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Light Weight Plywood Pallet Tests

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SUMMARY

This report provides test results of all plywood pallets with unidirectional base. Pallet bending and top (or bottom) deck bending tests per ISO 8611 Pallets for Materials Handling – Part 1: Test Methods were conducted on pallets made of different top deck and bottom strips. Test data were compared with PDS (Pallet Design System) predicted load capacities of the pallet with the same designs using equivalent SPF lumber bottom boards.

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1. INTRODUCTION

Plywood unidirectional base pallets have attracted customers because of smooth solid deck, good strength and durability, easy handling, low cost, and more importantly, their obvious money-saving feature in international shipment due to the extremely light weight. From an international shipping point of view, a lightweight plywood pallet of close to 40-pound tare weight rather than a regular 60-pound (or heavier) lumber pallet will translate into savings based on an airfreight \$1/per pound shipping cost.

It was discovered by APA staff that some limitations of the Pallet Design System (PDS), a computer pallet design software program developed by Virginia Polytechnic Institute and State University (VPI), made PDS (Version 3.0) impossible to analyze some types of all-plywood pallets including unidirectional base plywood pallets. In order to obtain the load capacities of the plywood unidirectional base pallet, it was suggested a test program be carried out. Pallets with top deck and bottom strips made of plywood of different thicknesses and species were tested in pallet bending (racking) and deck bending (stacking). It was also intended to compare the racking and stacking capacities of the test pallets with the PDS predictions on the properties of the equivalent designs.

2. OBJECTIVES

The objectives of this test program were to obtain the load capacities of the pallets through testing and to compare the obtained load capacities with the PDS predicted allowable loads of the equivalent designs.

3. MATERIALS AND METHODS

3.1 Sample Test Pallets

Table 1 lists the information on the test pallets. The plywood was provided by Willamette Industries. Nails used were from different manufacturers. All test pallets were fabricated in the workshop of APA Research Center, Tacoma, Washington, following the same design but use different top deck and bottom materials, as given in Table 1.

Table 1. Pallet material and test schedule

Code ^a	Species	Plywood used				Number of tests			
		Top Deck		Bottom Deck		No. of pallets	Pallet bending	Bottom deck	Top deck
		N. Thick ^b (in.)	No. of Plies	N. Thick (in.)	No. of Plies				
1S	Spruce	1/2	4	3/4	5	6	3	--	3
1H	Hem-Fir	1/2	4	3/4	5	6	3	--	3
2S	Spruce	3/4	5	3/4	5	9	3	3	3
3S	Spruce	5/8	4	5/8	4	6	3	--	3

^a Block assembling nails for 1S and 1H were four (4) 2.5" x 0.120" hardened steel spiral threaded pallet nails, two (2) from each side; for the 2S and 3S, two 3.5" x 0.135" hardened steel spiral threaded pallet nails were nailed from one side only. Nails used for deck to block connections were all 3" x 0.120" hardened steel spiral threaded pallet nails, three (3) nails per connection.

^b N. Thick = Nominal thickness.

3.2 Pallet Configuration

Figure 1 illustrates the configuration of the all-plywood unidirectional base pallet. All sample pallets were of the same configuration except plywood of different thickness and species were used as specified in Table 1.

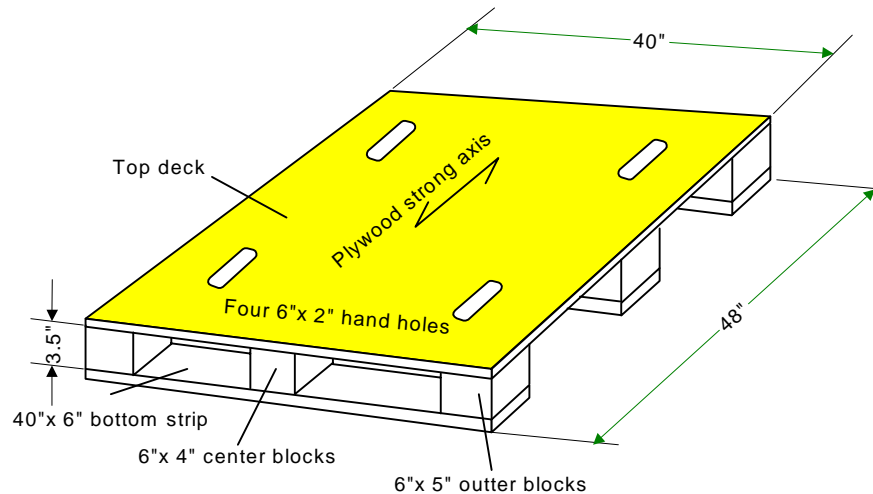


Figure 1. Sample pallet configuration

3.3 Test Methods

3.3.1 Pallet Bending Test

Pallet bending test, also called racking test, followed procedures described in ISO 8611 8.1. Bending test for pallet. Test span was chosen as 36 inches. Two line loads were applied through the two steel load applicators at a speed of 0.15 inch per minute. Deflections at the center of the pallet were measured at both ends using two (2) LPs (linear potentiometer), and the average of the two measurements were used. A data acquisition unit was connected to a computer that controlled the testing. Load and deflection data were collected prior to the ultimate load. Figure 2 shows the bending test setups.

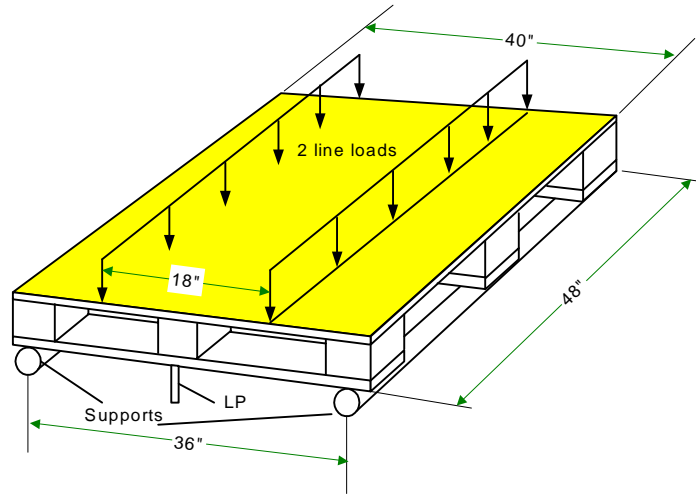


Figure 2. Pallet bending test setup

3.3.2 Deck Bending Test

Deck bending test of the pallet were conducted following procedures described in ISO 8611 8.8. Bottom deck test. For the top deck bending test, test pallets were fully supported on bottom while for the bottom deck bending test, the pallets were fully supported on top deck. The two load applicators were set in the middle distance between the center and the outer blocks. Test speed was 0.15 inch per minute. Two deflection measurements were made under each load applicator through the use of LPs. Load and deflection data were collected through the data acquisition unit prior to failure. Figure 3 shows the top deck bending test setups.

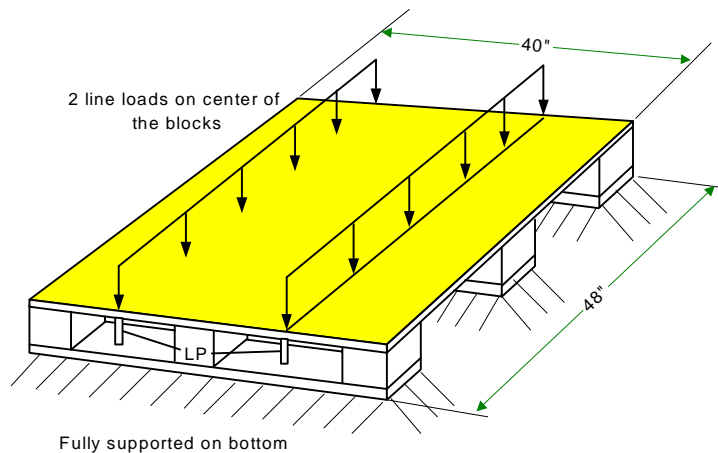


Figure 3. Top deck bending test setup

4. TEST RESULTS AND DISCUSSION

4.1 Test Results

Table 2 gives the average values of ultimate load, deflections at ultimate load and 2,000-lb load, and pallet weights in the pallet bending (racking) tests while Table 3 gives the same test results in the deck bending tests. The average test results are also shown graphically in Figure 4 and Figure 5, for pallet bending and deck bending tests, respectively. Individual pallet test results are given in Appendix Table A1.

Table 2. Average values in the pallet bending (racking) test^a

ID ^b	Ultimate load (lb)	Defl. @ ult. load (in.)	Defl. @ 2,000 lb load	Weight (lb)
1S	2,645 (10.1) ^c	1.052 (28.2)	0.598 (9.0)	38.3 (3.3)
1H	2,998 (11.2)	0.852 (NA)	0.445 (24.7)	39.7 (1.9)
2S	4,122 (7.5)	1.298 (25.6)	0.366 (4.4)	44.0 (2.3)
3S	3,021 (5.9)	1.540 (23.2)	0.620 (1.6)	39.7 (1.5)

^a Results shown are average values of 3 tests.

^b 1S = ½" spruce plywood top deck and ¾" spruce plywood bottom strips
 1H = ½" hem-fir plywood top deck and ¾" hem-fir plywood bottom strips
 2S = ¾" spruce plywood top deck and ¾" spruce plywood bottom strips
 3S = 5/8" spruce plywood top deck and 5/8" spruce plywood bottom strips

^c Values in the parentheses are coefficient of variation (COV, %); NA=not available.

Table 3. Average values in the deck bending test^a

ID ^b	Ultimate load (lb)	Defl. @ ult. load (in.)	Defl. @ 2,000 lb load	Weight (lb)
1S	3,444 (10.9) ^c	0.468 (12.2)	0.276 (2.9)	38.5 (1.3)
1H	4,831 (18.8)	0.687 (14.7)	0.248 (6.6)	39.8 (1.4)
2ST	6,711 (7.9)	0.404 (11.0)	0.135 (13.0)	44.0 (2.3)
2SB	6,667 (3.3)	0.367 (14.1)	0.117 (10.1)	45.0 (3.8)
3S	5,072 (18.0)	0.583 (16.9)	0.191 (15.9)	38.0 (2.6)

^a Results shown are average values of 3 tests.

^b 1S = ½" spruce plywood top deck and ¾" spruce plywood bottom strips
 1H = ½" hem-fir plywood top deck and ¾" hem-fir plywood bottom strips
 2ST = ¾" spruce plywood top deck and ¾" spruce plywood bottom strips, tested on top deck
 2SB = ¾" spruce plywood top deck and ¾" spruce plywood bottom strips, tested on bottom strips
 3S = 5/8" top spruce plywood and 5/8" spruce plywood

^c Values in the parentheses are coefficient of variation (COV, %).

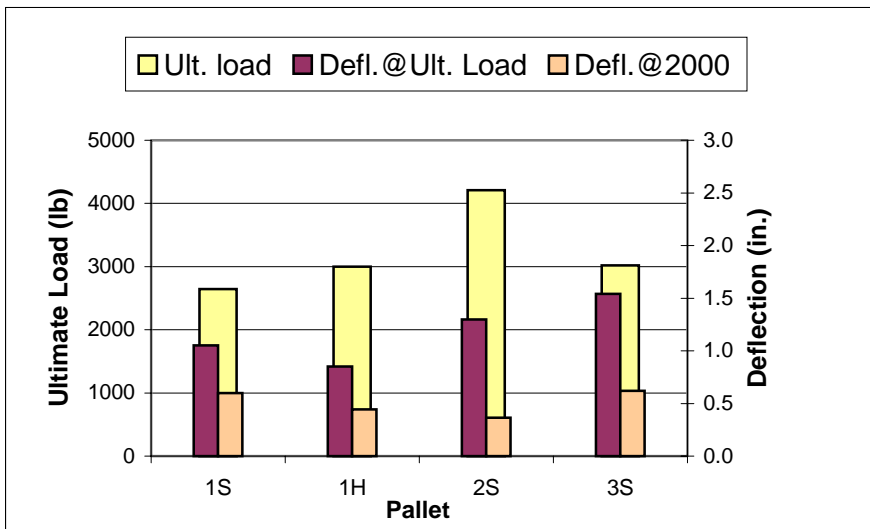


Figure 5. Average values of pallet bending test

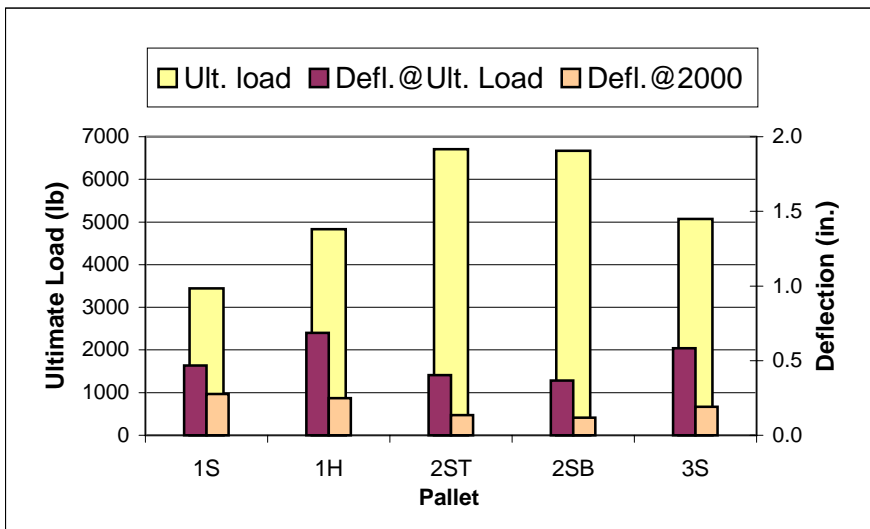


Figure 6. Average values of deck bending test (see Footnote b in Table 3 for 2ST and 2SB)

4.2 Discussion

4.2.1 Failure Mode

It appeared that for the given pallet designs in the testing, pallet racking strength was governed by the top deck. Top deck bending failure was observed. The pallets would have withstood further loads in the tests if the top decks did not fail. Figure 6 shows this typical top deck bending failure. No bottom strip failure was observed in the racking tests. Similar top deck

bending failure mode was also characterized for the top deck bending tests, as shown in Figure 7.

The results of 2ST and 2SB (Table 3) showed that, in the deck bending test, the top deck and the bottom strips had virtually the same bending resistance for the given design (3/4" top deck and bottom strips).



Figure 6. Top deck bending failure in racking test



Figure 7. Top deck bending failure in top deck bending test

4.2.2 Species and Plywood Thickness Effect

Pallets made of Hem-fir plywood had slightly higher ultimate load in racking but significantly higher ultimate load in top deck bending than the pallets made of Spruce plywood, given other variables remained unchanged (Tables 2 and 3). Pallets with 3/4" top deck and bottom strips showed much higher strength in both racking and top deck bending than the other two designs with thinner top or bottom materials. On the other hand, average pallet weight increased from about 40 pounds to 44 pounds due to the use of the 3/4"-thick top deck.

4.2.3 Comparisons Between PDS and Test Results

4.2.3.1 Plywood strips versus SPF lumber board

One interest is to compare the pallet load capacities between pallets with the plywood bottom strips and lumber bottom boards. It is based on the assumption that the allowable bending stress and stiffness of the plywood strips are equivalent to or better than the SPF lumber board. The comparison of the allowable bending stress is given in Table 4.

Table 4. Comparisons between plywood and SPF lumber board

Material	Bending Strength		Bending Stiffness
	F _b ^a (psi)	Size Adjustment ^b	MOE (10 ⁶ psi)
Group 2 plywood	1,200	1,200x 0.50 = 600	1.5
SPF No.3&btr ^c	500	NA	1.2

^a Per Table 3 in APA Plywood Design Specification (PDS)

^b A size factor of 0.50 is used per APA PDS 3.3.3 and APA N375 2.2.5

^c Properties are based on Table 4A of Supplement to NDS 1997 Edition

4.2.3.2 PDS predictions versus test results

PDS predicted load capacities of the equivalent pallet designs with lumber bottom boards were obtained. The PDS follows a "reliability-based" design approach in which resistance (ultimate load to failure) and load (stress), as well as their coefficient of variation are considered to determine the level of safety. In a conventional ASD (allowable stress design) approach, a safety factor is applied to the test data to derive the allowable load. There is no direct equivalency link between the "level of safety" used in PDS and the "safety factor" used in deriving the allowable design load in ASD approach. Therefore, comparisons between the PDS predictions and the derived design load based on an ASD procedure were for checking and referencing purposes.

An updated version of PDS, Version 3.15, was released by VPI in late 2001. The PDS V3.15 is capable of conducting structural analysis for all-plywood unidirectional base pallets and therefore, the updated version was used to predict the design loads of the pallets in this testing program, given the rest of the pallet design remained unchanged. PDS predicted load capacities of the same pallet designs with both plywood bottom strips and lumber bottom boards were obtained. Tables 5a and 5b list the allowable loads derived based on the two different approaches.

Table 5a. PDS predictions and derived allowable loads based on test data (racking)

ID ^a	Based on Test			Based on PDS (V3.15) Predictions			Test ^d /PDS ^e
	Top deck	Bottom	Design Racking Load (lb) ^b	Top deck ^c	Bottom ^c	Design Racking Load (lb)	
1S	½" PW	¾" PW	1,058	15/32" PW	23/32" PW	649	1.63
			--	15/32" PW	¾" LBR	1,319	0.80
1H	½" PW	¾" PW	1,199	15/32" PW	23/32" PW	649	1.85
				15/32" PW	¾" LBR	1,319	0.91
2S	¾" PW	¾" PW	1,649	23/32" PW	23/32" PW	898	1.84
				23/32" PW	¾" LBR	1,712	0.96
3S	5/8" PW	5/8" PW	1,208	19/32" PW	19/32" PW	467	2.58
				19/32" PW	5/8" LBR	1,202	1.00

^a See Table 2 for pallets configuration details.

^b A safety factor of 2.5 was applied to the average to derive the design load. The 2.5 factor was based on VPI's summary on test results and PDS predicted maximum loads.

^c PW = plywood; LBR = SPF lumber, 3& BTR per PDS PEP (Pallet Exchange Program) Study Grades. PDS has only 15/32", 19/32" and 23/32" panel thickness options. For the same span rating, 15/32" and ½", 19/32" and 5/8", and 23/32" and ¾", are equivalent in design capacities, respectively.

^d Design racking load derived based on test data.

^e Design racking load predicted by PDS.

Table 5b. PDS predictions and derived allowable loads based on test data (stacking)

ID ^a	Based on Test			Based on PDS (V3.15) Predictions			Test ^d /PDS ^e
	Top deck	Bottom	Design Stacking Load (lb) ^b	Top deck ^c	Bottom ^c	Design Stacking Load (lb)	
1S	½" PW	¾" PW	1,378	15/32" PW	23/32" PW	3,075	0.45
			--	15/32" PW	¾" LBR		
1H	½" PW	¾" PW	1,932	15/32" PW	23/32" PW	3,075	0.63
				15/32" PW	¾" LBR		
2S	¾" PW	¾" PW	2,684	23/32 PW	23/32 PW	6,300	0.43
				23/32 PW	¾" LBR		
3S	5/8" PW	5/8" PW	2,029	19/32" PW	19/32" PW	4,742	0.43
				19/32" PW	5/8" LBR		

^a See Table 2 for pallets configuration details.

^b A safety factor of 2.5 was applied to the average to derive the design load. The 2.5 factor was based on VPI's summary on test results and PDS predicted maximum loads.

^c PW = plywood; LBR = SPF lumber, 3& BTR per PDS PEP (Pallet Exchange Program) Study Grades.

^d Design stacking load derived based on test data.

^e Design stacking load predicted by PDS.

Table 6 summarizes the design racking strength comparison ratios. It was noticed that the design racking loads based on test data were comparable to PDS predicted design loads of an equivalent design using SPF lumber bottom boards of the same dimensions as the plywood strips. This indicated that the PDS predicted values for the pallets with lumber bottom boards are fairly close to the load capacity based on the actual test data of the given design with plywood bottom strips. The comparisons between the two PDS predictions, however, showed that the design racking strength of the pallet with plywood bottom strips was about 50% percent of the pallet with lumber bottom boards. It appears that the PDS predicted racking strength for an all-plywood pallet with plywood strip unidirectional base is too conservative. This is likely to be caused by the use of a 0.50 size factor on the bottom plywood strips. It seems reasonable and necessary that the plywood size factor be removed from PDS in order to better reflect the actual racking strength of all-plywood pallets with plywood bottom strips.

Table 6. Racking strength comparison ratios

ID	Tests	PDS w/plywood bottom strips
	PDS w/lumber bottom	PDS w/lumber bottom
1S	0.80	0.49
1H	0.91	0.49
2S	0.96	0.52
3S	1.00	0.39

Stacking capacity (deck bending) derived based on the test data, on the other hand, was approximately less than half of what was predicted by PDS, except for the 1H pallets that had a stacking load of 63% of the PDS predicted value.

5. CONCLUDING REMARKS

Based on the test data and findings of this test program, the following remarks can be made.

1. Hem-fir plywood pallet had higher racking and stacking strength than the spruce plywood pallet of the same design.
2. Pallets made of $\frac{3}{4}$ " spruce plywood top deck and unidirectional base strips had the highest racking and stacking strength and the lowest deflection at the 2000-lb load among other pallets using different top and bottom plywood panels. Its weight increased by 4 pounds, compared to the lightest pallet in the test program.
3. Both racking and stacking capacities were controlled by the top deck strength for the given designs.
4. The derived racking strength based on the test data is close to the PDS (current Version 3.15) predictions of the equivalent pallets using SPF lumber bottom boards. However, the stacking capacity derived based on the test data is below half of what is predicted by PDS (Version 3.15).

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7. APPENDIX

Table A1. Individual pallet test results

Pallet Bending (racking) Test (per ISO 8611 8.1, span =36 inches)

Specimen	Ultimate load (pound)	Deflection ^a (in.)	Deflection at 2000-lb load ^a	Weight of Pallet (pound)
1SB-1	2,373	0.899	0.601	37.0
1SB-2	2,909	1.393	0.650	39.5
1SB-3	2,654	0.864	0.542	38.5
Mean	2,645	1.052	0.598	38.3
COV (%)	10.1	28.2	9.0	3.3
1HB-1	3,219	NA	0.318	39.0
1HB-2	3,161	NA	0.513	40.5
1HB-3	2,613	0.852	0.504	39.5
Mean	2,998		0.445	39.7
COV (%)	11.2		24.7	1.9
2SB-1	4,253	1.628	0.385	43.0
2SB-2	4,345	1.302	0.356	44.0
2SB-3	3,767	0.963	0.358	45.0
Mean	4,122	1.298	0.366	44.0
COV (%)	7.5	25.6	4.4	2.3
3SB-1	2,957	1.468	0.616	40.0
3SB-2	3,223	1.927	0.631	40.0
3SB-3	2,883	1.224	0.612	39.0
Mean	3,021	1.540	0.620	39.7
COV (%)	5.9	23.2	1.6	1.5

Deck Bending Test (per ISO 8611 8.8)

Specimen	Ultimate load (pound)	Average Deflection ^b (in.)	Deflection at 2000-lb load ^b	Weight of Pallet (pound)
1ST-1	3,349	0.451	0.272	38.5
1ST-2	3,860	0.532	0.286	39.0
1ST-3	3,124	0.421	0.271	38.0
Mean	3,444	0.468	0.276	38.5
COV (%)	10.9	12.2	2.9	1.3
1HT-1	4,023	0.578	0.257	40.5
1HT-2	5,810	0.779	0.229	39.5
1HT-3	4,659	0.704	0.258	39.5
Mean	4,831	0.687	0.248	39.8
COV (%)	18.8	14.7	6.6	1.4
2ST-1	6,099	0.361	0.136	44.0
2ST-2	6,972	0.402	0.117	45.0
2ST-3	7,061	0.449	0.152	43.0
Mean	6,711	0.404	0.135	44.0
COV (%)	7.9	11.0	13.0	2.3
2SB-1	6,510	0.350	0.131	46.0
2SB-2	6,569	0.326	0.110	43.0
2SB-3	6,921	0.425	0.111	46.0
Mean	6,667	0.367	0.117	45.0
COV (%)	3.3	14.1	10.1	3.8
3ST-1	4,152	0.489	0.211	38.0
3ST-2	5,973	0.685	0.156	37.0
3ST-3	5,092	0.577	0.207	39.0
Mean	5,072	0.583	0.191	38.0
COV (%)	18.0	16.9	15.9	2.6

^a Average of two (2) measurements. ^b Average of four (4) measurements.

Table A2. Moisture and specific gravity data

1/2" spruce and hem-fir

Specimen	As-received					OD weight (gram)	SG	MC (%)
	Thick1 (in.)	Thick2 (in.)	Length (in.)	Width (in.)	Weight (gram)			
1	0.477	0.479	6.016	4.031	85.2	81.7	0.43	4.3
2	0.470	0.466	6.012	4.020	82.4	79.3	0.43	3.9
3	0.475	0.474	6.005	4.025	77.9	73.9	0.39	5.4
4	0.476	0.478	6.019	4.017	79.1	74.6	0.39	6.0
5	0.477	0.473	6.012	4.021	75.5	72.2	0.38	4.6
6	0.481	0.485	6.010	4.020	83.7	80.0	0.42	4.6
7	0.479	0.478	6.012	4.031	83.5	80.2	0.42	4.1
8	0.469	0.466	5.998	4.024	76.9	73.7	0.40	4.3
9	0.483	0.484	6.018	4.024	78.5	75.4	0.39	4.1
10	0.479	0.478	6.002	4.025	79.1	75.7	0.40	4.5
						Mean	0.41	4.6
						Std	0.02	0.65
						COV (%)	4.1	14.2

5/8" spruce and hem-fir

1	0.608	0.605	6.021	3.996	97.0	91.4	0.38	6.1
2	0.646	0.652	6.013	4.004	117.2	110.1	0.43	6.4
3	0.616	0.605	6.024	4.013	91.8	85.9	0.36	6.9
4	0.605	0.602	6.022	4.023	93.9	87.8	0.37	6.9
5	0.605	0.608	6.023	4.012	92.0	86.3	0.36	6.6
6	0.605	0.605	6.022	4.010	94.3	88.5	0.37	6.6
7	0.607	0.615	6.028	4.006	89.8	83.6	0.35	7.4
8	0.609	0.609	6.026	4.023	93.8	87.2	0.36	7.6
9	0.647	0.643	6.011	4.040	106.9	99.3	0.39	7.7
10	0.612	0.613	6.026	4.011	107.3	100.5	0.41	6.8
						Mean	0.38	6.9
						Std	0.03	0.51
						COV (%)	7.1	7.3

3/4" spruce and hem-fir

1	0.708	0.714	6.027	4.986	152.2	143.2	0.41	6.3
2	0.729	0.725	5.999	5.014	149.7	141.0	0.39	6.2
3	0.719	0.719	6.016	4.998	157.0	148.4	0.42	5.8
4	0.715	0.709	6.006	5.007	145.3	138.9	0.40	4.6
5	0.724	0.725	6.004	5.009	141.1	135.4	0.38	4.2
6	0.715	0.720	6.020	4.991	163.1	156.7	0.44	4.1
7	0.716	0.717	6.008	5.005	155.7	148.0	0.42	5.2
8	0.734	0.731	5.985	5.016	165.5	156.5	0.43	5.8
9	0.720	0.718	6.003	5.013	143.7	137.4	0.39	4.6
10	0.719	0.724	6.004	5.007	149.8	142.7	0.40	5.0
						Mean	0.41	5.2
						Std	0.02	0.80
						COV (%)	5.1	15.5