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THE DETERMINATION OF THE TRANSVERSE SHEAR STRENGTH FOR 3/8 INCH UNSANDED DOUGLAS FIR PLYWOOD

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Dale R. Cree

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THE DETERMINATION OF THE TRANSVERSE SHEAR STRENGTH FOR 3/8 INCH UNSANDED DOUGLAS FIR PLYWOOD

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A B S T R A C T

The purpose of this research was to re-evaluate the transverse shear strength of 3/8" unsanded Douglas fir plywood.

A series of tests was made with present standard shear tests and modifications of these standard tests. The results were statistically evaluated.

Shear strength values found are presented. A comparison is made of the results of different shear test methods used.

Recommendations for further studies are made based on the findings of this research.

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THE DETERMINATION OF THE TRANSVERSE SHEAR STRENGTH FOR 3/8 IN. DOUGLAS FIR UNSANDED PLYWOOD.

INTRODUCTION

The problem of determining true horizontal shear strength values for plywood has been investigated extensively in the past. At the present time there are two tests which have been accepted as standard shear tests. (9)* Results from these tests have been used as a basis for determining design stress values for the various grades of Douglas fir plywood.

Recent work done on the development of glue-nailed beams (8) with a 3/8" Douglas fir C-D web, indicates there exists a question as to whether the allowable shear strength value for this particular grade of plywood is not too conservative. Using the present allowable shear value for plywood webs, computations indicated horizontal shear failure would limit the load carrying capacity of the beams. Full scale testing of the beams proved this was actually not the case. (8) In these tests, Radcliffe, Luebs and Sliker (8) found that deflection rather than shear strength was the criteria limiting design.

( )*Indicates reference cited.

At maximum allowable deflections no shear failures occurred, although calculated values were far above allowable shear strength for the plywood. As a result of these tests, two questions were raised. First, are the present allowable shear strengths reasonable? Second, do the currently accepted shear tests yield true values of ultimate shear strength for plywood?

The problem of designing a test method is devising a test which yields pure shear stresses of uniform distribution and not a combination of normal stresses and shear stresses. (7)

The testing in this investigation involved a comparison of the results of the Standard Block Shear Test for Small Clear Specimens, ASTM Designation D143-52, the modification of the Standard Block-Shear Test (which will be referred to as the "Modified Block-Shear Test"), the Panel Shear Test, ASTM Designation D805-52, and the "Notched Beam Shear Test", developed by Radcliffe and Suddarth at Purdue University. (13)

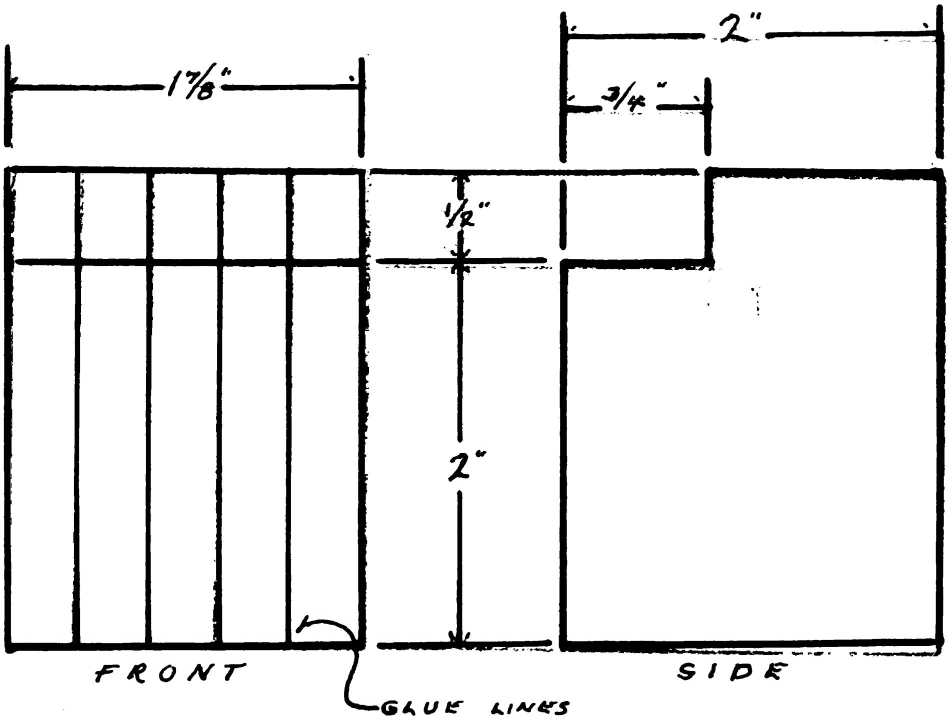
PREVIOUS WORK

The problem of determination of a horizontal shear stress for plywood has been a difficult one since the first time plywood was used in constructing structural components. Forest product research laboratories in foreign countries such as England [5] and Germany [2] have conducted considerable research in this area.

At the present time there are three shear tests for plywood which have been accepted as standards. These tests are described in ASTM Standards on "Wood Preservatives and Related Materials. [1] The first of these tests is a block-shear test for small, clear specimens. This test was first developed by the Forest Products Laboratory in about 1910. The test is called the ASTM Standard Block-Shear Test for Small Clear Specimens.

This block-shear specimen is used for testing shear strength of plywood. The specimen, machined from several pieces of plywood glued together, is shown in Fig. 1.

At the time of the development of this test, it was realized that the test did not subject the specimen to uniformly distributed pure shear stress. [11] During the years that followed the questionable validity of this test was commented on by such investigators as Coker, and Coleman [3], who made photo-elastic studies of the shear stress distribution in wood. They pointed out that the shear stress is not uniformly distributed across the shear



STANDARD SHEAR BLOCK

FIG 1

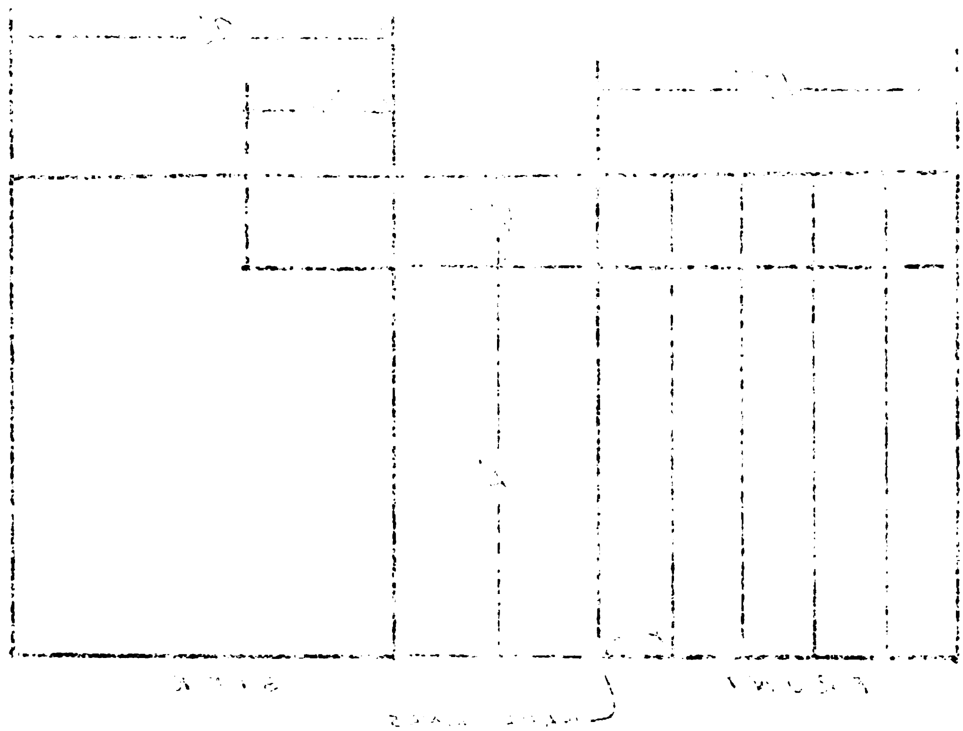
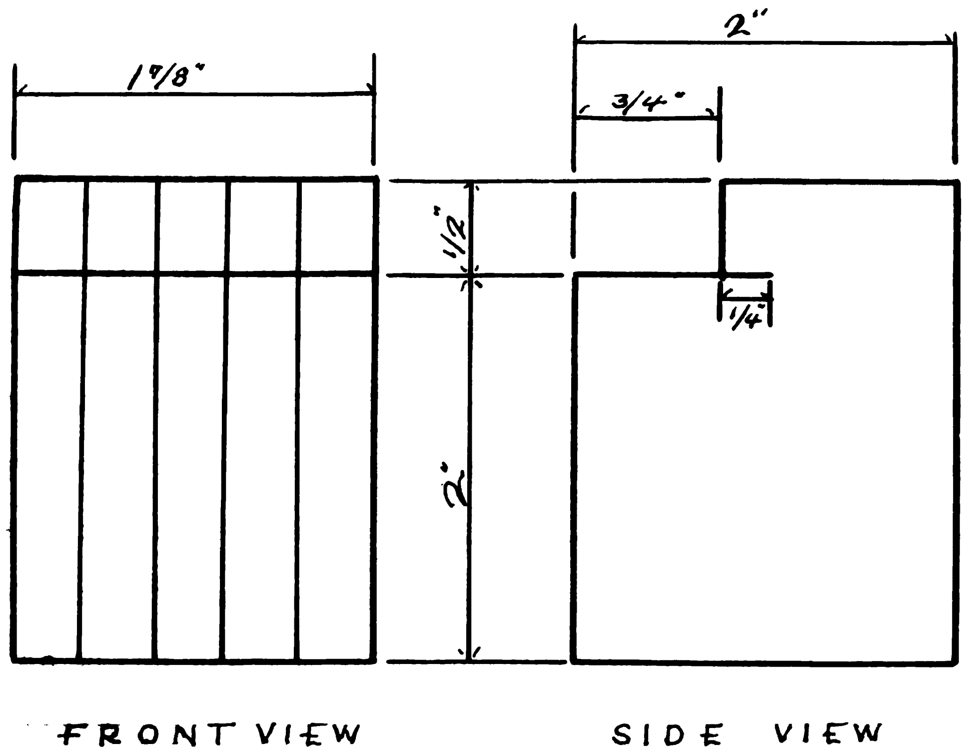
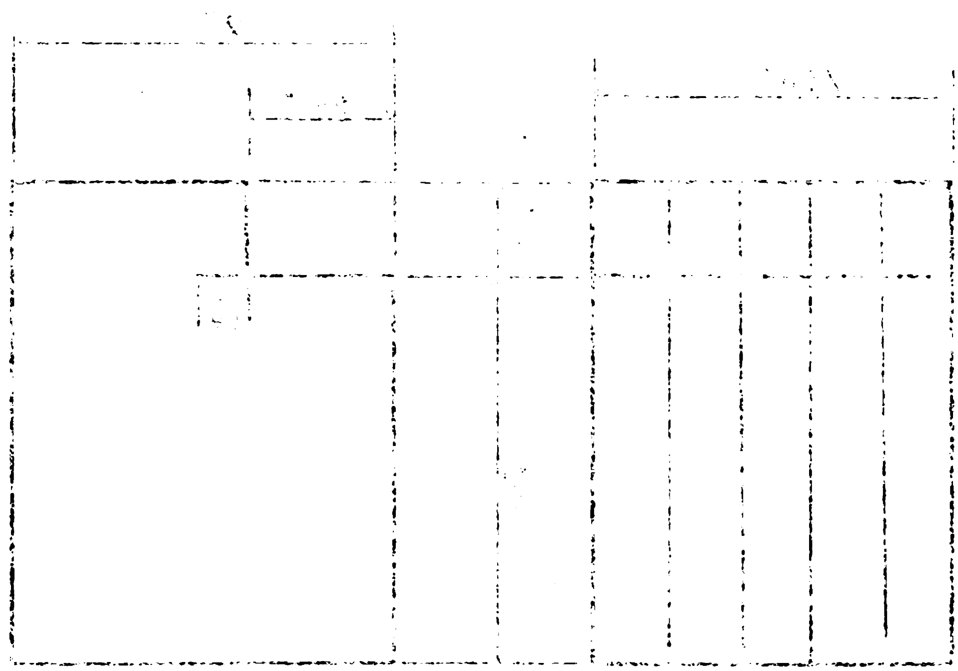


FIG 1



MODIFIED SHEAR BLOCK

FIG. 2



FRONT VIEW SIDE VIEW

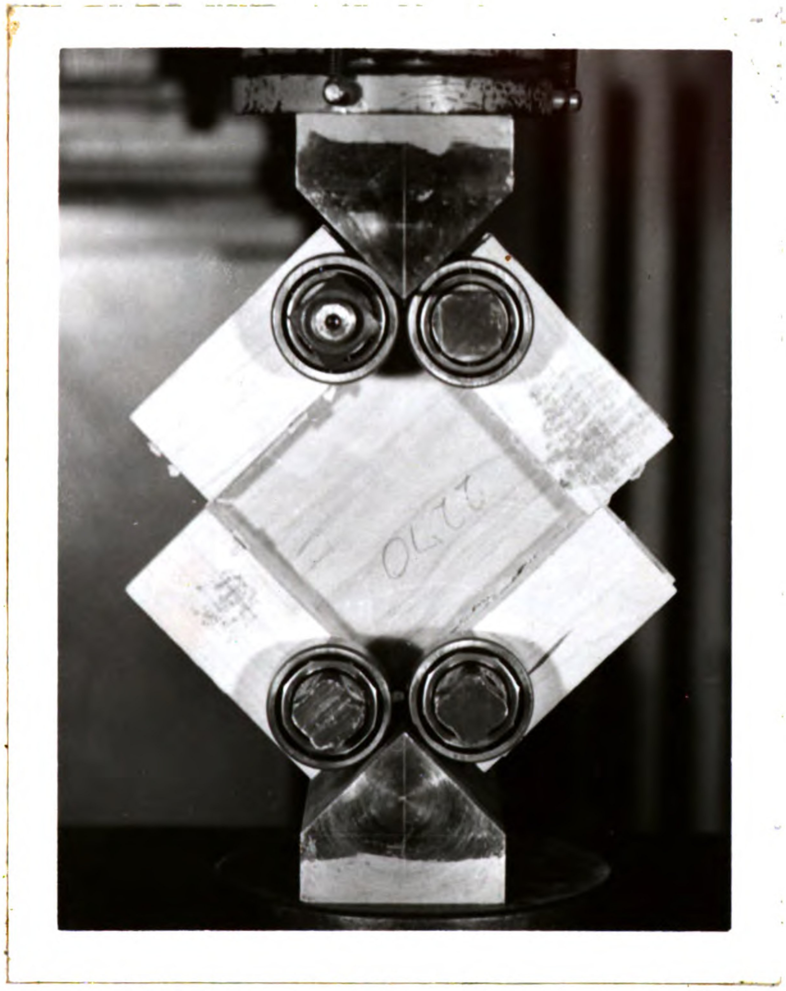
MODIFIED SHEAR BLOCK

FIG. 2

plane and that normal tensile and compressive stresses exist on this plane. DeBruyne and Houwink [4] pointed out that shear stresses increase as compression and tensile stresses are reduced. This would indicate a higher allowable shear stress if stress concentrations could be reduced.

In more recent work Radcliffe and Suddarth [13]Fig.2 suggested the use of a modified block shear test. A small notch was cut horizontally at the reentrant point to relieve stress concentrations. An electric resistance strain gage analysis of this modified shear block showed very close agreement between the experimental and theoretical stress distribution. Radcliffe and Suddarth also devised a "Notched Beam Shear Test" [13] which gave shear strength values which proved to be significantly higher, as shown statistically, than those indicated by the standard block shear test. In this work a stress analysis of the notched beam was made using electric resistance strain gages. The experimental results showed excellent agreement with the theoretically calculated values.

The most recent test accepted as a standard is the Panel Shear Test. [1]Fig.3 This consists of a plywood panel shaped as indicated in ASTM Standards. [1] Hard maple blocks are glued to the arms of the panel. Steel pins are inserted into holes through the blocks and roller bearings are mounted on the pins. In the testing procedure the central square of the panel is subjected to shearing forces. The use of electric resistance strain



PANEL SHEAR TEST

APPARATUS

FIG. 3

gages applied during tests conducted by Norris [12] indicated a nearly uniform distribution of shear stress over the test area. Norris [11] investigated the relationship of values obtained by the Standard Block-Shear Test and the Panel Shear Test. In the analysis of the test results Norris reported good agreement between the shear strength values obtained from both tests.

The question of determination of strength properties of plywood at various moisture contents has been raised by the Forest Products Research Board of the Department of Scientific and Industrial Research. [5] They found that there was some question as to the true evaluation of moisture contents within plywood. Since plywood is not a homogeneous product it was felt that oven-drying did not give true moisture content values. Therefore the basic strength values of plywood conditioned to 12% are not the most accurate. This author will contrive to assume 12% m.c. as directed in the ASTM Standard [1], to be the optimum for determining basic strength values.

MATERIALS AND PREPARATION

The initial problem was to obtain a representative sample of the 3/8" C-D grade Douglas fir plywood and to obtain the plywood from as many different mills as the number of sheets that was determined to be necessary for an adequate sample. In order to obtain a random sample, twenty sheets of plywood were obtained from different mills. Adequate randomness of the sample would result.

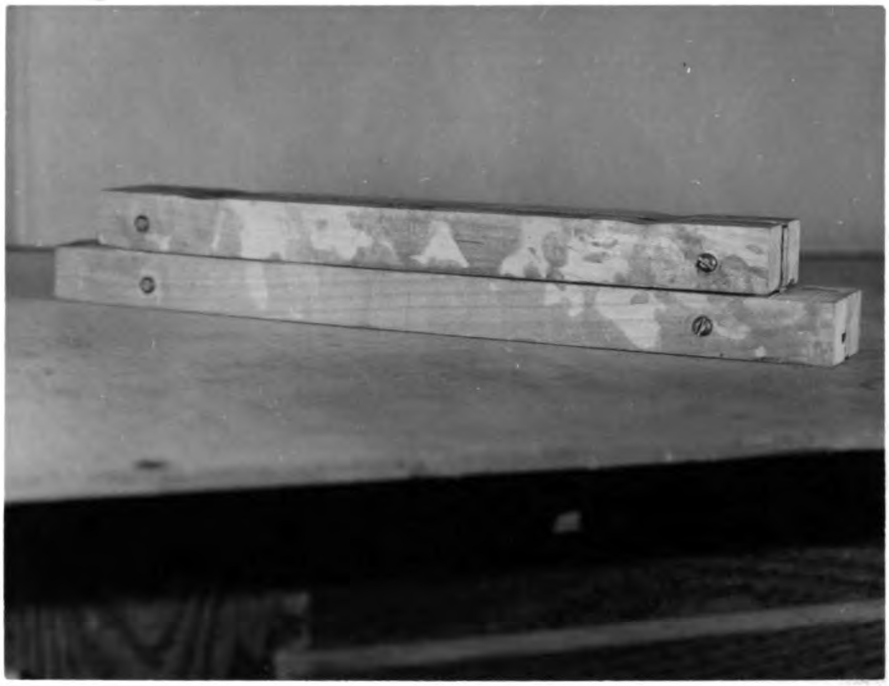
The plywood sheets were numbered from 1 to 20 for identification. For the first series of tests, i.e., between the Standard Block-Shear Test and the Modified Block-Shear Test, a minimum of 450 2" x 2½" clear pieces were cut from each sheet and numbered accordingly. The 450 pieces were chosen as free from any visible defects on the faces or in the core material. A total of 80 test blocks, four from each sheet, were made up from the 2" x 2½" pieces, using five pieces per block. The blocks were assembled with Casein glue, U.S. Government Specification MMM-125A. Squeeze out at the glue line indicated a sufficient quantity of glue had been used. The blocks were held under pressure in pole clamps for 24 hours while drying. The test blocks were then placed in a conditioning room at 66% relative humidity and 70°F. during the assembly period.

After all 80 test blocks were assembled, 2 blocks from each sheet or a total of 40 blocks were selected for

the Modified or notched shear blocks. The blocks are shown in Figures 1 and 2. For a period of time prior to testing, the 80 blocks were placed in a humidity control chamber with conditions of 63°F. wet bulb temperature and 70°F. dry bulb temperature, until the blocks had attained a moisture content of 12%. The moisture content was determined by the oven-dry method. The blocks were taken from the humidity control chamber immediately prior to testing.

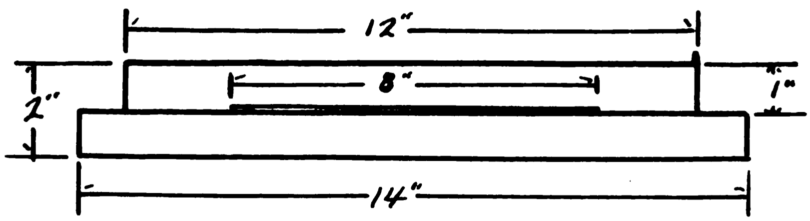
The Panel Shear Test specimens and testing apparatus were made in accordance with the specifications of the ASTM Standards. The maple blocks were adhered to the plywood with polyvinyl adhesive. A total of 20 test specimens were made, one from each sheet of the 20 sheets of plywood. The plywood was selected as being free from visible defects on the faces and in the core material. The moisture content of the maple was determined with a moisture meter and found to be less than 12%. The specimens were placed in a humidity chamber until testing time.

Three test specimens of the Notched Beam type were assembled according to specifications of Radcliffe and Suddarth. (13)Fig.5 It was observed that these beams did not fail in horizontal shear. Three new beams were modified to produce a smaller shear area. Fig. 6 A slit the width of a saw kerf, approximately 1/8", was cut in the web to



NOTCHED SHEAR BEAM

FIG. 5



NOTCHED BEAM WEB
3/8" PLYWOOD

FIG 6

reduce the shear area. The flanges of the beam were cut from select structural Douglas fir 2" x 4" which had been conditioned to a moisture content of 12%. The plywood webs were conditioned to a moisture content of 12% after the specimen was assembled.

TEST METHODS

The tests of standard and modified shear blocks were conducted in a 10,000# capacity Dillon testing machine. Rate of machine speed was .027"/min., according to ASTM specifications. Each shear block was taken from the humidity control chamber just prior to testing. The exact shear area of each specimen was measured. The block was placed in a standard Forest Products Laboratory shear tool and the entire assembly placed in the testing machine. Fig.7&8 Load was applied until failure of the specimen.

The Panel Shear tests were made in a 30,000# Riehle testing machine, at a standard ASTM load rate of .005"/min. of diagonal length. Each test specimen was taken from the humidity control chamber just prior to testing asabove. Exact measurement of the shear area was made for each specimen. The apparatus was assembled and placed in the machine for test to failure. Fig.3 Immediately upon failure a moisture sample was cut from the shear area and moisture content was determined by the oven-dry method. (1)

The Notched Beam tests were made in a 100,000# Riehle testing machine at a head speed of 1/8"/min. Two-point loading was used. Fig.9 Loading was continuous to failure.

TABLE I

STANDARD SHEAR TESTS 9-29-59

Sample No.	Actual Dimensions. Inches	Shear Area Sq. In.	Plywood Sheet No.	Moisture Content	Lbs. P	P.S.I. $\tau = \frac{P}{A}$
1	1.90 x 1.95	3.70	1	12%	3800	1025
2	1.78 x 1.95	3.41	9	12%	3525	1040
3	1.78 x 1.95	3.41	4	"	3400	997
4	1.80 x 1.96	3.53	8	"	3700	1050
5	1.78 x 1.97	3.46	10	"	3600	1040
6	1.60 x 1.96	3.13	3	"	3800	1211
7	1.72 x 1.92	3.30	16	"	4100	1240
8	1.70 x 1.95	3.32	20	"	3650	1100
9	1.88 x 1.96	3.68	7	"	4000	1086
10	1.87 x 1.97	3.68	6	"	4050	1100
11	1.70 x 1.96	3.33	12	"	3750	1125
12	1.75 x 1.95	3.41	11	"	4050	1190
13	1.70 x 2.0	3.40	15	"	4250	1250
14	1.70 x 1.98	3.36	14	"	3850	1150
15	1.75 x 2.0	3.50	17	"	3600	1025
16	1.75 x 1.96	3.42	18	"	3000	880
17	1.78 x 1.96	3.48	19	"	3550	1020
18	1.72 x 1.95	3.35	13	"	3550	1060
19	1.72 x 1.96	3.35	5	"	3100	928
20	1.76 x 1.95	3.43	2	"	3750	1090
21	1.90 x 1.96	3.72	7	"	4100	1100
22	1.70 x 2.0	3.40	14	"	3900	1142
23	1.76 x 1.95	3.43	4	"	3200	935
24	1.70 x 1.93	3.28	12	"	3700	1125
25	1.72 x 1.98	3.40	16	"	4100	1210
26	1.78 x 1.96	3.46	10	"	3500	1000
27	1.71 x 1.95	3.34	5	"	3000	900
28	1.75 x 1.93	3.37	2	"	3550	1045
29	1.90 x 1.96	3.72	1	"	4000	1068
30	1.78 x 1.97	3.50	19	"	3300	940
31	1.75 x 2.0	3.50	18	"	3400	970
32	1.80 x 1.96	3.52	8	"	3650	1035
33	1.86 x 1.98	3.68	6	"	4000	1090
34	1.70 x 1.96	3.34	15	"	3700	1110
35	1.76 x 1.96	3.45	9	"	3600	1040
36	1.72 x 1.97	3.38	13	"	3600	1060
37	1.73 x 2.0	3.46	17	"	3550	1025
38	1.76 x 2.0	3.52	20	"	3800	1080
39	1.72 x 1.95	3.35	11	"	4500	1320
40	1.71 x 1.97	3.36	3	"	4450	1320

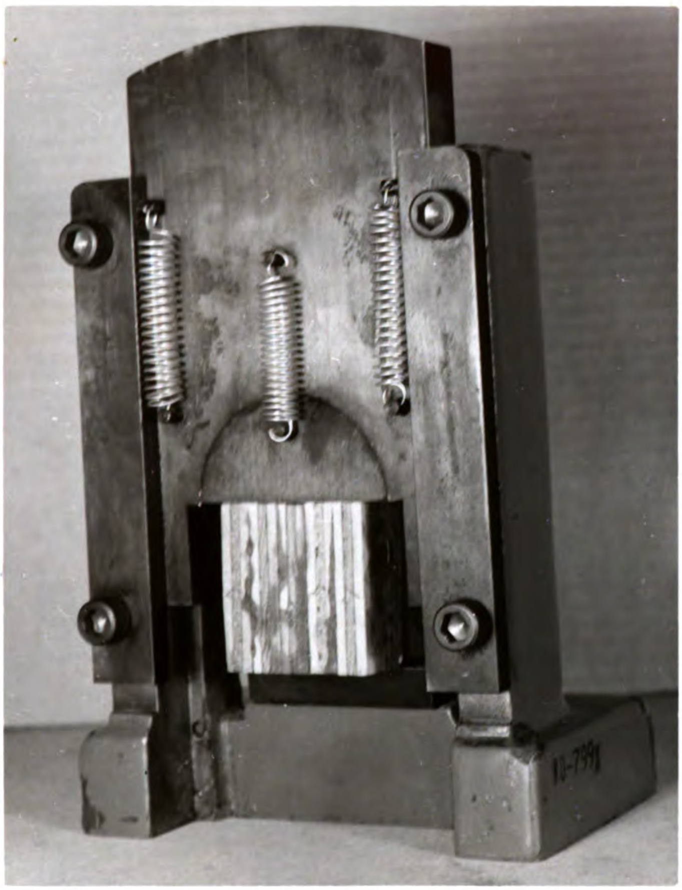
					Average...	1050

TABLE II

NOTCHED SHEAR TESTS 9-29-59

Sample No.	Actual Dimensions, Inches	Shear Area Sq. In.	Plywood Sheet No.	Moisture Content	Lbs. P	P.S.I. $\tau = \frac{P}{A}$
1	1.75 x 2.0	3.50	20	12%	3800	1085
2	1.70 x 1.97	3.35	13	"	2950	880
3	1.72 x 1.99	3.42	15	"	5450	1585
4	1.72 x 1.97	3.38	14	"	4670	1385
5	1.79 x 1.98	3.54	19	"	3400	960
6	1.73 x 2.0	3.46	18	"	3750	1085
7	1.76 x 1.96	3.44	4	"	3500	1020
8	1.76 x 2.0	3.52	17	"	4000	1128
9	1.72 x 1.97	3.38	12	"	3750	1110
10	1.73 x 2.0	3.46	16	"	5250	1518
11	1.80 x 1.95	3.51	8	"	3750	1069
12	1.80 x 1.96	3.52	9	"	3725	1090
13	1.75 x 1.90	3.42	11	"	4600	1345
14	1.90 x 1.96	3.72	1	"	3950	1060
15	1.78 x 1.95	3.47	10	"	3000	910
16	1.70 x 1.95	3.32	3	"	4700	1415
17	1186 x 1.95	3.62	6	"	4450	1230
18	1.89 x 1.96	3.70	7	"	4860	1315
19	1.75 x 1.95	3.41	2	"	4800	1405
20	1.70 x 1.95	3.31	5	"	4750	1435
21	1.90 x 1.96	3.72	1	"	3950	1060
22	1.78 x 1.92	3.42	2	"	3400	995
23	1.70 x 1.92	3.26	3	"	4800	1470
24	1.76 x 1.93	3.40	4	"	2800	825
25	1.70 x 1.92	3.26	5	"	3600	1110
26	1.86 x 1.96	3.64	6	"	3900	1070
27	1.90 x 1.96	3.72	7	"	5000	1345
28	1.82 x 1.98	3.60	8	"	3950	1100
29	1.75 x 1.96	3.43	9	"	3450	1010
30	1.80 x 1.96	3.52	10	"	3850	835
31	1.75 x 1.95	3.41	11	"	5300	1555
32	1.70 x 1.95	3.41	12	"	3600	1088
33	1.72 x 1.95	3.37	13	"	4150	1248
34	1.70 x 2.0	3.40	14	"	4450	1310
35	1.69 x 1.95	3.30	15	"	5000	1515
36	1.72 x 1.98	3.40	16	"	4000	1175
37	1.72 x 2.0	3.44	17	"	3550	1035
38	1.72 x 1.98	3.42	18	"	3750	1095
39	1.76 x 1.98	3.48	19	"	4000	1150
40	1.72 x 1.93	3.32	20	"	4200	1265

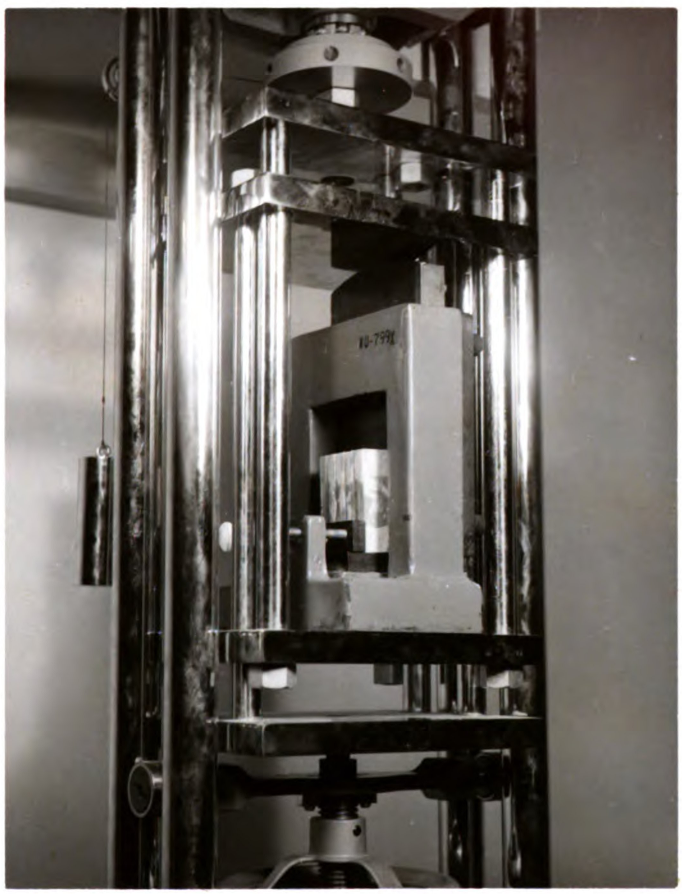
Average 1190



SHEAR BLOCK IN STANDARD

SHEAR TOOL

FIG. 7



SHEAR TOOL POSITIONED IN

DILLON TESTING MACHINE

FIG. 8

TEST RESULTS

The computed experimental stress at failure for the Standard Block Shear and Modified Block-Shear test series are shown in Table 1 and 2 of the Appendix. The experimental stress was computed by means of the shear equation:

1 - P/A, p.s.i.

P - Load at Failure, lbs.

A - Shear area, sq. in.

1 - Shear Value - p.s.i.

The average shear strength for the Standard Block-Shear test was 1010 p.s.i. That of the Modified Block-Shear test was 1190 p.s.i; a difference of 140 p.s.i.

A two-way analysis of variance of the mean was made and results show: 1. the variance between plywood sheets to be insignificant, 2. variance between sheets of plywood and tests insignificant, 3. the variance of the mean between the two tests to be significant to the f-.01 level. (Table 3)

The Panel Shear test gave shear strength results which were extremely close to those of the Standard Block-Shear test. The results are shown in Table IV of the Appendix. The computed stresses from test values were obtained using the shear formula for the Panel Shear

TABLE III

ANALYSIS OF VARIANCE

	d.F.	s.s.	M.S.	f	Tabled f.-03	Tabled f-.01
Total	79	8,731,332	110,523			
Tests	1	1,260,960	1,260,960	7.27	4.00	7.08**
Sheets	19	2,743,030	144,370	.83	1.75	
Tests & Sheets	19	2,006,854	105,624	1.55	1.84	
Within	40	2,720,488	68,012			

NOTCHED BEAM POSITIONED IN

RIEHLE TESTING MACHINE

FIG. 9

test of:

(10)

$$f_s = \frac{.707P}{Ll}, \text{ p.s.i.}$$

P - Load at failure, lbs.

L - Length of Tab, in.

l - Thickness of the Plywood, in.

The average ultimate shear strength for the Panel Shear test was 1010 p.s.i. which was within 3.9% of the average value for the Standard Block-Shear test. This was in close agreement with Norris' findings. (11)

The load at shear failure of the Notched Beams was used in the following formula for horizontal shear in built-up beams with plywood webs:

$$f_s = \frac{V\,Q}{I\,b}, \text{ p.s.i.}$$

V - Vertical Shear, lbs.

Q - Statical Moment about the Neutral Axis, $in.^3$

I - Moment of Inertia, $in.^4$

b - Thickness of the Web, in.

Shear values of 3,740# were obtained for the three beams tested.

Due to the high shear values actually observed, a notched beam specimen was tested with electric resistance strain gages attached to the flanges as shown in Fig. 10. The gages were applied to analyze the stress distribution of the beam while under load. It was found that the top and bottem of each flange were under compression and

STRAIN GAGES ATTACHED TO
FLANGES OF NOTCHED BEAM
WHILE BEAM IS UNDER STRESS

FIG. 10

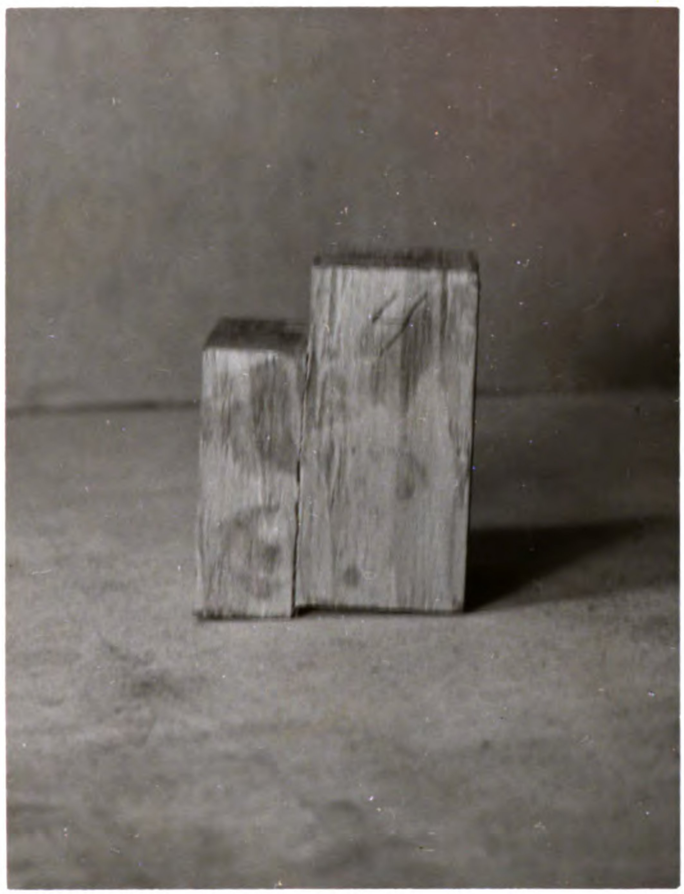
tension respectively, indicating that the notched beam was acting as two separate beams.

DISCUSSION OF RESULTS

It was obvious from the comparison of results of the standard and modified block shear tests that stress concentrations, as well as combined stress conditions, complicate the stress distribution in the standard block shear specimen. As is shown in Fig. 11, shear failure began at the reentrant point and travels at an angle to the shear face. This indicated a tension failure as well as shear failure. If a pure failure had developed, the line of failure would have been parallel with the face of the shear block. Failure in the modified shear block more closely follows the pattern of failure expected. (13)Fig.4 Figure 12 shows that a failure occurred in the plies parallel to the load applied while the core or center ply bends with the stress applied.

In the two-way analysis of variance of the means of the two block shear tests, it was shown that the difference of the means of the two tests was significant at the .01 level, for shear stress applied.

The Panel Shear test has been compared with the Standard Block-Shear test and found to give results with 3.9% difference (Table V.) Since the Standard Block-Shear test was shown to give a statistically significant lesser value than the Modified Block-Shear test it was assumed the Panel Shear test does not produce uniform shear. It is questionable whether the pins apply uniform stress to the shear



TYPICAL FAILURE OF STANDARD

SHEAR BLOCK

FIG. 11

TYPICAL FAILURE OF PLIES
PARALLEL TO APPLIED FORCE

FIG. 12

TABLE IV

PANEL SHEAR TESTS

Sheet No.	Actual Dimensions, Inches	Shear Area Sq. In.	M.C. %	707P	P	$\tau = \frac{.707P}{A(Lt)}$
1	3.70 x 0.36	1.33	11.91	1440	2030	1080
3	3.70 x 0.32	1.18	11.97	1520	2150	1290
7	3.70 x 0.36	1.33	12.02	1480	2090	1110
6	3.70 x 0.36	1.33	12.05	1340	1760	1000
17	3.69 x 0.36	1.32	11.93	1040	1470	790
14	3.68 x 0.33	1.31	11.98	1550	2190	1180
4	3.70 x 0.32	1.18	12.00	1370	1800	1160
19	3.70 x 0.32	1.18	11.93	1340	1900	1120
15	3.70 x 0.33	1.22	12.04	1460	2060	1200
8	3.68 x 0.36	1.32	12.02	1030	1480	780
18	3.66 x 0.33	1.21	11.84	1130	1590	930
13	3.70 x 0.34	1.26	11.91	1070	1510	850
20	3.68 x 0.35	1.29	12.00	1220	1720	950
10	3.63 x 0.35	1.27	11.86	1060	1500	840
11	3.69 x 0.33	1.22	11.74	1250	1770	1020
16	3.68 x 0.36	1.32	11.00	1145	1620	855
12	3.64 x 0.35	1.27	11.56	1440	2040	1130
5	3.65 x 0.32	1.17	12.00	1190	1680	1010
9	3.65 x 0.33	1.20	12.02	920	1290	760
2	3.68 x 0.35	1.29	11.92	1340	1900	1040
					Average . .	1010

TABLE V

COMPARATIVE VALUES OF PANEL SHEAR TEST

AND STANDARD BLOCK SHEAR TEST

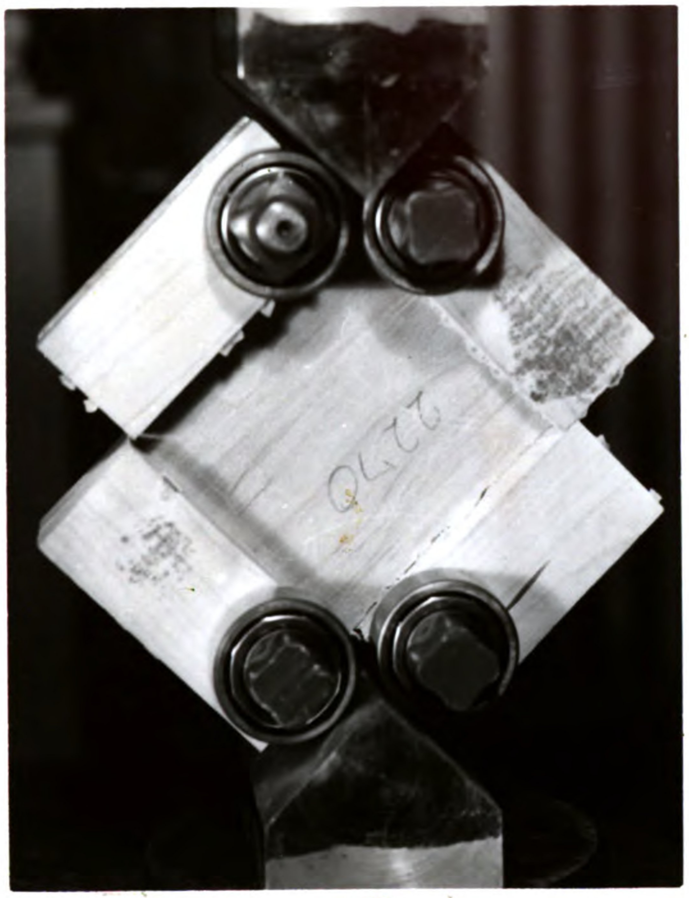
Sheet No.	Standard * Block-Shear	Panel Shear
1	1050	1080
2	1070	1040
3	1260	1290
4	820	1160
5	915	1010
6	1110	1000
7	1130	1110
8	1045	780
9	1040	760
10	1020	840
11	1255	1020
12	1125	1130
13	1060	850
14	1135	1180
15	1180	1200
16	1225	855
17	1025	790
18	925	930
19	980	1120
20	1090	950
	1050 Average	1010 Average
		3.9% difference

*Average of two values for two tests from each sheet.

area since there would be some bending of the pins when the load is applied.

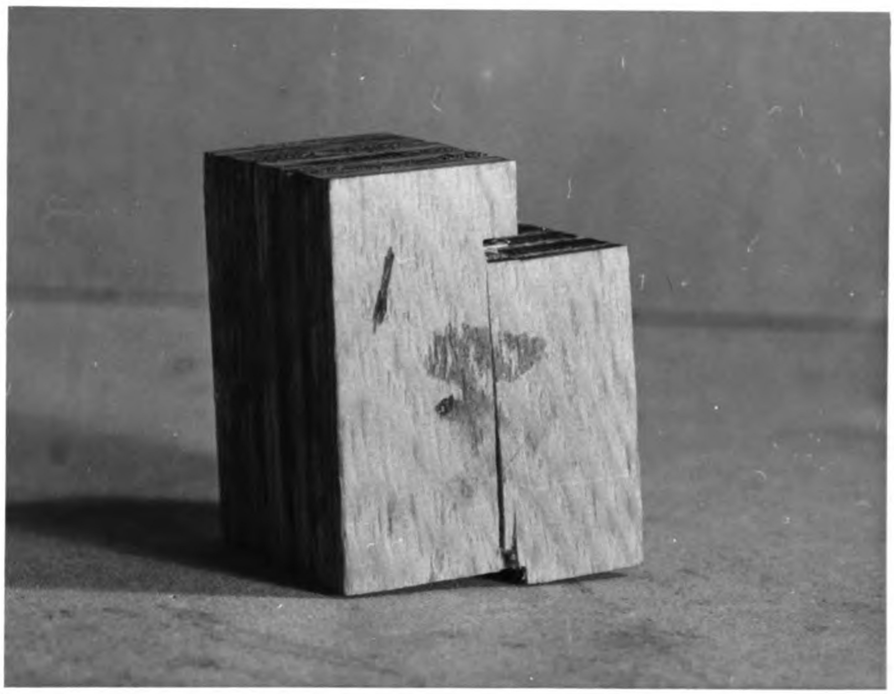
The formula for the shear values in the panel shear test assumes even stress is applied over the shear area. However, it is questionable whether the stress nearest the point of application is equal to that at the most distant part. Failure of the panels occurs at one of the two parallel edges next to the maple blocks. Fig.13 This would indicate a stress concentration, thus suggesting that the test does not produce uniform shear stress distribution.

In selecting the notched beam shear test it had been assumed that a glued-up beam would act as the beam made up from solid wood by Radcliffe and Suddarth. (13) However this design failed to produce horizontal shear failure in the 3/8" plywood web. The reduction of this shear area did accomplish this purpose. The resultant shear values were unrealistic. Fig.6 The analysis of the electric resistance strain gages indicated the beams were not producing pure shear in the web. However, the strain gages were placed on the flanges of the beam and not on the web. Further, visible shear failure of the web did occur at the values indicated. Further study of this test is recommended with the use of electric resistant strain gages, stress coat application, and variation in the geometry of the specimen.



TYPICAL FAILURE OF SHEAR
AREA OF PANEL SHEAR TEST
(FAILURE AT LOWER RIGHT
EDGE OF SHEAR AREA)

FIG. 13



MODIFIED SHEAR BLOCK

(AFTER FAILURE)

FIG. 4

CONCLUSIONS AND RECOMMENDATIONS

1. Average transverse shear stress, as indicated by the results of three methods of tests, was found to be:
   a. 1050 p.s.i. Standard Block Shear Test
   b. 1190 p.s.i. Modified Block Shear Test
   c. 1010 p.s.i. Panel Shear Test
2. A significant statistical difference was found to exist between the results of the Standard Block-Shear test and the Modified Block-Shear test.
3. Close agreement was found between the results of the Panel Shear tests and the Standard Block-Shear test.
4. The notched beam shear test, as modified for use with a plywood web, did not produce pure transverse shear.
5. Further study should be made of the stress distribution within the panel shear area.
6. The modified block-shear test should replace the standard block-shear test.

A P P E N D I X

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