Improved Arcan Shear Test For Wood

Jen Y. Liu, Robert J. Ross, and Douglas R. Rammer
USDA Forest Service, Forest Products Laboratory,[1] Madison, WI, USA

Abstract

A new shear test fixture design that uses Arcan specimen geometry has been developed for wood. The design applies mechanical fastening to fix the specimen to the fixture rather than adhesive bonding as in the original Arcan design. The new design can be correlated with the current ASTM shear block test. It can also be used to evaluate the shear modulus for wood. 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. Special considerations are presented on preparation of specimens based on test results of white spruce.

Keywords: Arcan shear test; ASTM shear block test; Iosipescu shear test; shear modulus; shear strength; wood; wood grain

Introduction

The determination of shear strength of solid wood has been hampered by the difficulty in designing a specimen and loading device to produce a state of pure uniform shear at the critical section in the specimen. In the standard ASTM D 143 shear test (ASTM 1981), the specimen is a cubical block with a raised step or notch on the top (Fig. 1). In testing, the portion with the step rests on a fixed support and the other portion is sheared off by a plunger. In addition to shearing force, the plunger introduces normal stresses perpendicular to the surface of shear. These stresses are far from uniform and strongly influence the condition of failure (Coker and Coleman 1935; Radcliffe and Suddarth 1955; Youngs 1957).

Arcan et al. (1978) developed a method for testing mechanical properties of isotropic as well as orthotropic materials under uniform plane stress conditions by means of a specially designed butterfly-shaped specimen (Fig. 2). The method includes pure shear as a special case, when the angle $\alpha = 0$. The principle behind the geometry of the specimen is that in the pure shear zone, the isostatics will intersect the sheared cross-section (AB in Fig. 2) at an angle of ± 45° (Goldenberg et al. 1958).

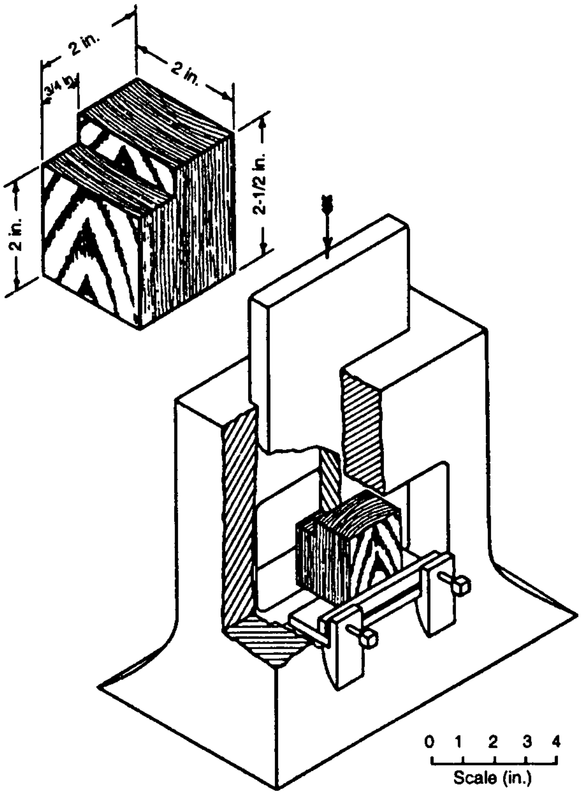

Figure 1—ASTM standard shear specimen and apparatus.

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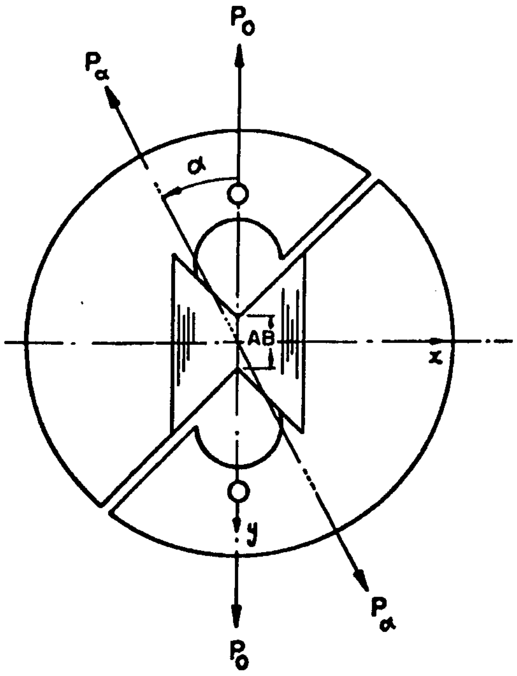

Figure 2—Test fixture and specimen by Arcan et al. (1978).

Photoelastic results demonstrate that along the critical section, the isochromatic value is constant and maximum, the isoclinic angle is 45°, and consequently the nearly pure-shear stress is uniform (Arcan 1984)

Voloshin and Arcan (1980) used the method to determine a failure envelope for unidirectional fiber-reinforced materials and Jurf and Pipes (1982) used the method to investigate the interlaminar fracture characteristics of graphite-epoxy composite material with satisfactory results.

Liu (1984) and Liu and Fleeter (1984) were the first to use the method to determine the shear strength of Sitka spruce and Douglas-fir. Following Arcan et al. (1978) and Voloshin and Arcan (1980), they glued each specimen on the halves of the aluminum fixture (Fig. 2) with a commercially available epoxy, which was to be cured for at least 12 h before testing. After each test, the broken specimen was removed and the aluminum fixture cleaned for reuse. The test results were reasonable, but the time needed to conduct a series of tests was excessive.

The Arcan fixture was modified by Yen et al. (1988) to eliminate the use of adhesive. The modified Arcan fixture was made of two pairs of stainless steel parts, each pair equivalent to one-half of the original Arcan fixture.

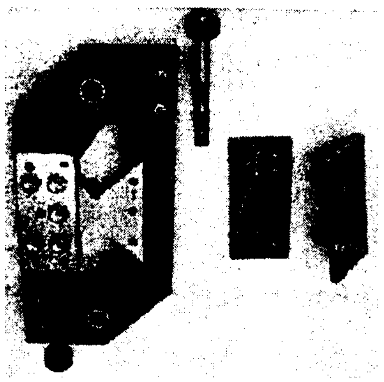

Figure 3—Improved Arcan test fixture and specimen.

A trapezoidal cutout was machined to half the thickness in each part to house the specimen. Three holes were drilled at the cutout section in each part to allow for tightening the two parts together with bolts. The authors found that the shear properties of aluminum, Plexiglass, and a thermoplastic composite obtained using the modified Arcan shear test were in excellent agreement with the reference data provided by other reliable test methods.

In the present study, we improved the Arcan fixture and its modified version by Yen et al. (1988) to determine the shear strength and shear modulus of solid wood and, possibly, other composite materials. Because of the inhomogeneity of wood properties, we were interested in discovering what problems may occur in the new test fixture and specimen designs and how these problems can be corrected.

Improved Arcan Fixture

The test fixture used in the present study, referred to as the improved Arcan shear test, was designed to facilitate the testing of solid wood specimens. The fixture consists of two identical aluminum parts that are antisymmetric and form a six-sided configuration. A butterfly-shaped specimen is located in the center, as shown in Figure 3; in this figure, an assembled specimen is shown on the left and the constituent components on the right. The total weight of the test fixture without specimen is 17.78 N.

The specimen is fastened to each half of the fixture by a pair of restraining plates connected by five bolts. Portions of the fixture and specimen are sandwiched between the plates with knurled inner faces to provide the gripping forces. Each half of the fixture also contains a ball bushing for joining with a shaft temporarily

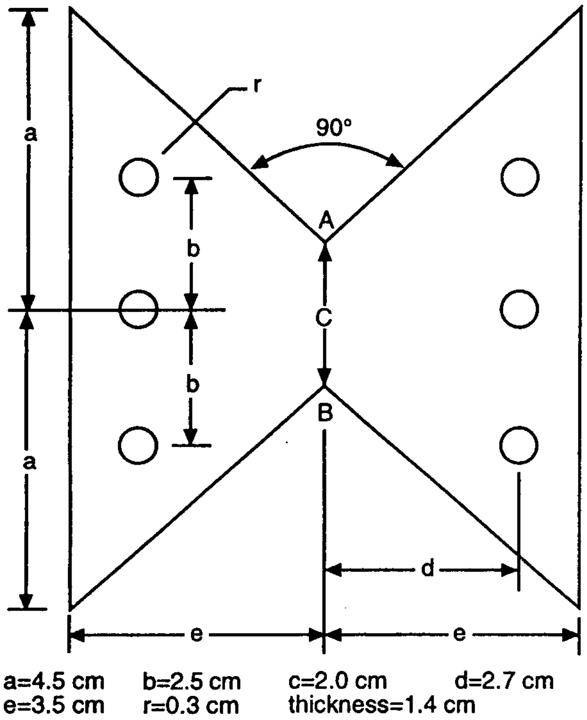

Figure 4—Geometrical dimensions of specimen.

mounted on the other half, which restricts the halves from moving apart and breaking the specimen during assembly. Once the specimen has been properly fastened, the two shafts must be removed before testing. The shafts are thus called assembling assistance shafts. As will be discussed later, the shafts can also be used to demonstrate that the current design is more suitable for wood than the much publicized Iosipescu shear test (Ifju 1994) for composites.

Specimen and Experimental Procedures

The current shear data of all wood species in the ***Wood Handbook*** (Forest Products Laboratory 1987) were obtained using the shear block test. To find the differences in test results between the shear block test and the Arcan shear test, it would be necessary to make specimens from the same source of materials for both tests to reduce material property variability. However, such an endeavor was not the purpose of the present study.

The geometrical dimensions of the specimen are shown in Figure 4. The grain of the specimen was parallel to section AB and the thickness parallel to the tangential direction. The thickness of the specimen was such that the specimen could be tightly clamped by the restraining plates.

For preliminary testing, we made six specimens from Douglas-fir. The satisfactory results led to the production of 70 specimens from three flitches of white spruce taken from storage at the Forest Products Laboratory. The flitches were from logs of the same batch and bore close resemblance in color and anatomical properties. The spruce specimens were stored in an environmental room at 23°C and 50 percent relative humidity for several weeks until all weight changes were negligible. Specimens were mounted immediately before the test.

Five specimens were also tested for shear modulus using two side-by-side gauges (Ifju 1994) on the two faces of each specimen. The strain gauge bad a nominal length of 11 mm. It would have been better to select a gauge length the same as section AB. However, in this exploratory study, we assumed that the strains along section AB were relatively uniform and therefore any gauge length was suitable.

The tensile load was applied with an Instron test machine as shown in Figure 5. Crosshead speed was 1.27 mm/min. Displacement and load were electronically recorded for shear modulus estimates. Figure 6 shows the test fixture with a broken specimen. After each test, the broken specimen was removed and a new specimen mounted for the next test.

Results and Discussion

In mounting a specimen to the test fixture, the assembling assistance shafts must be mounted first to avoid breaking the specimen, but they must be removed prior to the test. The shafts run on ball bushings, which provide negligible friction along the shafts and permit easy mounting or removal. When mounted, the shafts also restrict the halves of the test fixture from approaching each other under load in the horizontal direction. This is the situation that exists in the Iosipescu shear test (Adams and Walrath 1987). In the Iosipescu shear test, the applied loads are compressive; in the Arcan shear test, the applied loads are tensile. For the critical section AB, which is supposed to be under pure shear, the two loading conditions should make no difference. Of the six Douglas-fir specimens for preliminary testing, three were tested with the shafts mounted to create the situation of the Iosipescu shear test, and the other three were tested without the shafts. When the shafts were mounted, all the specimens failed prematurely at locations away from section AB. The failure mode had the characteristic of tension perpendicular-to-grain, in which

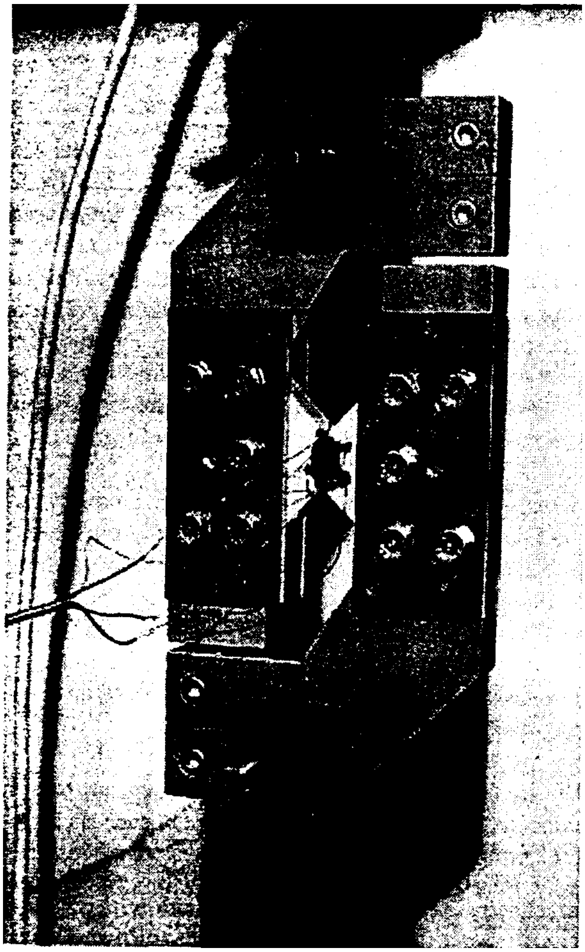

Figure 5—Application of tensile load in improved Arcan shear test.

cracking sounds preceded gradual fracturing. When the shafts were removed, all the specimens failed at section AB. The failure mode was pure shear, characterized by a sudden split across the whole section. These results clearly demonstrate that because of the low resistance of wood to tension perpendicular-to-grain, the Arcan shear test is more suitable for wood. As a matter of fact, according to Walrath and Adams (1983), the specimen for the Iosipescu shear test was taken as a simply supported, notched beam with no restrictions imposed at the loading or support locations. In the modified design of the test fixture (Adams and Walrath 1987), the specimen was actually like a short beam with built-in ends, making it impossible to realize the state of pure shear at the critical or notched section when the fixture was in operation.

The white spruce specimens were conditioned in a different environment until stabilized. This process proved to be problematic. During conditioning, minor geometrical changes occurred. While being mounted to the test fixture, most of the specimens could not accommodate one or more of the six bolts designed to connect the restraining plates. Consequently, it was necessary to either redrill some holes or press the bolts in by force, causing high stress concentrations at or near the holes. Of the 70 specimens tested, 50 failed prematurely in those areas covered by the restraining plates. Two specimens with such premature failures are shown in Figure 7.

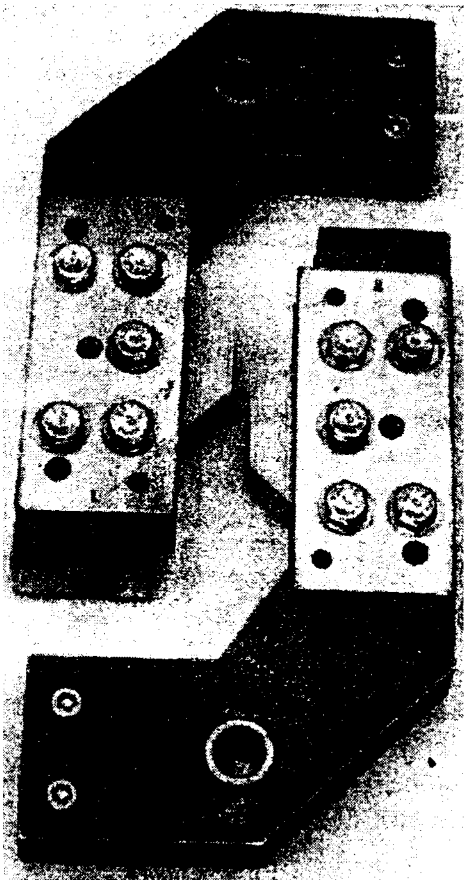

Figure 6—Improved Arcan test fixture with broken specimen.

If the white spruce flitches had been conditioned in the test room environment prior to specimen fabrication, the geometrical changes in the specimens could have been avoided. Failures in the gripping areas are common in the tension test of wood. The remedy is to either reinforce the gripping areas or reduce the cross-section of the gauged length. Such a remedy can easily be introduced in the shear test. If the thickness of a specimen is reduced by 50 percent and the materials removed from the restraining plate areas are restored using adhesive, the chances for any premature failure can be drastically reduced, if not totally eliminated.

Figure 7—Premature failure of specimens.

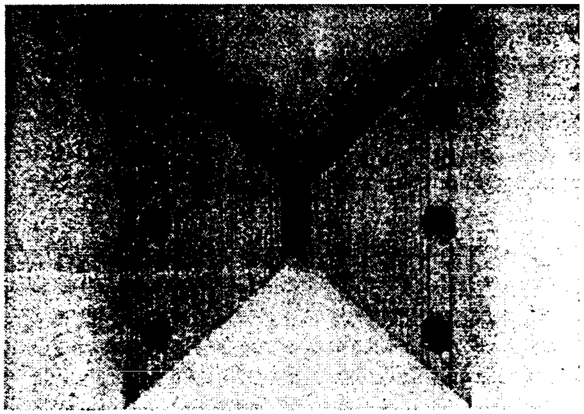

Figure 8—Shear failure of specimen.

A specimen broken by shear is shown in Figure 8. Any possible contribution from the minor geometrical changes to the recorded shear strength could not be estimated. Also, the specimens of one flitch were not separated from those of the other flitches, Nevertheless, a statistical analysis was conducted on the 20 specimens that failed in shear, assuming that the 50 specimens that failed at the grips could be culled. Results are presented in Table 1.

It is interesting that the shear strength data in Table 1 are generally somewhat lower than those reported in the ***Wood Handbook*** (Forest Products Laboratory 1987). These results were also observed for Sitka spruce and Douglas-fir (Liu 1984). In the shear block test, the stress concentrations and tension perpendicular-to-grain should result in lower strength values. However, since the sheared surface passes through both early- and latewood, the strength values should be higher than those obtained from the test reported here. How these factors balance is a very complex phenomenon, which may reduce the credibility of the shear block test.

In the ***Wood Handbook*** (Forest Products Laboratory 1987), the modulus of elasticity of dry white spruce is 9,859 MPa. The ratio of shear modulus as listed in Table 1 to modulus of elasticity is then 0.067.

Table 1—Shear strength test data for white spruce

	Shear strength (MPa)				Shear strength COV	Shear modulus[a]	Specific	Moisture content[a]
Data	Avg.	Min	Max.	SD	(%)	(MPa)	gravity[a,b]	(%)
Test results[c]	5.9	4	7.48	1.17	19.81	663[d]	0.4	10.4
Wood Handbook[e]	6.69	—	—	—	—	—	0.36	12.0

[a] Average value.
[b] Based on ovendry weight and volume at test.
[c] Test of 20 specimens, except where indicated.
[d] Test of five specimens.
[e] Forest Products Laboratory 1987.

This compares with the same ratio recommended in ASTM D 2555, 0.069 (ASTM 1988). The literature does not suggest any special criticism of the conventional approaches for estimating shear modulus and modulus of elasticity for wood. The close agreement between the two ratios therefore lends additional support for the reliability of the Arcan shear test, although these values represent only average estimates.

Conclusions

Adoption of the Arcan shear test by the wood industry has been hampered by the requirement that the specimen be glued to the test fixture. The improved Arcan shear test removes this impracticality by substituting adhesive bonding with mechanical fastening without sacrificing the original design requirements. The butterfly-shaped specimen must be prepared in such a way that its geometrical stability is maintained during testing. This can be achieved by conditioning the raw material in the test environment before the specimen is fabricated. For materials that tend to fail prematurely in the combined stress condition under the restraining plates, the specimen needs to be reinforced at the gripping areas as in the tension test for wood.

Acknowledgments

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References

Adams, D.F.; Walrath, D.E. 1987. Further development of the Iosipescu shear test method. Experimental Mechanics. 27(2): 113–119.

ASTM. 1981. Standard methods of testing small clear specimens of timber. ASTM D 143–52. Philadelphia, PA: American Society for Testing and Materials.

ASTM. 1988. Standard test methods for establishing clear wood strength values. ASTM D 2555–88. Philadelphia, PA: American Society for Testing and Materials.

Arcan, M. 1984. Discussion: The Iosipescu shear test as applied to composite materials. Experimental Mechanics. 24(1): 66–67.

Arcan, M.; Hashin, Z.; Voloshin, A. 1978. A method to produce uniform plane-stress states with application to fiber-reinforced materials. Experimental Mechanics. 18(4): 141–146.

Coker, E.G.; Coleman, G.P. 1935. Photoelastic investigation of shear tests of timber. Institute of Civil Engineers (England). Selected Engineering Papers. London: William Cloroes and Sons, Ltd.

Forest Products Laboratory. 1987. Wood handbook. Wood as an engineering material. Agric. Handb. 72. (Rev.) Washington, DC: U.S. Department of Agriculture, Forest Service. 466 p.

Goldenberg, N.; Arcan, M.; Nicolau, E. 1958. On the most suitable specimen shape for testing shear strength of plastics. ASTM STP 247. 115–121.

Ifju, P.G. 1994. The shear gauge: For reliable shear modulus measurements of composite materials. Experimental Mechanics. 34(4): 369–378.

Jurf, R.A.; Pipes, R.B. 1982. Interlaminar fracture of composite materials. Journal of Composite Materials. 16: 386–394.

Liu, J.Y. 1984. New shear strength test for solid wood. Wood and Fiber Science. 16(4): 567–574.

Liu, J.Y.; Floeter, L.H. 1984. Shear strength in principal plane of wood. Journal of Engineering Mechanics. 110(6): 930–936.

Radcliffe, B.M.; Suddarth, S.K. 1955. The notched beam shear test for wood. Forest Products Journal. 5(2): 131–135.

Voloshin, A.; Arcan, M. 1980. Failure of unidirectional fiber-reinforced materials—New methodology and results. Experimental Mechanics 20(8): 280–284.

Walrath, D.E.; Adams, D.F. 1983. The Iosipescu shear test as applied to composite materials. Experimental Mechanics. 23(1): 105–110.

Yen, S.C.; Craddock, J.N.; Teh, K.T. 1988. Evaluation of a modified Arcan fixture for the in-plane shear test of materials. Experimental Techniques. 12(12): 22–25.

Youngs, R.L. 1957. The perpendicular-to-grain mechanical properties of red oak as related to temperature, moisture content, and time. Rep. 2079. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

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