NEW SHEAR STRENGTH TEST FOR SOLID WOOD[1]

J. Y. Liu

Research General Engineer
Forest Products Laboratory,[2] Forest Service, U.S. Department of Agriculture
Madison, WI 53705

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ABSTRACT

A new method for testing material properties has been applied to determine the shear strengths of specimens of Sitka spruce and Douglas-fir. The method permits the realization of pure shear in the critical section of the specimen. Pure shear is not achieved in the current American Society for Testing and Materials (ASTM) shear test. The large strength ranges of wood fibers and the vast differences in strength between earlywood and latewood fibers can still cause significant scatter in the test data, but the effect of combined stresses can be effectively controlled. Because of the special properties of wood, failure always follows the slope of the grain. The new method can only yield shear strength parallel to grain, which is required for engineering design purposes.

Keywords: Shear strength, shear test, wood, wood grain.

INTRODUCTION

The determination of shear strength of solid wood has been hampered by the difficulty in devising specimens and loading devices to produce a state of uniform shear stress. Many investigators have studied this problem and developed different methods for shear testing, but the presence of complex stress conditions at the site of failure remains unresolved.

In the standard ASTM D-143 shear test, as shown in Fig. 1, the specimen is a nearly cubical block with a step on one end. The unstepped portion rests on a fixed support, and the stepped portion is sheared off by a plunger, which also serves to keep the unstepped part of the specimen from tilting. The plunger actually introduces normal stresses perpendicular to the surface of shear, which may strongly influence the condition of failure. Coker and Coleman (1935) made a photoelastic analysis of the stepped block under load, and found a very unsymmetrical distribution of stress over the section where pure shear was supposed to exist. Radcliffe and Suddarth (1955) measured the strain variation along a vertical edge of the same section using strain gages, and found high shear stress concentration close to the step. The complex stress conditions have masked a clear picture of the shear phenomenon in the block specimen. Many other methods used throughout the world were reported by Rhude (1950), but none was considered superior to the standard ASTM test.

Recently, Arcan et al. (1978) developed a new method for testing material properties under uniform plane-stress conditions by means of a specially designed butterfly-shaped specimen. The method includes pure shear as a special case. Photoelastic and strain gage techniques were used to verify the case of pure shear

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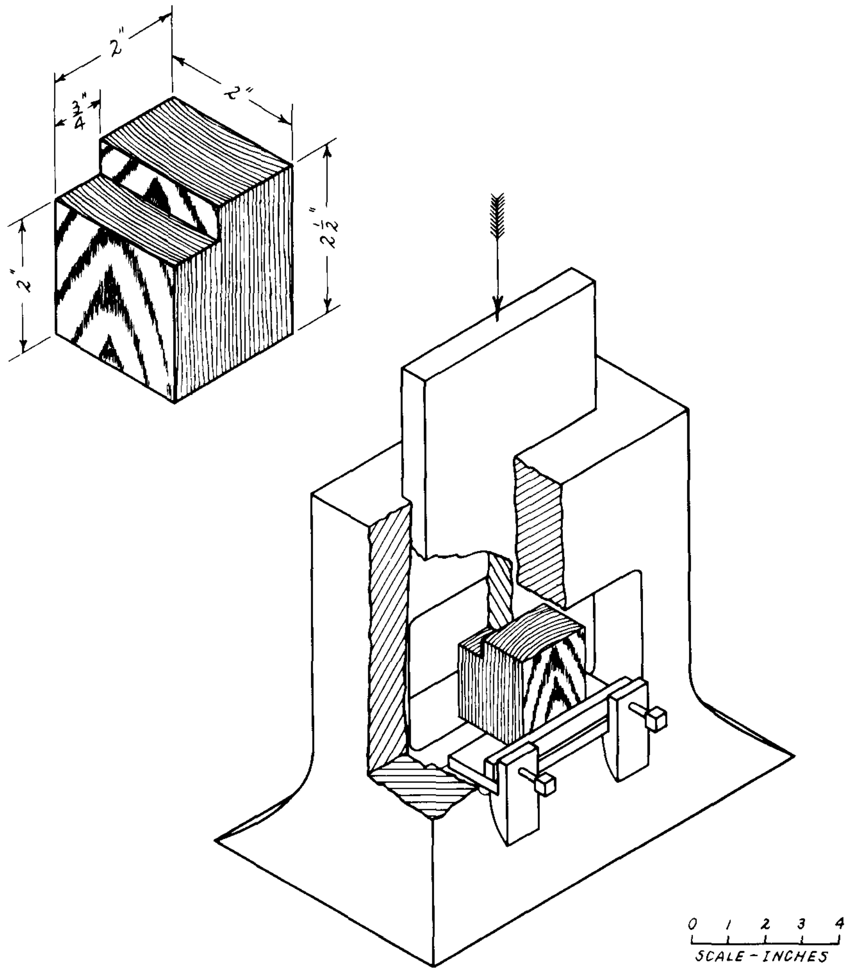

FIG. 1. ASTM standard shear specimen and apparatus.

in both isotropic and orthotropic specimens. They found that a homogeneous state of pure shear did exist at the critical section of the specimens as predicted. More recently, Voloshin and Arcan (1980) used the procedure to determine a failure envelope for unidirectional fiber-reinforced materials, and Jurf and Pipes (1982) to investigate the interlaminar fracture characteristics of a graphite/epoxy composite material with satisfactory results.

A similar method was suggested by Herakovich and Bargner (1980) for studying in-plane shear behavior of composites. They performed a finite element stress analysis which demonstrated that a uniform, pure shear state exists in the central section of the specimen.

In the present study, the method by Arcan et al. (1978) is evaluated for the first time in determining the shear strength of wood. Sitka spruce and Douglas-fir were used to make the specimens. Because of the inhomogeneity of the wood properties, special considerations that must be observed in performing the tests are reported.

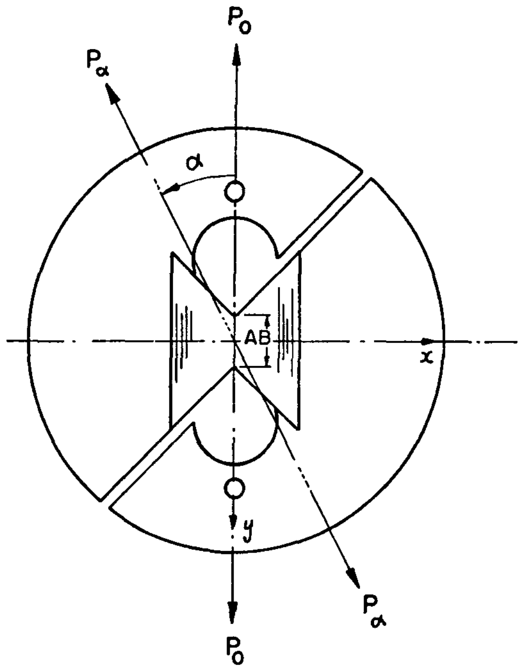

FIG. 2. Test fixture and specimen by Arcan et al. (1978).

EXPERIMENTAL PROCEDURES

The test fixture and the specimen used are shown in Fig. 2. The test fixture is a circular plane with antisymmetric cutouts. The critical section of the specimen is the narrow section at the center, AB. The rectilinear portions of the cutouts are oriented at ±45° from AB and, therefore, the principal stresses in the vicinity are also in these directions. It had been shown by Arcan et al. (1978), on the basis of photoelastic analysis, that the principal stresses throughout section AB are oriented at ±45°. It follows that the shear stress on the section is a principal shear stress.

The normal and shear stresses on section AB are:

$$\sigma_x = \sigma_y = \frac{P_\alpha \sin \alpha}{A} \tag{1}$$

$$\tau = \frac{P_\alpha \cos \alpha}{A} \tag{2}$$

where P_α is the applied load at an angle of α from AB and the cross-sectional area of AB is A. When α is zero, the normal stresses, σ_x and σ_y, vanish and a state of pure shear exists at AB.

In the present study, the relative dimensions of the test fixture and the specimen recommended by Arcan et al. (1978) were used. The section AB of the specimen

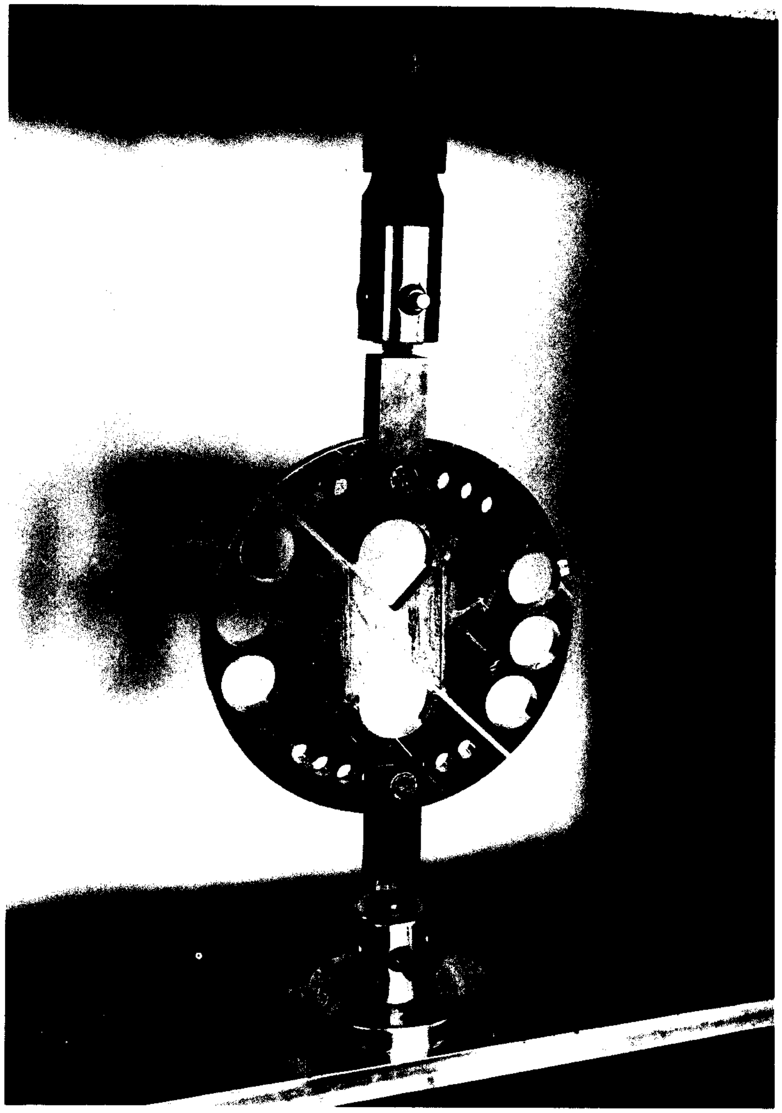

FIG. 3. Setup of shear test.

has a length of 1 inch and a thickness of ½ inch; the total width across the specimen is 2½ inches. The circular fixture has a diameter of 10 inches, a thickness of ½ inch, and is made of aluminum with a total weight of 2.6 pounds.

The specimens were cut from a Sitka spruce board and a Douglas-fir board taken from storage at the Forest Products Laboratory. The history of each board is unknown. The boards had been in outdoor storage under cover for several years at FPL. They were from trees of considerable size, free of visible drying defects, and air-dried to approximately 12% moisture content.

The grain of the specimen was parallel to section AB, whose cross section was

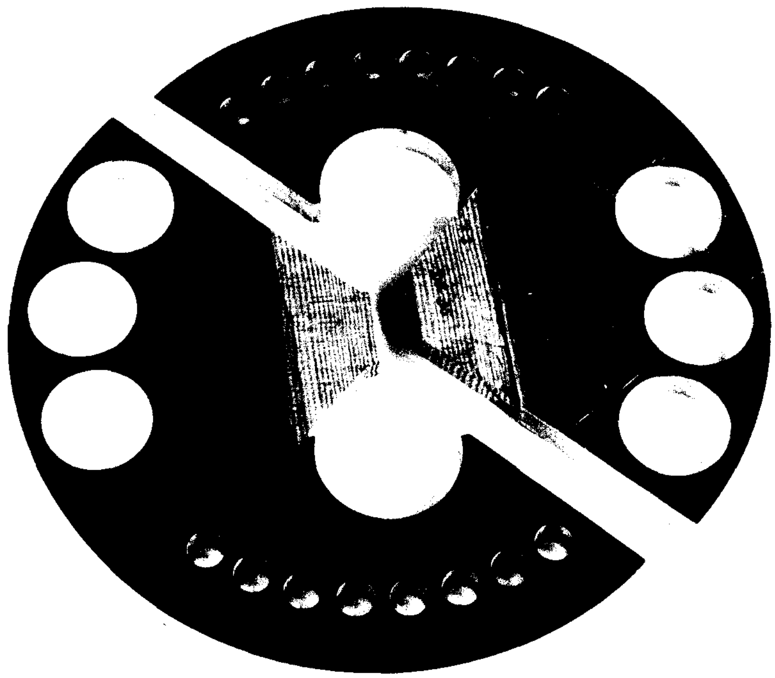

FIG. 4. Test fixture with broken specimen.

in the longitudinal-tangential plane. After the specimens had been fabricated, they were stored in an environmental room with constant 74 F temperature and 65% relative humidity until they were to be bonded to the aluminum fixture.

The adhesive used was a commercially available epoxy. After a specimen had been bonded to the two fixture halves, the fixture was secured in place for at least 12 h for the adhesive to be cured.

The tensile loads were applied with a test machine as shown in Fig. 3. Crosshead speed was 0.05 in./min. Displacement and load were recorded, using an xy plotter until failure occurred. Figure 4 shows an aluminum test fixture with a broken specimen. After each test, the broken specimen was removed and the aluminum fixture cleaned to be used again.

EXPERIMENT RESULTS AND OBSERVATION

Thirty specimens of Sitka spruce and an equal number of Douglas-fir specimens were tested to failure. Only 25 of them from each species are reported in Table 1. The others did not fail at section AB of the specimen, but failed at very low loads, indicating that failure was due to some material abnormalities.

The two wood species have a clear contrast in color between earlywood and latewood, with the contrast in Douglas-fir more pronounced than that in Sitka

TABLE 1. *Summary of shear strength test data.*

Species	Number of tests	Average shear strength	Range Minimum	Range Maximum	Standard deviation	Coefficient of variation	Average specific gravity[a,b]	Average moisture content[b]
		Lb/in.²				%		%
Sitka spruce	25	906 (1,143)[c]	602	1,288	186 (160)[c]	20.6	0.38	11.8
Douglas-fir	25	868 (1,130–1,515)[c]	630	1,159	159 (164–243)[c]	18.3	0.50	10.9

Note: Lb/in.² = 6.8947 kPa.
[a] Specific gravity based on weight when ovendry, and volume at test.
[b] From 10 separate specimens from same board for shear specimens.
[c] Values from ASTM D 2555.

spruce. The tensile strengths of earlywood and latewood fibers for these species were reported by Jayne (1959, 1960) and are shown in Table 2. A tremendous difference in tensile strength exists between the individual fiber and sawn wood. This can be attributed to relative density, stress concentrations in sawn wood due to external shape and ray tissue, early-latewood boundaries and other anatomical features. According to Kollmann and Côté, Jr. (1968), the shear strength along the grain is about 6 to 10% of the tensile strength. Thus the differences in tensile-strength properties in Table 2 can, at least partially, explain the data scatter in Table 1. If latewood of high strength is located at or close to section AB, failure can initiate at another section due to the combined effect of shear and tension perpendicular to grain. Specimens that fail at off-center locations can simply be culled in the data analysis, as those failures are due to combined stresses rather than pure shear. Any stress raisers such as cross grain or small cracks can, of course, trigger a failure due to high stress concentrations. Since the weakest link cannot be identified when cutting a specimen, one has to make a large number of tests to obtain reliable strength estimates.

In Table 1, the coefficient of variation for Douglas-fir is lower than that for Sitka spruce. This does not seem to agree with the fiber strength values in Table 2, where the strength difference between earlywood and latewood for Douglas-fir is much higher than that for Sitka spruce. This can be attributed to the use of only one board of each species to fabricate the specimens, as well as the relatively small sample size.

The same reasoning can be applied to explain the higher strength values based

TABLE 2. *Tensile strength of wood fibers (Jayne 1959, 1960).*

Species	Fiber type	Average tensile strength	Range Minimum	Range Maximum
		Lb/in.²·10³		
Sitka spruce	Earlywood	117	77	175
	Latewood	129	83	165
Douglas-fir	Earlywood	51	42	58
	Latewood	142	114	185

Note: Lb/in.² = 6.8947 kPa.

on the ASTM D-143 test, as shown in Table 1. In the ASTM test the stress concentrations and tension perpendicular to grain should result in lower strength values, but with the sheared surface passing through both early and latewoods, the strength values should be higher than those obtained from the present test. How these two factors will balance each other presents a very complicated phenomenon.

Another point that is worth reporting is that in the preliminary testing some specimens were intentionally made with the grain oriented at an angle with respect to section AB. In those tests, failure in a specimen always followed the grain. This makes it impossible to establish the relation between shear strength and grain slope using the present method. Cowin (1979) stated that a material could be constrained to fail on the shear plane where the shear strength is higher than that on a perpendicular plane. For solid wood this is unlikely to be true unless the failure is due to combined stresses.

SUMMARY AND CONCLUSIONS

The shear strengths of Sitka spruce and Douglas-fir specimens have been determined by the test method developed by Arcan et al. (1978). They had shown that the method can induce a pure shear state in the critical section of a butterfly-shaped specimen of either isotropic or orthotropic material using photoelastic and strain gage techniques. These same techniques had been used by others to reveal that a pure shear state does not exist in the current ASTM shear block. It has been confirmed in the present study that the method can be successfully applied on wood. This confirmation may have ended the search of many decades for a reliable shear test method for wood.

For nonhomogeneous materials with embedded stress raisers, failure may first occur at locations where normal and shear stresses are present. This happened in the present study, but not to the degree to cause any special difficulty in data analysis. When a failure was due to combined normal and shear stresses, the specimen was simply culled, as its shear strength was not known.

In the present study on Sitka spruce and Douglas-fir, shear failure across the grain was not possible as failure always followed the grain. The new test method can only yield shear strength parallel to grain in the longitudinal-tangential plane, which is needed in engineering applications.

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