MECHANICAL PROPERTIES OF BRITTLE MATERIAL

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PREREQUISITE KNOWLEDGE: This experiment is suitable for students who have been introduced to the concepts of ductility and brittleness. They should also understand the meaning of modulus of elasticity.

EQUIPMENT AND SUPPLIES: Universal testing machine such as Instron and MTS, bending fixture, rectangular wood specimens 1 cm by 1 cm 15 cm, glass slides.

INTRODUCTION

Brittle materials are difficult to tensile test because of gripping problems; they either crack in conventional grips or are crushed. Furthermore they may be difficult to make into tensile specimens for example threaded ends or of dogbone shape. To overcome the problem simple rectangular shapes can be used in bending (i.e., a simple beam) in order to obtain the modulus of rupture and the elastic modulus. The equipment necessary consists of a fixture for supporting the specimens horizontally at two points, these contact points being rollers which are free to rotate. The force necessary to bend the specimen is produced by tup attached to the crosshead of an Instron machine.

PROCEDURE

The specimens are rectangular in shape and are measured for width and thickness; the length is the distance between the two supports. The wood specimens we used were ash, oak and cherry and were cut along the grain and normal to it. Most kinds of wood are suitable for this experiment and will show anisotropy. Three glass slides are used with a single scratch in each made with a suitable instrument such as a glass cutter. Effort should be made to keep the depths of scratches the same. The three scratches will be in different directions: one transverse, one longitudinal and the third at an angle of 45°, and with lengths equal to the transverse dimensions.

Each specimen is placed on the supports and subjected to a bending load until fracture. The Instron will record bending load against crosshead movement i.e., deflection in the specimen. Strictly speaking the crosshead movement recorded will include machine deformation but since the loads involved are small, the deformation will be small and will not detract from the utility of the experiment.

The maximum fiber stress, tensile on the bottom of the specimen is given by the standard formula,

$$S = \frac{MC}{I}$$

where S is the stress, I the second movement of inertia, C is half the specimen thickness and M the bending moment, PL/4, where P is the load and L the distance between supports. For a rectangular bend this translates to,

$$S = \frac{3PL}{2bh^2}$$

where b is the width and h the thickness. If P is the maximum load in kg and the dimensions are in meters then S is called the modulus of rupture in Pascals. It can be shown that the bending modulus E is given by

$$E = \frac{L^3}{4bh^3} \frac{\Delta P}{\Delta \delta}$$

where $\Delta P/\Delta \delta$ is the slope of the load-deflection curve. Thus the modulus of rupture and bending modulus can be calculated and compared to values obtained from the literature. Some typical values are given in the Appendix. A sketch of the support is shown in figure 1.

The distance between the supports is adjustable so that specimens of variable length L can be used. Note the smaller rollers on each support allow relative motion between the specimen and supports as the specimen begins to deflect. Otherwise frictional forces at this point would increase the load.

Note that if a fairly ductile material is tested resulting in significant deflection the specimen may slip off the supports.

The purpose of the scratches on the glass is to show the influence of scratch orientation on strength. For the glass specimens one specimen is fractured without any surface stratches. For the other specimens scratches are placed on the tensile surface preferably with a diamond cutter with the same pressure. Sharp notches stay sharp in a perfectly brittle material since there is no mechanism for plastic flow. To demonstrate the influence of orientation on fracture behavior scratches are placed transverse to, 45° and along the length of the glass slides. The equation governing the stress intensity is

$$K_I = 1.12\,\sigma\, Cos^2\,\beta\,\sqrt{\Pi a}$$

where ß is the angle of the crack to the transverse direction and a is the crack depth. This relationship predicts that K_I is largest when ß = 0, i.e. for the tranverse crack. Thus the fracture strength will be lowest for this orientation. When ß = 45°, the stress intensity falls to half the transverse value. Strictly speaking this is only approximate since mode II on K_{II} is ignored so this would be a lower limit. When ß= 90, i.e. for a longitudinal crack K_I becomes zero and this scratch should have no effect. Another way to think of this is the stress concentration at the side of a hole

$$\sigma_c = \sigma_n\left(1 + \frac{2a}{b}\right)$$

where σ_c is the stress concentration factor for a nominal stress σ_n applied at an ellipse with major axis 2a and minor axis 2b. In this case b $\gg$ a so that $\sigma_c = \sigma n$ or a stress concentration of one.

The experimental values for an unscratched glass side approximate those of published values, see Table II. The largest drop in fracture strength is shown by the specimen with a transverse scratch, no effect with the longitudinal stratch, and the 45° scratched specimen in between.

In conclusion we would like to add that we tried the experiment described last year by Roy Bunnell on stress skin composites using paper reinforcement since our apparatus was ideally suited to the experiment. Essentially it shows that a very weak material like styrofoam can be strengthened considerably against bending by placing a piece of cardboard on the tensile side of the specimen. The demonstration was very convincing.

REFERENCES

ASM Metals Handbook, Vol. 8, Ninth Edition, p. 115, 1985.

Table I
Typical Values For Different Woods

Type	Young's Modulus Gpa		Rupture Modulus Mpa
	Along Grain	Perpendicular to Grain	Along Grain
Douglas Fir	16.4	1.1	70
Birch	16.3	0.9	---
Ash	15.8	1.1	116
Oak	16.6	1.0	97

Suggested values of allowable stress in construction
along grain 3.45 - 6.9 MPa

Table II
Properties of Soda Lime Glass

Density	Young's Modulus	Modulus of Rupture
$Mg\,m^{-3}$	GPa	MPa
2.48	74	50

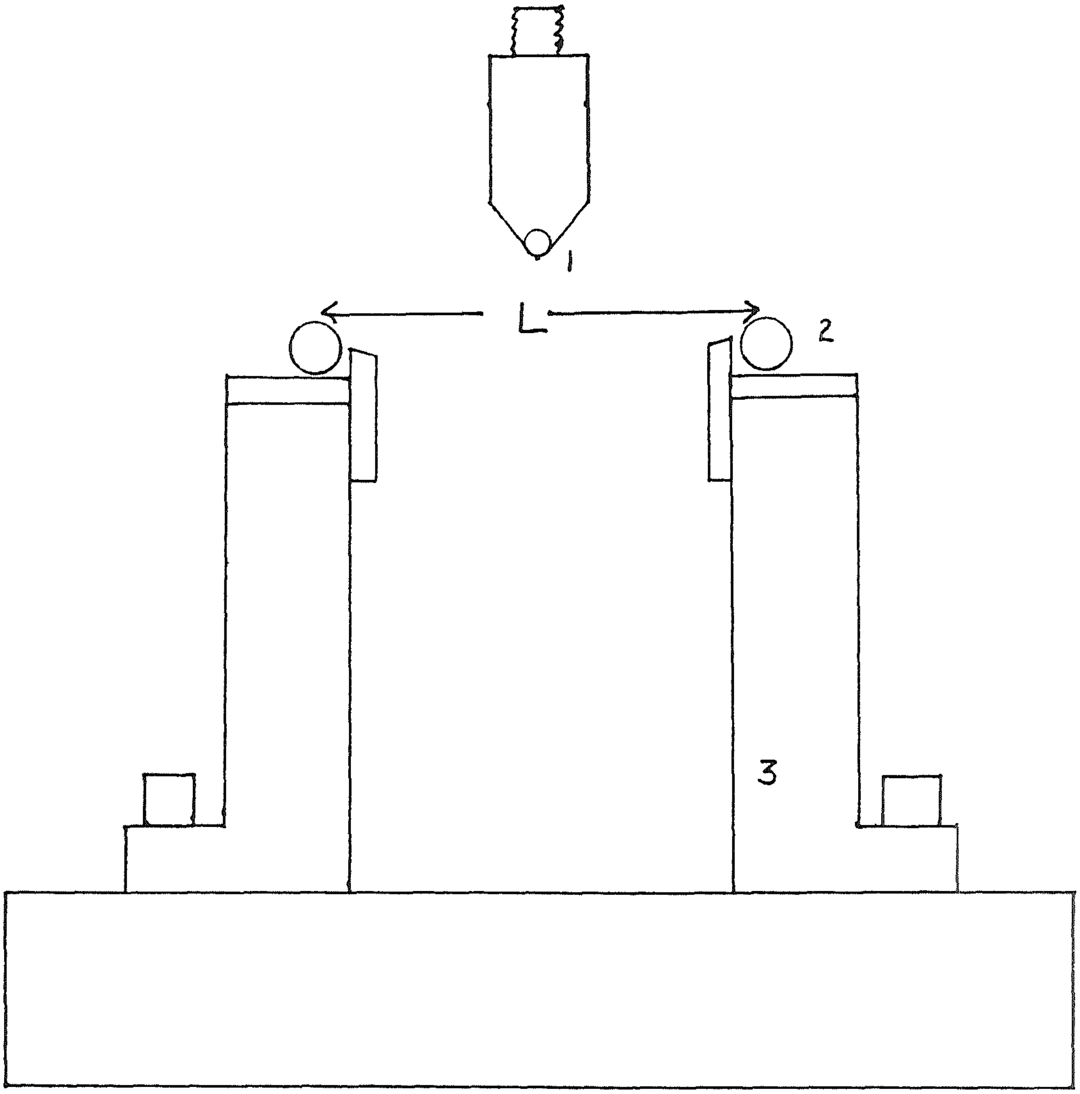

Fig. 1 Sketch of three point bending fixture

Note: 1) Hardened steel pin .1 cm diameter
2) Steel rollers, held in place by rubber bands attached to hooks in side of support
3) Vertical supports slide in groove in base
4) Scale approximate half size