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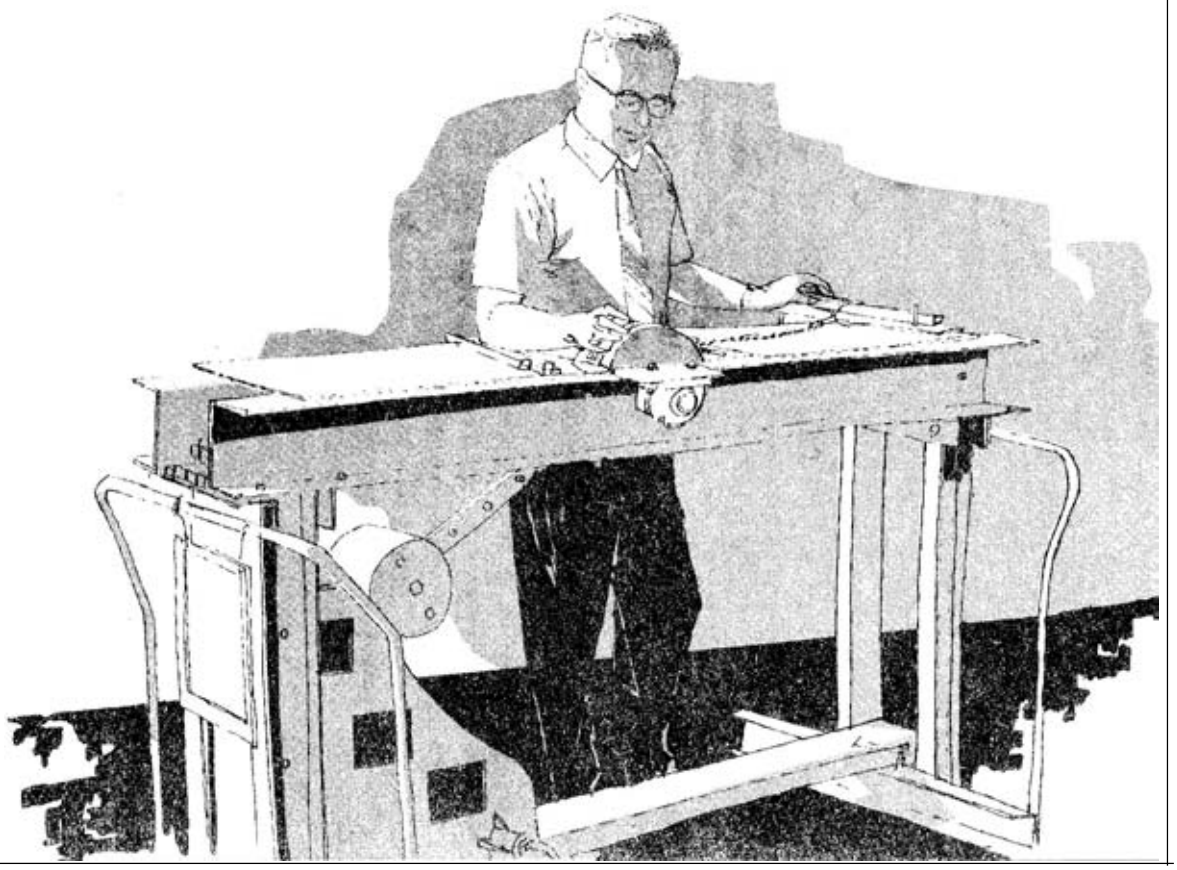
EFFECTS OF TYPE OF TESTING EQUIPMENT AND SPECIMEN SIZE ON TOUGHNESS OF WOOD



SUMMARY

Experimental results from four studies that dealt with effects of type of testing equipment or specimen size on toughness of a number of species of wood in green or air-dried conditions are summarized. The Forest Products Laboratory toughness testing machine (FPL machine) always indicated higher toughness than the Amsler Universal wood testing machine. Machine relationships differed somewhat according to moisture condition, type of test, and species. As a general approximation however, the FPL machine can be expected to yield toughness values about 16 percent higher than the Amsler machine.

Comparative tests of specimens with 5/8-inch and 2-centimeter (0.79 inch) cross sections were made only on the FPL machine. In general, unit toughness (toughness per unit volume between supports) tended to be slightly higher for the smaller size. Test results indicate some minor differences that depend upon species, moisture condition, and type of test. However, for all practical purposes, the two sizes have about the same unit toughness. On a per specimen basis, toughness of the larger specimen may be estimated as 89 percent higher than toughness of the smaller specimen.

EFFECTS OF TYPE OF TESTING EQUIPMENT AND SPECIMEN SIZE ON TOUGHNESS OF WOOD

By C.C. GERHARDS, Engineer

Forest Products Laboratory [1]
Forest Service
U.S. Department of Agriculture

INTRODUCTION

A single-blow impact test known as the toughness test has been used to evaluate shock resistance of wood since about 1920. Among the many different strength properties of wood, shock resistance has been found to be the most sensitive to deteriorating effects such as those from fungal or chemical attack, or from prolonged exposure to elevated temperature (8).[2] Because of this sensitivity, the toughness test has served as a rapid and inexpensive means of judging effects of decay, chemicals, and heat on strength of wood. It has also served as the basis for selecting wood requiring assured high shock resistance.

The Forest Products Laboratory developed a toughness testing machine (FPL machine) about 1920 (7). It is shown in figure 1. This machine has been widely used in the United States and other English-speaking countries. A testing machine developed in Europe, the Amsler Universal wood testing machine (fig, 2), includes apparatus for toughness testing. Both machines employ the energy of a falling pendulum. Toughness is measured by the reduction in free-fall energy of the pendulum resulting from the fracture of a small specimen of wood in bending.

Although employing the same principle, the machines differ. The Amsler machine is designed so that the specimen is struck by the falling pendulum. Initial potential energy of the pendulum in the Amsler machine is fixed. In contrast, the FPL machine is designed so that the impact bending load is applied to the specimen through a chain attached to a drum that rotates with the pendulum. The position of the weight on the pendulum arm and the initial angle of the arm in the FPL machine are adjustable, making available 15 different initial potential energies. When required, larger potential energies are obtained by adding weight to the pendulum

Standard toughness specimen size has changed through the years in the United States. Originally, a 3/4-inch cross section was used. Later, a 5/8-inch-square, 10-inch-long specimen was adopted (1). The Forest Products Laboratory used the latter size to evaluate toughness of a number of species (8). Concurrently a 2-centimeter-square (0.79 inch), 28-centimeter-long (11 inch) specimen was widely used with the Amsler machine in Europe and elsewhere. In the interest of permitting direct comparison of international data obtained with the Amsler and FPL machines, the American Society for Testing and Materials (ASTM) (2) adopted the

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Underlined numbers In parentheses refer to Literature Cited at the end of this report.

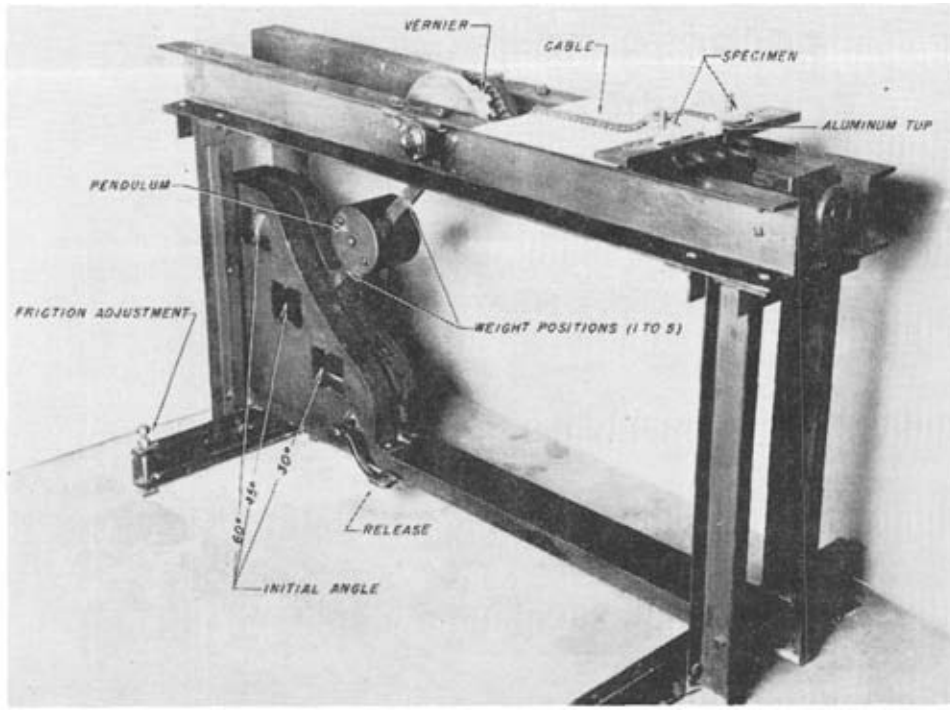


Figure 1.--Forest Products Laboratory toughness testing machine. M 721 45 F

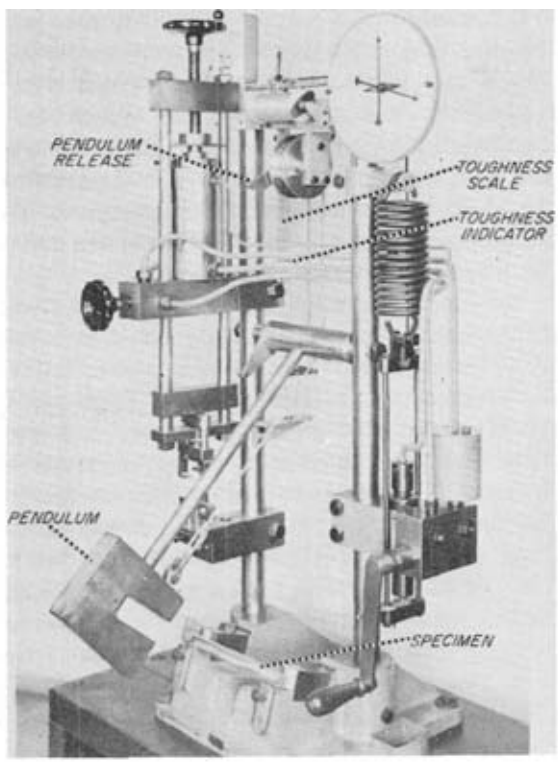


Figure 2.--Amsler Universal wood testing machine. M 107 141

2-centimeter specimen as standard following a recommendation made in 1949 by the Committee on Mechanical Wood Technology of the Food and Agriculture Organization of the United Nations.

At the time, it was recognized that differences in characteristics of the machines might have an effect on measured toughness values of specimens even though a single standard specimen size was used. Some differences in measured toughness values were expected because of probable different energy absorption characteristics of the supports, and because of vibration and tossing the failed specimens from machines. Additionally, it was recognized that some energy is absorbed by the chain of the FPL machine. There is no comparable energy loss in the Amsler machine, These energy losses are, in effect included in the measured toughness and can only be evaluated empirically.

No fully satisfactory method was developed for converting toughness data from one specimen size to another, even when data were obtained on the same machine. Theoretically, unit toughness (toughness per unit volume between supports) should be independent of specimen size. In practice, however, the amount that a specimen overhangs the supports must have some effect

on measured toughness, since the specimen must be drawn completely through the supports in the test. The 5/8-inch-square ASTM size (10-inch long, 8-inch span) had a relatively larger support overhang than the size presently used (2-centimeter-square, 28-centimeter-long, 24-centimeter span); therefore, unit toughness ought to be variously higher for the 5/8-inch size, depending on moisture content and species characteristics. For example, brittle material should not be affected by the relative amount of overhang as much as fibrous material. Brittle specimens are generally broken into two pieces or axe held together by only a few fibers; but, fibrous specimens remain intact and may have substantial strength remaining after test.

Several studies have been conducted at the Forest Products Laboratory to evaluate the toughness machines and the effect of specimen size on toughness, The purpose of this paper is to combine and discuss the results of these studies.

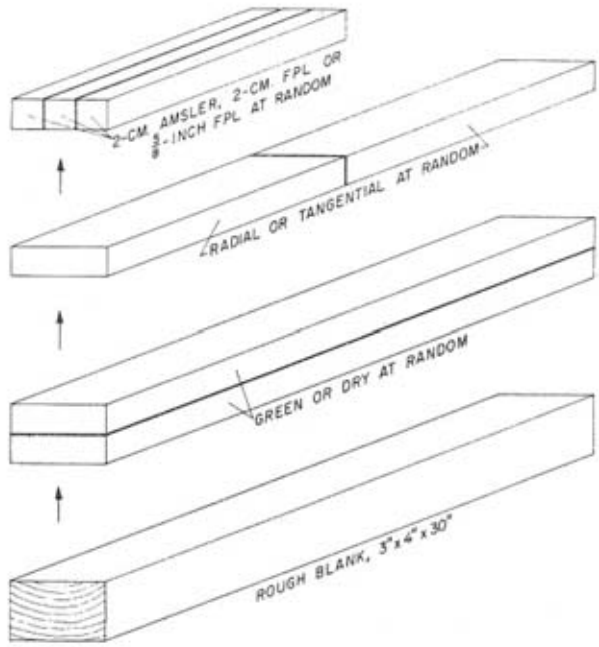


Figure 3.--Cutting diagram and method of selecting specimens used in Study I (5). ZM 134 927

SCOPE OF RESEARCH

This report: presents research data obtained from four separate studies that involved:

1. Effects of testing machine and specimen size on toughness of green and air-dried Douglas-fir, red oak, and yellow birch (5).
2. Effects of testing machine and specimen size on toughness of green and air-dried loblolly pine (4).
3. Effect of specimen size on toughness of green and air-dried hickory.
4. Effect of specimen size on toughness of air-dried Douglas-fir and Pacific silver fir.

EXPERIMENTAL PROCEDURES

Experimental procedures used in the four studies are discussed in the sequence given above.

Study 1.--Bolts were obtained from 70 Douglas-fir, 4 red oak, and 3 yellow birch trees. Sample Douglas-fir trees grew in seven widely separated locations in the Rocky Mountain region. Bolts of the other two species were obtained from Laboratory stock. A single blank measuring 3 inches radially, 4 inches tangentially, and 30 inches in length was cut from an outer portion of each Douglas-fir bolt. Blanks of the same size were cut from red oak and yellow birch bolts, but in contrast to Douglas-fir procedure, as many blanks as possible were cut from each bolt. A total of 70 Douglas-fir, 39 red oak, and 49 yellow birch blanks were obtained.

The blanks were cut according to the random sequence shown in figure 3 to provide green and dried specimens of 2-centimeter size for testing with Amsler and FPL machines and of 5/8-inch size for testing with the FPL machine only. For tests of material in the dried condition, Douglas-fir was air seasoned and red oak and yellow birch were kiln dried. These specimens received final conditioning at 75° F. and 64 percent relative humidity before testing.

Study 2.--Three-foot bolts were cut at 11- to 14-foot heights from 10 loblolly pine grees grown in the Crossett Experimental Forest near Crossett, Ark. A 2-1/2-inch-thick bark-to-bark flitch containing the pith was cut from each bolt.

The flitches were cut according to the plan shown in figure 4. They provided specimens €or the same test conditions given for Study 1. Blanks for testing in the dry condition were air seasoned and given final conditioning at 75° F. and 64 percent relative humidity.

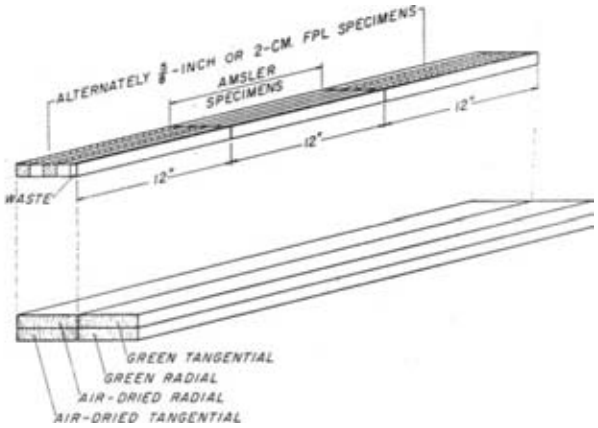


Figure 4.--Cutting diagram for 2-1/2-inch by 36-inch bark-to-bark flitches and specimen locations for loblolly pine used in Study 2. ZM 134 925

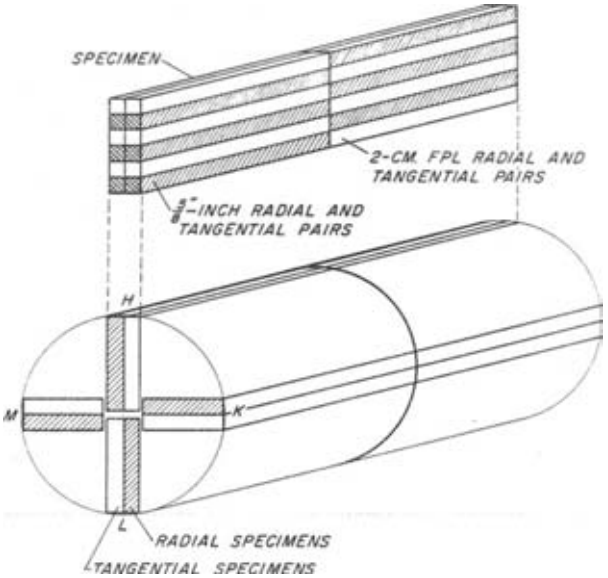


Figure 5.--Cutting diagram and specimen locations of hickory species used in Study 3. Flitches are 2-1/2-inches thick and 24-inches long. H and K portions used for tests in the green condition, L and M portions used for tests of air-dried wood. ZM 134 926

Study 3.--Three species of hickory, mockernut, pignut, and sand were used. Bolts 2-1/2-feet long were cut from six mockernut, six pignut, and four sand hickory trees from a virgin stand in Pickens County, S.C. Bolts came from heights ranging from 3 to 30 feet above the stump, and the trees ranged from 12 to 17 inches in diameter at breast height.

The bolts were cut according to the plan shown in figure 5. Both 5/8-inch and 2-centimeter specimens were obtained for testing in green and dry conditions with the FPL machine. Specimens for tests in the dry condition were seasoned and received final conditioning at 75° F. and 64 percent humidity before testing.

Study 4.--Fifteen Pacific silver fir trees and 77 Douglas-fir trees were sampled. The Pacific silver fir trees grew in Gifford Pinchot and Olympic National Forests in Washington. The Douglas-fir trees grew in the Wenatchee National Forest, Wash., Umatilla National Forest, Oreg., Trinity National Forest, Calif., and Shasta County, Calif. A 12-inch-long bolt was cut from each sample tree about 16 feet above the stump.

The bolts were cut according to the plan shown in figure 6. Specimens were air dried and tested after final conditioning at 75° F. and 64 percent relative humidity. This study was concerned only with the effect of specimen size in testing air-dried materials with the FPL machine.

In all four studies, moisture content, specific gravity (ovendry weight-test volume basis), and dimensions were recorded far each specimen, in addition to toughness.

After test, all specimens were examined. Those containing defects that appeared to affect test results were culled. In Study 1, all specimens from a given blank were culled if one of them was a cull, except for yellow birch. For that species only the green or air-dried specimens from a blank were culled if one was a cull; otherwise, there would have been few acceptable specimens of yellow-birch, Study 2 culling followed the general scheme used in Study 1.[3] Rather than blanks, however, all specimens equidistant from the exterior of the flitch were culled if one was a cull, because of the systematic sampling plan used. In Study 3, all specimens of the same type (green or dried and radial or tangential), but of

[3]The original report did not include the specimen size effects (4). Reported results excluded data for green or dried specimens pair-matched to a cull.

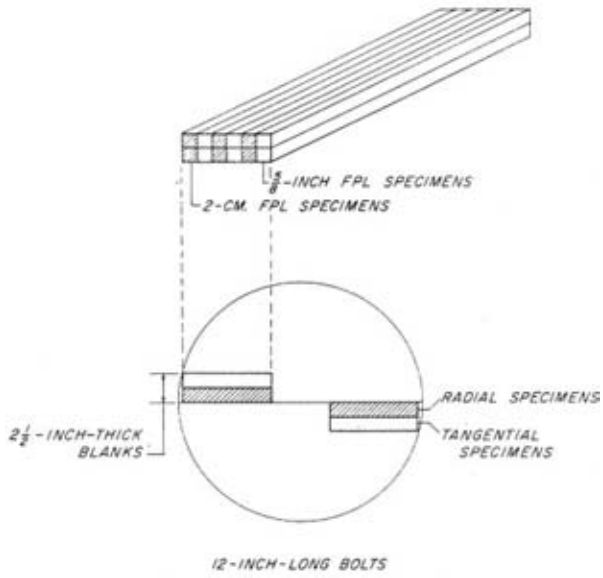


Figure 6.--Cutting diagram and specimen locations for Pacific silver fir and Douglas-fir used in Study 4. M 134 924

different size, that were equidistant from the exterior of the bolt were culled if one was a cull. However, results for defect-free specimens matched to culls were used in regressions of toughness on specific gravity. In Study 4 culling was limited to radially matched specimens of like type (radial or tangential). but different size.

ANALYSIS AND PRESENTATION OF DATA

Average values of specific gravity and toughness and associated coefficients of variation were computed for each type of test (radial or tangential), moisture condition (green or air-dried) , and species variable in Studies 1 and 2. Comparative data obtained from Amsler and FPL machines for the 2-centimeter specimens are presented in table 1. Analyses of variance were computed on toughness data used in deriving those average toughness values. Data for green and air-dried yellow birch were treated in separate analyses of variance because data for those two conditions were not matched after rejection of culls. Results of analyses of variance are presented in table 2.

Some of the data used for comparing size effect was adjusted to remove dimensional differences between specimens of the same nominal size and to remove differences in specific gravity. This was done in Study 3 (hickory) by first converting all toughness data for defect-free samples to unit toughness, where unit toughness equals the actual toughness divided by the volume between supports. Unit toughness values for each moisture condition-type of test variable were then regressed on specific gravity using a simple linear regression ($Y = A + BX$, where Y = unit toughness, X = specific gravity, and A and B axe constants). Similar analyses were conducted on the data for Douglas-fir and Pacific silver fir collected in Study 4, except silver fir data were not computed on a unit toughness basis. Data for the unit toughness-specific, gravity regressions, reconverted for hickory and Douglas-fir to toughness of nominal sized specimens, are presented in table 3.

Average toughness data for all 5/8-inch and 2-centimeter matched specimens tested on the FPL machine axe summarized in table 4. The averages for hickory are based on the data for matched defect-free samples adjusted to the average specific gravity of 0.635 for green wood and 0.709 for dried wood. Similarly, the averages for the Douglas-fir and Pacific silver fir from Study 4 are based on adjustments to the average specific gravities of 0.460 and 0.407, respectively.

DISCUSSION

Effects of Type of Machine

Results of Studies 1 and 2 indicate that average toughness is always higher when determined with the FPL machine even though specimen size and span are the same. This may be seen in the ratios of toughness obtained from the FPL machine and the Amsler machine given in the last column of table 1. Except for air-dried yellow birch, differences in toughness determined by the two machines are highly significant, as shown in table 2.

Results also demonstrate that species, moisture condition (green or air-dried), and type of teat (radial or tangential) affect relative differences obtained by the two machines. This is again shown by the ratios in table 1. However, in only two cases did the effect of higher moisture condition or type of test interact significantly with the effect of type of machine on toughness.

Table 1.--Results of toughness tests to compare FPL and Amsler toughness testing machines

Type of test[1]	Number of matched pairs	Moisture content	Forest Products Laboratory toughness machine: Specific gravity: Mean[2]	Forest Products Laboratory toughness machine: Specific gravity: Coefficient of variation	Forest Products Laboratory toughness machine: Toughness: Mean	Forest Products Laboratory toughness machine: Toughness: Coefficient of variation	Amsler toughness machine: Specific gravity: Mean[2]	Amsler toughness machine: Specific gravity: Coefficient of variation	Amsler toughness machine: Toughness: Mean	Amsler toughness machine: Toughness: Coefficient of variation	Ratio FPL toughness divided by Amsler toughness
		Pct.		Pct.	In.-lb.	Pct.		Pct.	In.-lb.	Pct.	
DOUGLAS-FIR[3]											
Radial	49	49	0.40	12	149	28	0.40	12	134	30	1.11
Tangential	49	50	.40	11	205	33	.40	12	197	42	1.04
Radial	49	14	.43	12	139	22	.43	12	104	30	1.33
Tangential	49	14	.42	13	200	38	.42	12	171	35	1.16
LOBLOLLY PINE[4]											
Radial	28	113	.47	10	293	32	.47	11	260	27	1.13
Tangential	28	111	.47	7	412	27	.47	10	320	33	1.29
Radial	28	13	.51	9	180	24	.50	9	138	20	1.30
Tangential	28	13	.51	9	309	28	.51	9	250	37	1.24
RED OAK[3]											
Radial	22	78	.53	6	281	30	.53	5	256	27	1.10
Tangential	22	78	.53	6	307	33	.53	7	272	26	1.13
Radial	22	12	.58	6	277	26	.59	5	234	30	1.19
Tangential	22	12	.58	5	284	20	.58	6	247	26	1.15
YELLOW BIRCH[3]											
Radial	17	76	.55	6	422	33	.55	5	353	40	1.20
Tangential	17	77	.55	6	411	26	.55	6	382	31	1.08
Radial	13	10	.64	8	375	24	.64	8	348	29	1.08
Tangential	13	10	.63	9	372	18	.63	8	349	19	1.07

[1]Radial, load applied to radial face; tangential, load applied to tangential face.
[2]Based on ovendry weight and volume at indicated moisture content.
[3]Data from Goodman (5).
[4]Based on data used In Forest Products Laboratory Report 2109 (4), except only matched pairs were used.

Significant interactions indicated in table 2 were between type of testing machine and moisture condition for Douglas-fir and between type of testing machine and type of test for loblolly pine. However. those interactions are not as significant as the main effects due to machine differences. Although it was not possible to test for significance, an interaction between type of testing machine and moisture condition is also suggested by the data on yellow birch. There was a larger relative difference in toughness obtained on the two machines fox green birch than for dried birch and only the difference in toughness of green wood was significant.

Lower toughness values obtained with the Amsler machine may be due to smaller energy losses. The chain of the FPL machine is known to absorb substantial energy either as strain or vibration (3), but it is not known how much of that energy is used in breaking the specimen. Toughness values measured by the FPL machine and total work values obtained from electronically traced load-deflection diagrams (fig. 7) on the same specimen showed that, on the average, toughness was about 40 percent higher for green wood and about 20 percent higher for air-dried wood than total work values (6). This gives an indication of the energy absorbed by the machine, part of which would be absorbed by the chain Similarly, by combining data in table 1, toughness determined with the FPL machine averages about 12 percent higher for green softwoods or hardwoods, about 25 percent higher for air-dried softwoods, and about 13 percent higher for air-dried hardwoods than toughness determined with the Amsler machine. These two similar results indicate that toughness determined by the Amsler machine more nearly agrees with total work determined electronically,

Conflicting results between machines, species.

Table 2.--Results of analyses of variance on Amsler and Forest Products Laboratory toughness data[1]

Species	Source of variation[2]	Degrees of freedom	Variance ratio	Significance[3]
Douglas-fir	T	1	29.9	***
	M	1	20.5	***
	G	1	245.8	***
	T x M	1	6.3	*
	T x G	1	.6	
	M x G	1	.4	
	T x M x G	1	.0	
	Error	336		
Loblolly pine	T	1	41.6	***
	M	1	136.9	***
	G	1	143.8	***
	T x M	1	.5	
	T x G	1	4.9	*
	M x G	1	3.2	
	T x M x G	1	1.3	
	Error	189		
Red oak	T	1	8.6	**
	M	1	2.3	
	G	1	1.7	
	T x M	1	.2	
	T x G	1	.0	
	M x G	1	.2	
	T x M x G	1	.1	
	Error	147		
Yellow birch[4]				
Green	T	1	15.2	**
	G	1	.5	
	T x G	1	2.6	
	Error	48		
Air-dry	T	1	2.7	
	G	1	.0	
	T x G	1	.0	
	Error	36		

[1]Except for loblolly pine, data taken from Goodman (5).
[2]T--between Amsler and FPL tests.
M--between green and air-dry tests.
G-between radial and tangential tests.
[3]*--significant at 5 percent level.
**--significant at 1 percent level.
***--significant at 0.1 percent level.
[4]Green and air-dry tests not matched.

moisture conditions, and type of test may be partly due to methods of using the FPL machine. Recommendations state that the difference between initial and final angles of the pendulum should be at least 10° on the average (7). To satisfy this recommendation would require prior knowledge of the average toughness of specimens to be tested. It has been the practice to select the best of the 15 pendulum settings on the basis of a few sample tests. Because toughness within a species varies greatly, some specimens may be fractured but incompletely ruptured with the chosen setting, resulting in a value below their true toughness. In other words, toughness can be biased by the setting of the pendulum

Figure 7 may be used to illustrate the effect of incomplete rupture on toughness. Three essentially complete load-deflection diagrams obtained electronically (6) from teats with the FPL toughness machine are shown. The highest point on any of the three curves represents the maximum load supported by a specimen before it fractures. and the area under the curve to that load represents the energy required just to cause fracture. However, total toughness is represented by the area under the complete load-deflection curve (from zero load-zero deflection to essentially zero load-maximum deflection) . If energy supplied

Table 3.--Regressions of toughness on specific gravity for hickory species, Douglas-fir, and Pacific silver fir

Type of test	Specimen size		Number of specimens	A[1]	B[1]	Coefficient of correlation	Standard error of estimate of Y	Average specific gravity[2]
	Cm.	In.		In.-lb.	In.-lb.		In.-lb.	
HICKORY SPECIES (GREEN)								
Radial	2		99	445	416	0.18	138	0.638
Tangential	2		106	355	579	.26	136	.637
Radial		5/8	104	75	552	.30	100	.636
Tangential		5/8	110	139	457	.29	97	.630
HICKORY SPECIES (AIR-DRIED)								
Radial	2		100	-309	1,322	.58	138	.707
Tangential	2		103	-264	1,302	.55	135	.712
Radial		5/8	118	-182	779	.53	88	.706
Tangential		5/8	118	- 93	691	.48	88	.711
DOUGLAS-FIR (AIR-DRIED)								
Radial	2		392	- 35	466	.54	42	.458
Tangential	2		379	-109	803	.49	84	.459
Radial		5/8	362	- 38	279	.65	19	.461
Tangential		5/8	364	- 73	465	.49	47	.460
PACIFIC SILVER FIR (AIR-DRIED)								
Radial	2		103	- 94	636	.72	29.6	.406
Tangential	2		98	- 11	635	.50	56.8	.406
Radial		5/8	100	- 52	350	.84	11.2	.406
Tangential		5/8	97	- 17	371	.46	33.2	.403

[1] Coefficients in the relation Y = A + BX, where Y is toughness and X is specific gravity.

[2] Based on ovendry weight and volume at indicated moisture condition.

by the pendulum to the specimen just equals energy required to fracture the specimen, then the test will be incomplete; total toughness of the specimen will not be measured. Of course, there is no way to determine what the total toughness of such specimens should have been, but we know that the toughness indicated by the machine at least exceeds that for specimens completely fractured with the same pendulum setting. Such test results have been accepted in evaluating toughness of species, since excluding them would result in a lower average for the species.

As the Amsler machine has only one initial pendulum position, there is no way of introducing bias in toughness results due to the pendulum setting. Therefore, values obtained with the Amsler machine probably represent a more repeatable estimate of toughness than those obtained with the FPL machine.

Regardless of any shortcomings the FPL machine may have, many toughness results have been obtained with it, and it will undoubtedly continue in common use. If should also be recognized that toughness values are not usable in design and the information desired in most evaluations is comparative.

A simple relationship that may be used for general comparison of results obtained with the two machines is needed because variables considered in this study will seldom, if ever, be directly applicable to other results. The simplest relationship is a single factor that can be applied for any condition. The best available estimate of such a factor is a simple average of ratios given in table 1. The average is 1.16, indicating that toughness values obtained with the FPL machine will, on the average, be about 16 percent higher than those obtained with the Amsler machine.

Effect of Specimen Size

Results from all four studies on size effect conducted with the FPL machine (table 4) are about as variable as results from the studies on

Table 4.--Results of toughness tests on the Forest Products Laboratory machine to compare 5/8-inch and 2-centimeter specimen sizes

Species	Type of test[1]	Number of matched pairs	Moisture content	Specific gravity[2]	Toughness: 2-centimeter size	Toughness: 5/8-inch size	Ratio: 2-centimeter size divided by 5/8-inch size: Toughness	Ratio: 2-centimeter size divided by 5/8-inch size: Unit toughness[3]
			Pct.		In.-lb.	In.-lb.		
Hickory	Radial	85	53	0.64	699	411	1.70	0.90
	Tangential	92	53	.64	720	427	1.69	.89
	Radial	93	12	.71	625	365	1.71	.91
	Tangential	96	12	.71	661	402	1.65	.87
Average								.89
Douglas-fir	Radial	329	13	.46	178	90	1.98	1.05
	Tangential	313	13	.46	258	138	1.87	.99
Average								1.02
Pacific silver fir	Radial	90	13	.40	163	90	1.82	.96
	Tangential	83	13	.40	247	132	1.87	.99
Average								.97
Douglas-fir[4]	Radial	49	50	.40	149	83	1.79	.95
	Tangential	49	51	.40	205	116	1.77	.94
	Radial	49	14	.43	139	79	1.75	.93
	Tangential	49	14	.42	200	111	1.80	.95
Average								.94
Loblolly pine[5]	Radial	28	109	.47	293	162	1.81	.96
	Tangential	28	108	.47	412	242	1.71	.90
	Radial	28	13	.51	180	96	1.88	.99
	Tangential	28	13	.51	309	155	2.00	1.06
Average								.98
Red oak[4]	Radial	22	78	.53	281	169	1.66	.88
	Tangential	22	79	.53	307	162	1.89	1.00
	Radial	22	12	.58	277	161	1.72	.91
	Tangential	22	12	.58	284	163	1.75	.92
Average								.93
Yellow birch[4]	Radial	17	76	.55	422	220	1.92	1.02
	Tangential	17	77	.55	411	233	1.76	.93
	Radial	13	10	.64	375	184	2.04	1.08
	Tangential	13	10	.63	372	203	1.83	.97
Average								1.00

[1] Radial, load applied to radial face; tangential, load applied to tangential face.
[2] Based on ovendry weight and volume at indicated moisture content.
[3] Unit toughness equals toughness divided by volume of specimen between supports.
[4] Data from Goodman (5).
[5] Based on data used in Forest Products Laboratory Report 2109 (4), except only matched pairs were used.

machine effects. Variability may be seen by the different ratios given in the last two columna fox the different species and conditions of test. Ratios of unit toughness of 2-centimeter specimens to unit toughness of 5/8-inch specimens vary from 0.87 to 1.08, depending upon species and other conditions. Hickory and Douglas-fir (5) results show the least interaction among the variables: however, results for the larger study of Douglas-fir suggest that there is some interaction between specimen size and type of test, at least for air-dried Douglas-fir. Results for loblolly pine, red oak, and yellow birch also indicate interactions between specimen size, moisture condition, and

Figure 7.--Oscilloscope traces of the Toad-deflection diagrams of toughness specimens. From study by W. L. James (6). M 134 902

type of test, but these interactions are probably of little significance because of the limited number of tests involved.

Hickory, as shown on table 4, had the lowest overall ratio between unit toughness of the large size specimen and unit toughness of the small size specimen. This is at least partly due to incomplete tests for some of the large specimens. The FPL toughness machine had insufficient capacity to completely break all large hickory specimens. Additional energy was obtained by attaching weights to the pendulum Still, the toughness of some of the large specimens was greater than available pendulum energy. Thus, tests of some of the larger specimens were incomplete, resulting in an average lower than the true average fox that specimen size. Incomplete tests occurred in each moisture condition-type of test combination. Therefore, the true ratio between specimen sizes for hickory is higher than indicated by results.

The overall general trend of all the data indicates that unit toughness of the large specimen is slightly lower than unit toughness of the small specimen, disregarding species, moisture condition, and type of test. This is expected because the small size specimen has the larger relative span-overhang, However, as an approximation, the ratio between the two specimen sizes on a unit toughness basis may be taken as unity for general comparison. A ratio of unity on a unit toughness basis corresponds to a ratio of 1.89 on the basis of standard specimen sizes. That is, toughness values of 5/8-inch specimens may be multiplied by 1.89 to make them comparable to toughness values of 2-centimeter specimens.

Other Relationships

Results of linear regressions of toughness on specific gravity for the few species given in table 3 indicate that specific gravity accounts for only a small portion of the variability in toughness of green wood, about 3 to 9 percent in the case of hickory, and a moderate amount of variability in toughness of air-dried wood (about 23 to 70 percent, depending upon species and type of test). Nonlinear regressions were not used because plots of data indicated that further consideration of any relationship other than linear was unwarranted.

Results of these studies also indicate that toughness of green wood averages somewhat higher than toughness of comparable air-dried wood, even though the air-dried wood averages higher in specific gravity due to normal shrinkage. This is in general agreement with prior evidence (8).

Another result of these studies that generally agrees with other studies on toughness (8) is that radial toughness is much lower than tangential toughness in softwood species but, for all practical purposes, the same for hardwood species.

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CONCLUSIONS

Studies reported in this paper show that:

1. Toughness values determined with the FPL machine average higher than toughness values for comparable material determined with the Amsler machine. The difference in values apparently varies with species, moisture condition, and type of test.

2. For general comparison of data representing different samples, toughness values from the FPL machine may be assumed to be 16 percent higher than those from the Amsler machine.

3. Toughness values obtained with an Amsler-type machine are probably more repeatable than those obtained with an FPL-type, because results from the latter can be biased by selection of different pendulum potential energies.

4. Ratios of unit toughness values of 2-centimeter and 5/8-inch specimens may be taken as unity for practical comparison, although the unit toughness of the smaller specimen has a tendency to be slightly higher than that of the larger specimen.

5. Toughness of green wood is higher than toughness of comparable air-dried wood.

6. Hardwoods have about the Same toughness in the radial or tangential orientation, but radial toughness is considerably lower than tangential toughness in softwoods.

7. Specific gravity accounts for very little of the variability of toughness of green wood and only a moderate amount of the variability of toughness of air-dried wood,

8. To insure that toughness values of the tougher specimens in a sample are biased as little as possible, sufficient energy should be supplied by the pendulum of the FPL toughness testing machine to pull each specimen completely through the supports.

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