AMD-VOl. 231/MD-VOl. 85
Mechanics of Cellulosic Materials – 1999
ASME 1999

# AN IMPROVED SHEAR TEST FIXTURE USING THE IOSIPESCU SPECIMEN

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**ABSTRACT**

This paper describes a new shear test fixture designed with the Iosipescu specimen geometry. The special feature of the design is the introduction of four pairs of shafts that connect two controlling blocks to both halves of the fixture. The shafts run on ball bushings and serve to eliminate any misalignment of the fixture halves without preventing them from moving nonlinearly in the plane of loading during testing. The new test fixture was used to conduct shear strength tests on Sitka spruce specimens. The results showed that shear failure always occur in earlywood. There is only a weak relationship between shear strength and slope of grain.

## INTRODUCTION

In this study, we investigated a new design of a shear test fixture using the Iosipescu specimen geometry. Our objective was to determine whether this shear test fixture is able to generate reliable data for shear modulus and shear strength for wood and other materials.

The safe and efficient use of wood members in construction requires rational design criteria. For shear design, current criteria are shear strength values obtained by the shear block test and shear modulus values obtained by the plate twist test. The shear block test, described in ASTM D143–52 (ASTM 1981) is known to yield inaccurate results because of high stress concentrations (Coker and Coleman 1935, Radcliffe and Suddarth 1955, Youngs 1957). The plate twist test which was proposed by March et al. (1942), is described in ASTM D3044–76 (ASTM 1976) for determining shear modulus of plywood The shear modulus test for solid wood remains to be developed.

Arcan and Goldenberg (1957) and Goldenberg et al. (1958) presented a method for testing shear strength of plastics. This method was used for testing strength properties of isotropic as well as orthotropic materials under uniform plane stress conditions by means of a specially designed butterfly-shaped specimen (Fig 1). When $\alpha = 0°$, the shear stress distribution along the critical section AB is nearly uniform (Arcan et al. 1978, Arcan 1984).

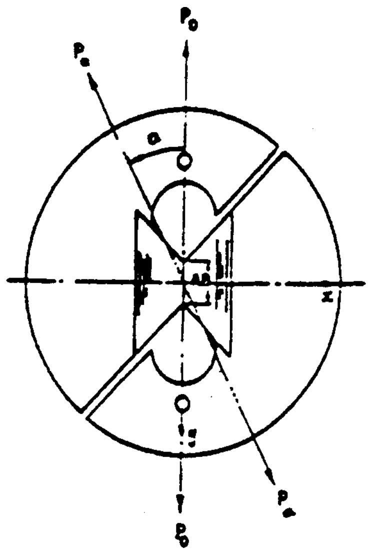

**Figure 1. Test fixture and specimen by Arcan et al. 1978.**

The method described by Arcan et al. (1978) was used to determine shear strength of Sitka spruce and Douglas-fir (Liu 1984) and shear strength variation in the longitudinal–tangential plane of Sitka spruce (Liu and Floeter 1984). The results of the latter study showed close agreement with the strength theory presented by Tsai and Wu (1971), indicating that the obtained shear strength values of Sitka spruce and Douglas-fir must also be reliable. These values were found to be somewhat lower than those from the shear block test and will be explained later in this report.

In the method by Arcan et al. (1978), the specimen (Fig. 1) is fastened to the test fixture using an adhesive, which requires many hours to set. To shorten the turnaround time, Liu et al. (1996) redesigned the fixture by using mechanical fasteners to secure the specimen. This modified fixture was used to determine the shear strength of white spruce. Again, the shear strength value obtained was lower than that obtained by the shear block test. Liu and Ross (1997) used this modified fixture to find shear modulus variation with grain slop in planes perpendicular to the longitudinal–radial plane of Sitka spruce. Their results agreed closely with the formula based on orthotropic elasticity theory (Jones 1975, Daniel and Ishai 1994). For the special case of 0° grain slope (i.e., along the longitudinal axis in the longitudinal–tangential plane), the shear modulus value closely agreed with that obtained by Kubojima et al. (1996) and was about 1.22 times that obtained by the plate twist test.

In the study of shear strength of white spruce (Liu et al. 1996), the authors observed that many specimens failed at the gripping areas close to the mechanical fasteners and the fixture had a tendency to twist in the final stages of the test. These findings might not have affected their results because the specimens that did not fail at the critical sections were culled in the analysis. Also, these findings did not affect the results obtained by Liu and Ross (1997) because that study focused on only the stress–strain relations in the early stages of the test. Nevertheless, Liu et al.'s findings did indicate that the test fixture needs to be improved to function as desired.

At about the same time when the Arcan test was published, Iosipescu (1967) published a shear test for metals. In this test, the specimen has the shape of a double-notched beam with a 90° notch at the top and bottom of the central portion. The notched-beam specimen and the butterfly-shaped specimen are based on the same design theory. The applied loads are tensile in the Arcan test and can be either tensile or compressive in the Iosipescu test. All versions of the Iosipescu test use compressive loads. In the so-called Wyoming version (Walrath and Adams 1983), the lower half of the fixture is increased in mass and made stationary, and the horizontal distance between the upper and lower halves is kept constant during testing of composite specimens. These changes were probably made to increase the stability of the fixture. However, both the Arcan test and the Iosipescu test required that both halves of the fixture be antisymmetrical with respect to the critical section of the specimen. These tests also require that no additional restraints are introduced that restrict the fixture halves from moving in the horizontal direction while the applied loads are acting in the vertical direction. These conditions were not observed in the Wyoming version of the Iosipescu test fixture. Nevertheless, this version was eventually adopted as ASTM D5379–93 (ASTM 1993).

The ASTM D5379–93 standard has not been found to function satisfactorily. During testing, the specimen may twist, resulting in unequal shear strains in the front and back. to eliminate the shortcomings of this standard, Conant and Odom (1995) designed a series of prototype fixtures. They reintroduced the antisymmetry of the fixture halves, but they did not change the restraints that prevent the halves from moving horizontally during testing. At about the same time, Adams and Lewis (1995) found fairly large transverse normal strains in the gage section of some carbon/epoxy specimens using the new ASTM standard. This finding was not taken into account by Conant and Odom (1995) in their improved design.

In the study reported here, we attempted to design an improved shear test fixture based on the designs by Liu et al. (1996) and Conant and Odom (1995). Our purposes were to control twisting of the two halves of the fixture and to eliminate or reduce any transverse normal strains in the critical section of the specimen inadvertently caused by the fixture design.

## FIXTURE DESIGN

The new shear test fixture is shown in Figure 2. the conventional antisymmetrical components consist of the right upper and left lower parts. The right lower and left upper parts are the two controlling blocks. Each block is connected to both halves of the fixture by two pairs of shafts that move on ball bushings. The left upper block is connected to the left lower part by two vertical shafts (visible in the figure) and to the right upper part by two horizontal shafts (only front shaft is visible). Figure 3 shows the tips of the two horizontal shafts that connect the right lower block to the left lower part.

The vertical shafts prevent any twisting about the vertical axis passing through the center of the fixture; the horizontal shafts prevent any twisting about the horizontal axis passing through the fixture center. Both halves of the fixture are free to move in either the vertical or horizontal direction without twisting during testing.

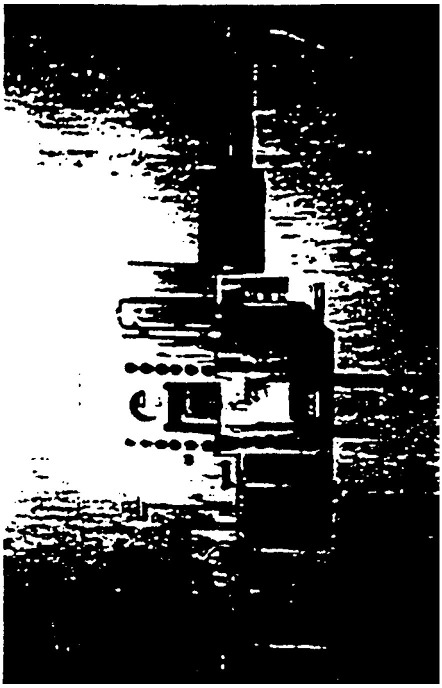

Figure 2. Front view of new shear test fixture.

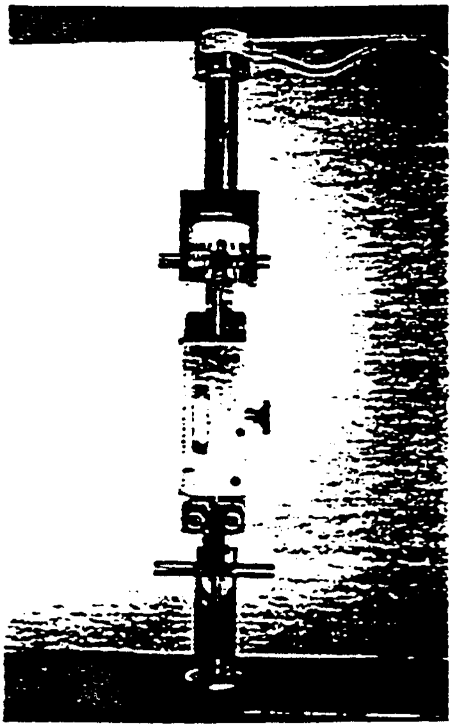

Figure 3. Right side view of new shear test fixture.

Two heavy plastic doors are used to mount and dismount the specimen (Fig.2). When closed, the doors also help locate the specimen in the horizontal direction (Fig. 3). Location of the specimen in this direction is also controlled through two knobs that are connected to steel components (Figs. 3 and 4). The specimen is centered in the fixture by two spring–controlled pegs that rest in the valleys of the V-notches when the specimen is properly located in the horizontal direction (Fig. 2). The loading devices rest on the top of the right upper part and at the bottom of the left lower part and are controlled by screws (Fig. 2). These screws must be tightened before the test.

Figure 5 shows the fixture with a specimen in place and ready for testing. The deflection of the spring between the fixture and the lower frame of the test machine is calibrated to support half of the fixture weight. At the start of a test, the initial load on the specimen can be adjusted to be close to zero. During testing, the lower frame of the test machine moves downward applying a tensile load to the fixture.

At the end of the test, the lower frame of the test machine returns to its initial position. The screws controlling the loading devices and the knobs controlling the alignment of the specimen are released, the plastic doors are opened, and the specimen is removed from the fixture.

## SPECIMENS AND TEST PROCEDURES

Specimen dimensions were as follows: total length, 95 mm; height, 38 mm; thickness. 12.7 mm, height of 90° notch, 9.5 mm; and length of critical section, 19 mm. The surface of the specimen was oriented in the longitudial–radial plane; the slope of the grain was oriented at a specified angle to the critical section. The specimen thickness was oriented in the tangential direction.

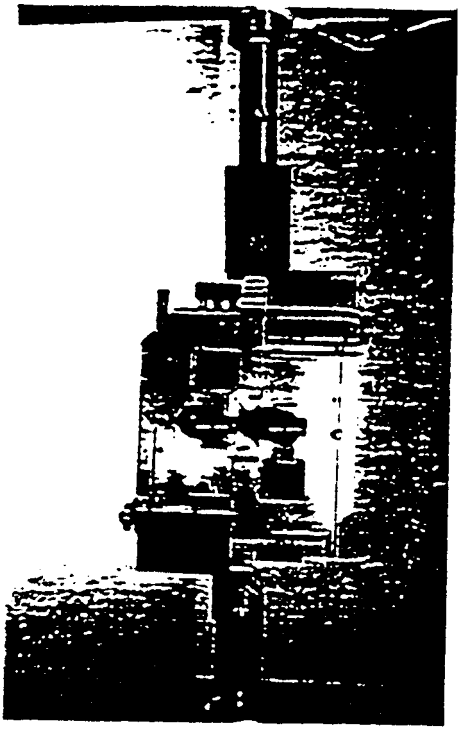

Figure 4. Rear view of new shear test fixture.

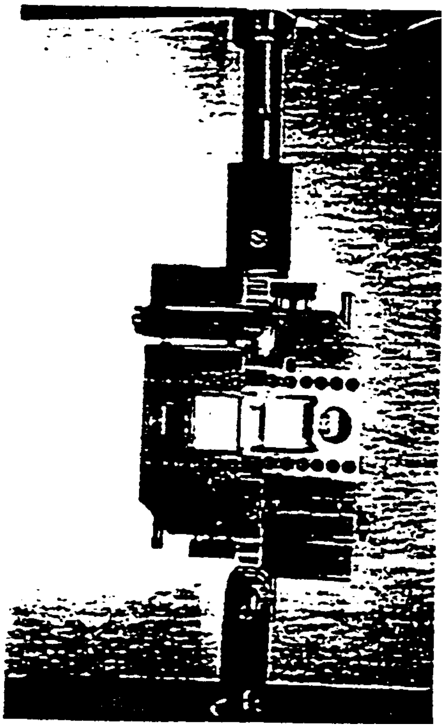

Figure 5. New shear test fixture with specimen in place.

A board of Sitka spruce (*Picea sitchensis*) of unknown history but of the desired grain and growth ring orientations was selected from storage at the Forest Products Laboratory. The board was cut into five samples by slope of grain (0°, 30°, 45°, 60°, and 90°). Each sample consisted of 20 specimens. The specimens were stored in a conditioning room at 20°C and 50% relative humidity for several weeks until stabilized before testing.

All specimens were tested for shear strength. Tensile loading was applied with an Instron test machine, which pulled the left half of the fixture downward while the right half remained stationary. Crosshead speed was 1.27 mm/min. Load and displacement data were recorded electronically.

## RESULTS AND DISCUSSION

In the process of designing the new shear test fixture, we followed the trial and error approach. In our first trial, all the specimens with 0° grain slope failed at the critical section. However, the loading devices were found to be inadequate for specimens with other grain slopes. While testing modified designs of the loading devices, some specimens broke or otherwise damaged, which reduced the number of specimens for testing.

Figure 6 shows two specimens with 30° grain slope. The specimens were mounted with the grain running in different directions. The test results differed for these specimens because of the change in sign of the normal strains induced by pure shear resulting from shear coupling effects (Daniel and Ishai 1994). For specimen B18, the grain lines tended to squeeze together at the critical section. Failure was initiated antisymetrically at the tension edge of the right and left sections away from the critical section. The latewood resisted the shear force at the critical section. For specimen B19, the grain lines at the critical section tended to move apart from one another. Failure was initiated at the earlywood in the critical section.

Results were similar for specimens with grain slopes between 0° and 90°. Failure did not occur in specimens with 90° grain slope. For these specimens, the applied load fluctuated somewhat about a high value with increasing displacement. The test was stopped and this high value was recorded as the maximum failure load. We suspended tests on the 90° grain slop specimens when five tests yielded the same result.

All of our test results and the results of tests on a 0° grain slope sample (Liu and Floeter 1984) are presented in Table 1. The coefficient of variation for the five samples was between 8.7% and 21.7% which is common in the evaluation of mechanical properties of wood. The data apparently indicate a weak relationship between shear strength and grain slope. (Statistical comparisons were not made because of the inequal sample sizes.) Since shear failure always occurred in earlywood has the shear strength properties of an isotropic material.

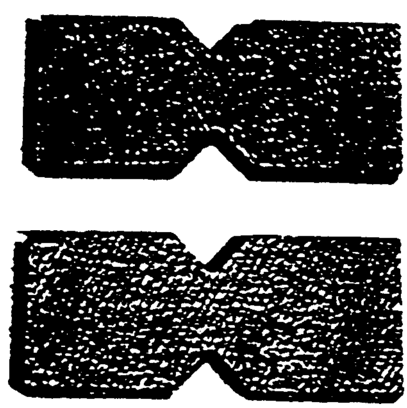

Figure 6, Specimens with 30° grain slope. Top, specimen B19; bottom, specimen B18.

Table 1. Shear strength of Sitka spruce specimens in planes perpendicular to longitudinal-radial plane

| Angle between shear force and grain (°) | No. of tests | Shear strength (Mpa) Average | Shear strength (Mpa) Range | Coefficient of variation (%) |
|---|---|---|---|---|
| 0[a] | 25 | 6.25 | 4.15–8.88 | 20.6 |
| 30 | 5 | 5.80 | 4.31–7.64 | 21.7 |
| 45 | 8 | 5.74 | 4.74–6.32 | 8.7 |
| 60 | 13 | 6.61 | 5.38–7.54 | 9.0 |
| 90[b] | 5 | 6.05 | 5.17–7.25 | 12.6 |

[a]Liu and Floeter 1984.
[b]Maximum load obtained; specimens did not fail.

Our results have given us additional insight into the shear block test compared to the Arcan and Iosipescu tests. As mentioned in the introduction, the shear block test was found to yield higher shear strength than do the Arcan and Iosipescu tests, although it is known to induce high stress concentrations. It is known that both earlywood and latewood are always cut in the shear block test. Since latewood shear resistance is much higher than that of earlywood, more force is required to split a shear block specimen.

## CONCLUSIONS

Many investigators have tried to improve the Arcan and the Iosipescu shear test fixtures to increase specimen stability and to reduce turnaround time in a large test program. In so doing, the investigators have either ignored the requirement for antisymmetry in the fixture halves or they have introduced the additional constraint that the relative movement of the fixture halves be confined to a fixed direction during testing. These modifications are at variance with the original design concepts advanced by Arcan and Iosipescu. The relative importance of the inaccuracy caused by these modifications depends on the specimen material; it is more important for some materials than for others. In our study, we removed the weaknesses of the test fixture without violating the basic requirements of the original design. This improved shear test fixture should be appropriate for studying shear properties of solid wood, plastics, metals and other materials.

## ACKNOWLEDGMENTS

The authors express their appreciation to M. Grambsch for conducting the experiments in this study.

REFERENCES


Adams, D.F. and Lewis, E.Q., 1995, Experimental Strain Analysis of the Iosipescu Shear Test Specimen, Experimental Mechanics, 35(4):352–360.

Arcan, M., 1984, Discussion: The Iosipescu Shear Test as Applied to Composite Materials, Experimental Mechanics, 24(1):66–67.

Arcan, M. and Goldenberg, N., 1957, On a Basic Criterion for Selecting a Shear Testing Standard for Plastic Materials (French), ISO/TC 61–WG2 ST.171, Bargenstock, Switzerland.

Arcan, M., Hashin, Z. and Voloshin, A., 1978, A Method to Produce Uniform Plane Stress States with Applications to Fiber-Reinforced Materials, Experimental Mechanics, 18(14):141–146.

ASTM, 1976, Standard Method of Testing for Shear Modulus of Plywood, ASTM D3044-76, American Society for Testing and Materials, Philadelphia, PA.

ASTM, 1981, Standard Method of Testing Small Clear Specimens of Timber, ASTM D143-52, American Society for Testing and Materials, Philadelphia, PA.

ASTM, 1993, Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method, ASTM D5379-93, American Society for Testing and Materials, Philadelphia, PA.

Coker, E.G., Coleman, G.P., 1935, Photoelastic Investigation of Shear Tests of Timber, The Institute of Civil Engineers (England), Selected Engineering Papers, William Cloroes and Sons, Ltd., London and Beccles.

Conant, N.R. and Odom, E.M., 1995, An Improved Iosipescu Shear Test Fixture, Journal of Composites Technology and Research, 17(1):50–55.

Daniel, I.M. and Ishai, O., 1994, Engineering Mechanics of Composite Materials, Oxford, 395 p.

Goldenberg, N., Arcan, M. and Nicolau, E., 1958, On the Most Suitable Specimen Shape for Testing Shear Strength of Plastics, ASTM STP 247, in Proceedings of International Symposium on Plastics Testing and Standard, Philadelphia, PA, 115–121.

Iosipescu, N., 1967, New Accurate Procedure for Single Shear Testing of Metals, Journal of Materials, 2(3):537–566.

Jones, R.M., 1975, Mechanics of Composite Materials, Scripta Book Co., Washington, D.C. 344 p.

Kubojima, Y., Yoshihara, H., Ohta, M. and Okano,T., 1996, Examination of the Method of Measuring the Shear Modulus of Wood Based on the Timoshenko Theory of Bending, Mokuzai Gakkaishi, 42(12):1170–1176.

Liu, J.Y., 1984, New Shear Strength Test for Solid Wood, Wood and Fiber Science, 16(4):567–574.

Liu, J.Y. and Floeter, L.H., 1984, Shear Strength in Principal Plane of Wood, Journal of Engineering Mechanics, 110(6):930–936.

Liu, J.Y. and Ross, R.J., 1997, Shear Modulus Variation with Grain Slope, In R. Perkins, ed., Joint ASME/ASCE/SES Summer Meeting, Mechanics of Cellulosic Materials, ASME AMD–Vol.221/MD–Vol.77:107-111.

Liu, J.Y., Ross, R.J. and Rammer, D.R., 1996, Improved Arcan Shear Test for Wood, In V.K.A. Gopu, ed., Proceedings of International Wood Engineering Conference, 2:85–90.

March, H.W., Kuenzi, E.W. and Kommers, W.J., 1942, Method of Measuring the Shearing Moduli in Wood, Report No.1301, USDA Forest Service, Forest Products Laboratory, Madison, WI.
Radcliffe, B.M. and Suddarth, S.K., 1955, The Notched Beam Shear Test for Wood, Forest Products Journal, 5(2):131–135.
Tsai, S.W. and Wu, E.M., 1971, A General Theory of Strength for Anisotropic Materials, Journal of Composite Materials, 5:58–80.
Walrath, D.E. and Adams, D.F., 1983, The Iosipescu Shear Test As Applied to Composite Materials, Experimental Mechanics, 23(1):105–110.
Youngs, R.L., 1957, The Perpendicular-to-Grain Mechanical Properties of Red Oak as Related to Temperature, Moisture Content and Time, Ph.D. Dissertation, Science, 16(4):567–574.

AMD-Vol. 231
MD-Vol. 85

# MECHANICS OF CELLULOSIC MATERIALS 1999

*presented at*

THE 1999 ASME JOINT APPLIED MECHANICS AND MATERIALS DIVISION MEETING
JUNE 27–30, 1999
BLACKSBURG, VIRGINIA

*sponsored by*

THE APPLIED MECHANICS DIVISION, ASME
THE MATERIALS DIVISION, ASME

*edited by*

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