64.62	3.64	18.00	265	14.25	-27	-1.75	182	10.00	40R653-14-78
72.16	3.61	20.00	292	14.75	-32	-1.50	201	10.00	40R653-14-78
79.09	3.54	22.00	324	15.25	-33	-1.25	222	10.50	40R653-14-78
86.33	3.59	24.00	353	15.50	-37	-1.50	243	10.25	40R653-14-78
93.46	3.59	26.00	386	15.00	-39	-1.00	263	10.50	40R653-14-78
100.70	3.59	28.00	413	14.25	-41	-1.50	285	10.50	40R653-14-78
107.83	3.57	30.00	443	15.50	-45	-1.75	305	10.50	40R653-14-78
114.97	3.64	32.00	475	15.00	-48	-1.50	327	10.50	40R653-14-78
122.41	3.59	34.00	503	15.75	-51	-1.50	347	10.00	40R653-14-78
129.34	3.49	36.00	538	16.00	-54	-1.50	367	10.25	40R653-14-78
136.38	3.59	38.00	567	15.50	-57	-1.25	388	10.50	40R653-14-78
143.71	3.59	40.00	600	15.50	-59	-1.25	409	10.50	40R653-14-78
100 MINUTES LOADING									
16.08	1.59	10.00	66	6.60	-7	-0.40	47	4.70	100R653-30-78
24.02	1.59	15.00	98	6.70	-11	-0.90	70	4.70	100R653-30-78
32.06	1.59	20.00	133	7.00	-16	-0.60	94	4.80	100R653-30-78
40.00	1.60	25.00	168	6.80	-17	-0.30	118	4.80	100R653-30-78
48.14	1.59	30.00	201	6.80	-19	-0.60	142	4.80	100R653-30-78
55.97	1.58	35.00	236	6.80	-23	-0.70	166	4.80	100R653-30-78
64.02	1.60	40.00	269	6.90	-26	-0.70	190	4.50	100R653-30-78
72.06	1.60	45.00	305	7.00	-30	-0.80	211	4.50	100R653-30-78
80.10	1.61	50.00	339	6.70	-35	-0.70	235	4.80	100R653-30-78
88.24	1.60	55.00	372	6.70	-37	-0.50	259	4.80	100R653-30-78
96.18	1.57	60.00	406	7.10	-40	-0.60	283	4.80	100R653-30-78
104.02	1.62	65.00	443	6.90	-43	-0.60	307	4.80	100R653-30-78
112.46	1.61	70.00	475	8.60	-46	-0.70	331	4.80	100R653-30-78
120.20	1.58	75.00	529	7.10	-50	-0.70	355	4.60	100R653-30-78
128.34	1.58	80.00	546	5.60	-53	-0.60	377	4.60	100R653-30-78
136.08	1.70	85.00	585	8.20	-56	-0.70	401	5.30	100R653-30-78
145.42	1.65	90.00	628	7.50	-60	-0.70	430	5.10	100R653-30-78
152.66	1.47	95.00	660	6.80	-63	-0.60	452	4.50	100R653-30-78
160.20	1.47	100.00	696	6.80	-66	-0.60	475	4.50	100R653-30-78
240 MINUTES LOADING									
13.80	0.58	24.00	54	2.29	-6	-0.20	43	1.75	240R653-6-78
21.00	0.58	36.00	80	2.33	-8	-0.20	64	1.75	240R653-6-78
27.73	0.57	48.00	110	2.45	-11	-0.33	85	1.75	240R653-6-78
34.87	0.57	60.00	139	2.54	-16	-0.20	106	1.79	240R653-6-78
41.60	0.57	72.00	171	2.45	-16	-0.20	128	1.79	240R653-6-78
48.44	0.58	84.00	198	2.20	-21	-0.25	149	1.70	240R653-6-78
55.57	0.57	96.00	224	2.37	-22	-0.20	169	1.70	240R653-6-78
62.11	0.56	108.00	255	2.50	-26	-0.20	190	1.75	240R653-6-78
69.04	0.57	120.00	284	2.37	-27	-0.20	211	1.70	240R653-6-78
75.77	0.56	132.00	312	2.45	-31	-0.25	231	1.75	240R653-6-78
82.61	0.57	144.00	343	2.45	-33	-0.25	253	1.79	240R653-6-78
89.44	0.56	156.00	371	2.45	-37	-0.25	274	1.83	240R653-6-78
96.08	0.56	168.00	402	2.54	-39	-0.20	297	1.91	240R653-6-78
102.81	0.56	180.00	432	2.50	-42	-0.20	320	1.87	240R653-6-78
109.54	0.56	192.00	462	2.54	-44	-0.20	342	1.83	240R653-6-78
116.28	0.56	204.00	493	2.54	-47	-0.20	364	1.91	240R653-6-78
122.91	0.56	216.00	523	2.50	-49	-0.25	388	1.87	240R653-6-78
129.64	0.56	228.00	553	2.62	-53	-0.20	409	1.79	240R653-6-78
136.48	0.56	240.00	586	2.62	-54	-0.20	431	1.79	240R653-6-78

LIST OF RAW DATA OF 90-DEGREE SPECIMEN(REDWOOD)

σ	dσ/dt	t	$\varepsilon_{\parallel}$	$\frac{d\varepsilon_{\parallel}}{dt}$	$\varepsilon_{\perp}$	$\frac{d\varepsilon_{\perp}}{dt}$	ε45	$\frac{d\varepsilon45}{dt}$	card control
15 MINUTES LOADING									
13.03	5.21	2.50	82	32.00	-7	-2.00	42	15.20	15R903-26-78
19.70	5.13	3.75	121	31.20	-9	-2.00	59	14.00	15R903-26-78
25.87	4.97	5.00	160	32.40	-12	-2.00	77	15.20	15R903-26-78
32.13	4.97	6.25	202	32.80	-14	-2.00	97	16.00	15R903-26-78
38.30	5.13	7.50	242	30.80	-17	-2.00	117	14.40	15R903-26-78
44.97	5.09	8.75	279	31.20	-19	-2.00	133	14.40	15R903-26-78
51.04	4.85	10.00	320	32.80	-22	-2.00	153	16.00	15R903-26-78
57.21	5.01	11.25	361	33.20	-24	-2.00	173	15.20	15R903-26-78
63.58	5.34	12.50	403	32.80	-27	-2.40	191	14.40	15R903-26-78
70.14	5.13	13.75	443	32.80	-30	-2.00	209	15.20	15R903-26-78
76.41	5.13	15.00	485	32.80	-32	-2.00	229	15.20	15R903-26-78
40 MINUTES LOADING									
13.93	2.08	6.67	89	13.49	-7	-0.89	41	6.29	40R904-2-78
20.89	2.10	10.00	135	13.64	-10	-0.74	62	6.29	40R904-2-78
27.96	2.10	13.33	180	13.64	-12	-0.74	83	6.29	40R904-2-78
34.92	2.13	16.67	226	13.64	-15	-0.89	104	6.29	40R904-2-78
42.18	2.10	20.00	271	13.49	-18	-0.89	125	6.44	40R904-2-78
48.95	2.07	23.33	316	13.49	-21	-0.89	147	6.59	40R904-2-78
56.01	2.11	26.67	361	13.94	-24	-0.89	169	6.44	40R904-2-78
63.08	2.13	30.00	409	14.24	-27	-1.04	190	6.29	40R904-2-78
70.24	2.13	33.33	456	13.64	-31	-0.89	211	6.44	40R904-2-78
77.31	2.10	36.67	500	13.64	-33	-0.59	233	6.59	40R904-2-78
84.27	2.10	40.00	547	13.64	-35	-0.59	255	6.59	40R904-2-78
100 MINUTES LOADING									
14.12	0.84	16.67	89	5.57	-3	-0.75	42	2.51	100R903-18-78
21.19	0.84	25.00	136	5.51	-7	-0.29	62	2.57	100R903-18-78
28.25	0.83	33.33	181	5.51	-8	-0.23	85	2.69	100R903-18-78
35.12	0.83	41.67	228	5.39	-11	-0.41	107	2.57	100R903-18-78
42.08	0.81	50.00	271	5.39	-15	-0.35	128	2.51	100R903-18-78
48.65	0.79	58.33	318	5.39	-17	-0.29	149	2.51	100R903-18-78
55.32	0.80	66.67	361	5.15	-20	-0.35	170	2.45	100R903-18-78
61.99	0.78	75.00	404	5.27	-23	-0.29	190	2.45	100R903-18-78
68.25	0.75	83.33	449	5.15	-25	-0.35	211	2.45	100R903-18-78
74.52	0.74	91.67	490	5.03	-29	-0.35	231	2.27	100R903-18-78
80.59	0.74	100.00	533	5.03	-31	-0.35	249	2.27	100R903-18-78
240 MINUTES LOADING									
14.02	0.35	40.00	92	2.42	-7	-0.12	40	1.07	240R903-9-78
21.19	0.36	60.00	140	2.35	-8	-0.10	62	1.10	240R903-9-78
28.45	0.36	80.00	186	2.35	-11	-0.17	84	1.12	240R903-9-78
35.82	0.35	100.00	234	2.37	-15	-0.15	107	1.10	240R903-9-78
42.68	0.35	120.00	281	2.35	-17	-0.12	128	1.07	240R903-9-78
49.75	0.35	140.00	328	2.40	-20	-0.15	150	1.12	240R903-9-78
57.01	0.35	160.00	377	2.37	-23	-0.12	173	1.12	240R903-9-78
63.88	0.34	180.00	423	2.30	-25	-0.12	195	1.10	240R903-9-78
70.84	0.35	200.00	469	2.32	-28	-0.12	217	1.07	240R903-9-78
77.81	0.35	220.00	516	2.35	-30	-0.12	238	1.07	240R903-9-78
85.37	0.36	240.00	563	2.35	-33	-0.12	260	1.07	240R903- - 8