

IOSIPESCU SHEAR TEST APPARATUS APPLIED TO WOOD COMPOSITES

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ABSTRACT

In-plane and transverse (through-the-thickness) shear strength properties were evaluated for three wood composite materials. A modified Iosipescu test apparatus was used to determine shear strength relative to the six possible material orientations. In-plane shear was also characterized using ASTM D1037-87 test standards. The Iosipescu shear test method was developed originally for metals testing. However, different forms of the test device have evolved for purposes of shear evaluation with numerous nonisotropic materials being evaluated. Previous research for various materials has shown satisfactory results with repeatability and apparent shear failure. The current research specifically utilized the University of Wyoming version of the original shear test device. Iosipescu test results for in-plane shear strength were comparable to values derived from the ASTM test method. Transverse shear strength values were found to exceed the magnitude of previously published ASTM test results. Greater directional or material orientation differences were observed for transverse shear properties.

Keywords: Iosipescu, in-plane, transverse, shear strength, wood composites.

INTRODUCTION

Shear property characterization utilizing the Iosipescu test method technique has been promoted through extensive experimentation (Walrath and Adams 1980a, b, c, 1981; Adams and Walrath 1982). However, test method development is attributable to Nicolae Iosipescu at the Rumanian National Laboratory of Strength of Materials Building Research Institute. Iosipescu's research efforts were specific to material-testing of metals and welded joints under pure shear loading or single shear loading which produces only shear stress within the test section. His efforts have been summarized (Iosipescu 1967) for various examined technique configurations and proposed method to advance pure shear testing.

Since Iosipescu's original work, several versions or modifications have evolved to the proposed testing scheme (Walrath and Adams 1979; Slepetz et al. 1978; Areat et al. 1978). An evolution has occurred towards adaption for nonisotropic composite materials. Composites evaluated through Iosipescu-shear test usage include three-dimensionally reinforced ceramic matrix and carbon-carbon com-

posites; unidirectionally reinforced glass/epoxy and graphite/epoxy; chopped-glass fiber reinforced polyester; and neat polymers such as polyethylene, polyurethane sheet, and polyurethane foams.

Interest in the Iosipescu-type test is related to finding an effective yet inexpensive shear characterization procedure. Currently, the most widely utilized method for graphite fiber-reinforced organic matrix composites is the ASTM Test for Apparent Interlaminar Shear Strength of Parallel Fiber Composites by Short-Beam Method (D2344). Primary D2344 usage has been as a quality-assurance tool for fabricated composites (Browning et al. 1983). However, the short-beam shear test suffers from a significant limitation in its ability to produce interlaminar shear failure for thin beam test specimens; thus the reason for interest in alternative shear test methods. Although numerous other methods are available—for example, the off-axis tensile (Chamis and Sinclair 1977), slotted-tension (Duggan 1980), picture-frame (Bryan 1961), double and three rail shear tests (Floeter and Boller 1967; Whitney et al. 1971; Garcia et al. 1980), etc., experimentation continues to isolate an optimum test procedure. An optimum or “ideal” procedure may be rationalized as relatively simple to conduct with minimum test specimen fabrication effort.

Traditional shear characterization procedures for wood-based composites are ASTM D1037.81 (in-plane shear), ASTM D1037.128 (interlaminar shear), ASTM D1037.136 (edgewise shear), ASTM D2718 (plywood in rolling shear), and ASTM D2719 methods A, B, and C (plywood in shear through-the-thickness) (American Society for Testing and Materials 1981). These procedures, with ASTM D1037.81 the exception, characterize shear strength properties through unique loading schemes that generate questionable or even limited states of pure shear stress. In addition, rather complex or large test specimen configurations are required, combined with time/labor intensity for the actual test setup. Various alternative methods for shear strength characterization have been proposed or examined by other investigators (Hall and Haygreen 1983; Hunt et al. 1980; Suchsland 1977; Gertjensen and Haygreen 1971; Shen 1970).

The research presented in this paper was conducted to assess the applicability of the Iosipescu method for wood composites. Significant advantages were viewed to exist in this adaptation, including effective reductions in specimen fabrication effort and an encompassing method for both in-plane and transverse shear strength evaluation. Of somewhat lesser, but of potential significance are reduced specimen size requirements, where limited amounts of experimentally derived material are available for multiple testing schemes. Of paramount consideration was the flexibility provided to evaluate shear strength within any material orientation.

THEORY

The loading configuration based on the University of Wyoming version (Walrath and Adams 1979) of the Iosipescu shear-test is depicted schematically in Fig. 1. Such a configuration achieves a pure shear stress state at specimen midlength through the application of two counteracting moments respective to the applied force couples. Figure 2 illustrates the system of applied force couples due to a total external load, P , along with resultant shear and moment diagrams. Shear and moment diagrams clearly identify pure constant shear loading for the test specimen midlength.

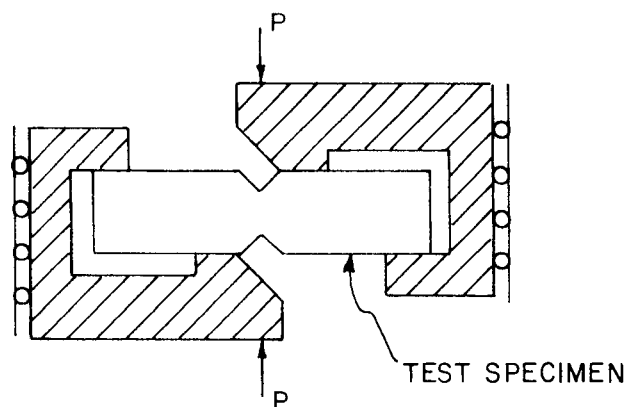


FIG. 1. Schematic of the loading fixture for the Iosipescu-shear-test.

Figures 1 and 2 also indicate that test specimens are processed, generally with 90 degree matching notches cut at specimen midlength in accordance with proposed specimen design (Iosipescu 1967). Iosipescu determined that stress distribution within the notched isotropic specimens was altered to uniform shear ($\tau = P/wt$) in contrast to parabolic distribution for constant cross-sectional beam specimen design. Potential stress concentrations, intuitively suggested for the notch-tip area of isotropic specimens, are unwarranted since implied normal stresses occur in parallel alignment to the notch sides. Uniformity of shear stress for orthotropic specimens was confirmed by Berger et al. (1977). However, the Berger material indicated the possibility of localized stress concentrations pertinent to specimen failure for highly orthotropic materials.

EXPERIMENTAL METHODS

Experimentation to characterize transverse shear strength was limited to the Iosipescu method, while in-plane shear evaluation included the conventional ASTM method. The Iosipescu-shear-test fixture utilized (Fig. 3) was, essentially, the same version that was developed at the University of Wyoming. Minor modifications were made to the Wyoming version fixture, which was designed initially to accommodate specimens with dimensions of 2 in. long by $\frac{1}{2}$ in. wide and $\frac{7}{16}$ in. deep. New loading blocks were machined to accept a 60% increase in specimen width and a maximum 1-in. depth.

Depth variations between in-plane and transverse shear specimens and variation that was inherent to the fabrication were accounted for by using bearing spacers and brass shim stock. Close tolerances of specimen surface contact to the loading block faces were required. Even parallel contact was a priority; otherwise specimen rotation occurred between the loading blocks causing an undesired bending moment inclusive within the specimen midlength. Thus, attention was necessary in alleviating potential asymmetrical contact between the loading blocks to assure a pure shear stress field.

Specimens were processed from each of the six possible material orientations enabling strength evaluation for shear stress tensors τ_{xy} , τ_{yx} , τ_{zx} , τ_{yz} , and τ_{zy} . Noting

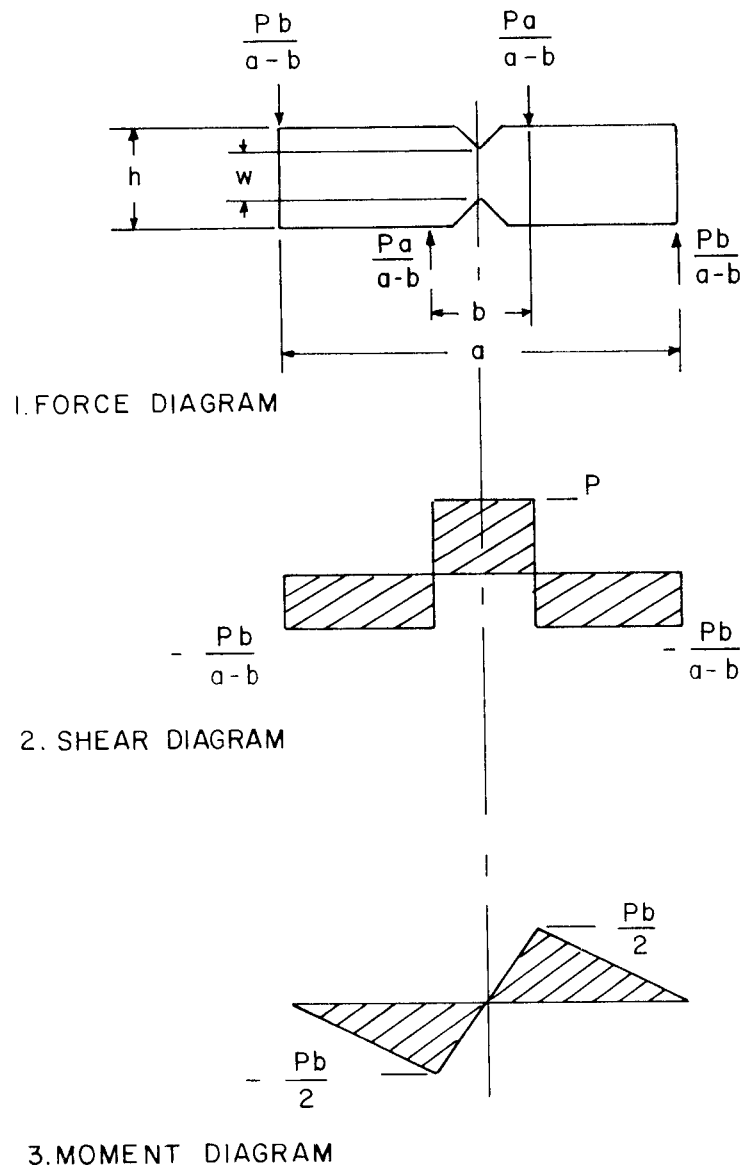


FIG. 2. Applied force, shear, and moment diagrams for Iosipescu shear specimen.

the x-y plane orientation defines the major panel surface where x and y, respectively, equal the longitudinal panel machine direction and opposite in-plane cross direction. In-plane specimens were fabricated through lamination of four specimen thicknesses with subsequent dimensioning to appropriate cross section. In contrast to the prescribed Iosipescu specimen configuration, all specimens were fabricated in constant cross-sectional beam form. This means that $\tau_{\max} = 3V/2A$. Three commercial panel materials were evaluated: $\frac{3}{4}$ in. underlayment-grade particleboard, $\frac{3}{4}$ in. waferboard, and $\frac{5}{8}$ in. oriented strand board.

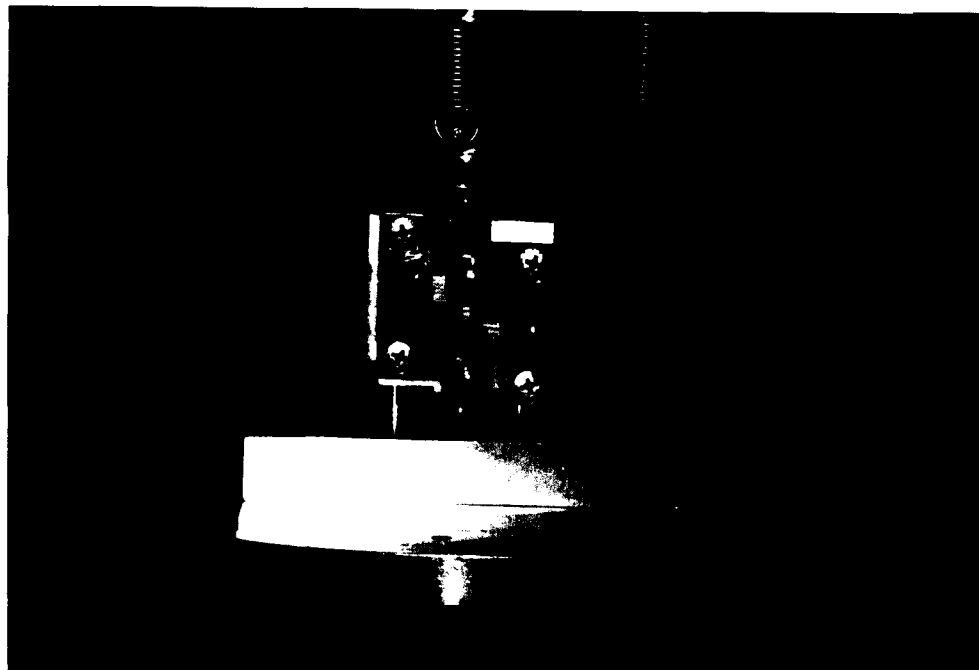


FIG. 3. Photograph of the Iosipescu shear-test fixture.

RESULTS AND DISCUSSION

Test results for in-plane shear strength evaluation, using ASTM D1037 (American Society for Testing and Materials 1981) and the Iosipescu method, have been summarized in Table 1. Shear strength statistics for both test methods were based on the evaluation of eighty specimens. Specimens were obtained randomly from five full-sized panels for each composition board type. In-plane shear strength (τ_{21}) was not evaluated for the $\frac{3}{4}$ in. underlayment using the Iosipescu method. Transverse shear strength descriptive statistics are presented in Table 2. Descriptive statistics for transverse shear were based on forty specimens randomly obtained from twenty panels. ASTM D1037 and Iosipescu in-plane specimens were tested respectively, at 11.9 and 10.6% average moisture content. Transverse shear specimens were tested at an average of 6.3% moisture content. Loading rate for all shear strength testing was 0.024 in./min.

Examination of Table 1 would suggest that the Iosipescu method yielded higher average shear strength values with one apparent exception for the $\frac{5}{8}$ in. oriented strand board. Closer examination using statistical analysis, notably hypothesis testing of equivalent means for paired comparisons (Huntsberger and Billingsley 1977), indicated limited significant difference between evaluation methods. Only τ_{12} for $\frac{3}{4}$ -in. underlayment was found to be significantly greater as evaluated through the Iosipescu method. The consistently greater variability associated with the Iosipescu test may be assumed to be attributed to specimen size effect rather than to a treatment error. Shear plane area for the ASTM test specimen configuration was roughly four times larger. Other researchers given smaller test spec-

TABLE 1. *In-plane shear strength data derived using the ASTM 1037 and the Iosipescu method.*

Shear strength	Composition board type ¹	Mean (psi)		Maximum (psi)		Minimum (psi)		Standard deviation (psi)	
		ASTM 1037	Iosipescu	ASTM 1037	Iosipescu	ASTM 1037	Iosipescu	ASTM 1037	Iosipescu
$\tau_{12}(\tau_{xy})$	A	163	237	216	313	114	148	24	36
	B	118	147	183	267	60	42	26	49
	C	253	259	391	389	175	158	43	46
$\tau_{21}(\tau_{yx})$	A	158	NT ²	205	NT	111	NT	21	NT
	B	141	153	218	254	61	55	36	48
	C	299	290	439	415	198	130	51	62

¹ A = 3/4 in. underlayment grade particleboard; B = 3/4 in. waferboard; C = 3/4 in. oriented strand board.² Not tested.

imen size (McNatt 1973; Szabo 1982), have acknowledged the potential for greater strength property variability.

Through-the-thickness shear strengths (Table 2) are of greater magnitude in comparison to previously published ASTM test data (McNatt 1973). Iosipescu shear strength values compare more favorably with results reported by Suchsland (1977). Using a compressive loading scheme, Suchsland determined the average shear strength for ten different particleboard materials, which ranged from 408 to 1,920 psi. Similarly, Shen (1970) computed interlaminar shear strength values, ranging from 800 to 2,160 psi, using torsional loading. In light of these results, Iosipescu values are not extreme in magnitude. Shear strength differences between test methods, with other influencing factors being constant, must originate within the loading scheme environment. Keenan (1974) had a similar conclusion in that solid wood shear strength was a material property of constant value, but not without dependence upon the testing method. Direct comparison of shear strength between test methods is complicated because of specimen size differences. Consistently higher values were found for the ASTM D905 test method using reduced size specimens (Okkonen and River 1988). Higher shear strength can be rationalized as a function of smaller test cross-sectional area with associated lower probability for the occurrence of a dislocation or strength reducing defect.

TABLE 2. *Transverse shear strength data derived using the Iosipescu method.*

Shear strength	Composition board type ¹	Mean (psi)	Maximum (psi)	Minimum (psi)	Standard deviation (psi)
$\tau_{13}(\tau_{xz})$	A	992	1,280	769	125
	B	1,282	2,788	409	434
	C	2,059	3,098	1,194	478
$\tau_{31}(\tau_{zx})$	A	1,517	1,938	1,227	172
	B	1,465	2,335	699	417
	C	2,327	3,107	1,254	372
$\tau_{23}(\tau_{yz})$	A	1,002	1,327	762	129
	B	1,471	2,318	469	408
	C	2,497	3,712	1,587	505
$\tau_{32}(\tau_{zy})$	A	1,515	1,827	1,182	159
	B	1,446	2,244	619	413
	C	2,372	3,190	1,739	342

¹ A = 3/4 in. underlayment grade particleboard; B = 3/4 in. waferboard; C = 3/4 in. oriented strand board.

TABLE 3. *Duncan Multiple Range Test ($\alpha = 0.05$) for comparison of directional differences for in-plane ASTM-derived shear strength.*

Shear strength	Composition board type					
	$\frac{3}{4}$ in. underlayment		$\frac{3}{4}$ in. waferboard		$\frac{3}{8}$ in. oriented strand board	
	Mean ¹ (psi)	Significance ²	Mean (psi)	Significance	Mean (psi)	Significance
τ_{xy}	163	A	118	A	253	A
τ_{yx}	158	A	141	A	299	B

¹ Based on 80 specimens.² Means with the same capital letters are not significantly different.

One particular concern observed during testing was specific to the Iosipescu fixture design. The concern was the inner loading point proximity relative to the specimen midspan. Visual inspection for the loading cycle confirmed varying degrees of compression deformation or failure at the load-bearing points. Undoubtedly, concentrated load-induced compressive stresses may extend into the test section. Compressive stresses within the test section would have an adverse effect, causing restriction of shear distortional stresses. The close proximity of loading points to the test region may be viewed as a fixture design deficiency that interjects a test error, possibly accounting for the higher ultimate shear strength observed. Interestingly, this test limitation has been observed by other researchers (Spigel et al. 1987). However, further development of the Iosipescu fixture has occurred to rectify this design deficiency and reduce the strict specimen depth tolerance requirement (Adams and Walrath 1987).

Directional differences in shear strength both in-plane and transverse were evaluated using Duncan's Multiple Range Test (DMRT). Tables 3 and 4 present the statistical test results to examine directional shear strength ($\tau_{xy} = \tau_{yx}$, $\tau_{xz} = \tau_{zx}$, and $\tau_{yz} = \tau_{zy}$). Table 3 shows that directional in-plane shear strengths for composition board types A ($\frac{3}{4}$ -in. underlayment particleboard), B ($\frac{3}{4}$ -in. waferboard), were not significantly different. However, composition board C ($\frac{3}{8}$ -in. oriented strand board) was found to be significantly different.

Directional transverse shear strength (Table 4) in the xz planar orientation was to be significantly different for all composition board types. Directional shear strengths in the yz to zy orientations were determined as significantly different for composition board type A while composition boards B and C, in contrast, were not found as significantly different.

TABLE 4. *Duncan Multiple Range Test ($\alpha = 0.05$) for comparison of directional differences for transverse Iosipescu derived shear strength.*

Shear strength	Composition board type					
	$\frac{3}{4}$ in. underlayment		$\frac{3}{4}$ in. waferboard		$\frac{3}{8}$ in. oriented strand board	
	Mean ¹ (psi)	Significance ²	Mean (psi)	Significance	Mean (psi)	Significance
τ_{xz}	992	A	1,282	A	2,059	A
τ_{zx}	1,517	B	1,465	AB ³	2,327	B
τ_{yz}	999	A	1,471	A	2,497	A
τ_{zy}	1,515	B	1,446	A	2,372	A

¹ Based on 40 test specimens.² Means with the same capital letters are not significantly different.³ Means found significantly different at $\alpha = 0.10$.

SUMMARY

Statistical hypothesis testing for paired comparisons identified the equivalence of in-plane shear strength derived through Iosipescu-shear-test usage relative to the ASTM D-1037 test procedure. This equivalence, combined with the general assumption of ASTM D-1037 method reliability, suggests the applicability for Iosipescu usage in characterizing in-plane shear strength. In contrast, transverse shear values exceeded earlier published ASTM D-1037 test data. The higher magnitude of Iosipescu strength values compared more directly with other research results obtained using alternative shear test methods. This apparent contradiction in shear strength may be attributed to test method dependence. Significance of shear strength values between varying methodologies may also be assumed to be dependent upon differences in spatial test area. However, experimental observation identified a limitation in the Iosipescu fixture design with regard to potential compressive stress influence within the short test region. Additional experimental efforts are warranted to explore the compressive influence on ultimate shear strength properties.

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