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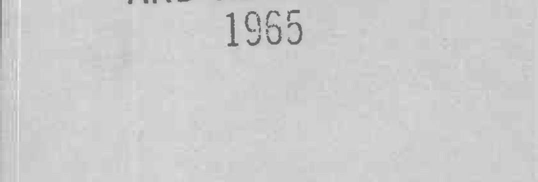

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

RESULTS OF IMPACT TESTS TO COMPARE THE PENDULUM IMPACT AND TOUGHNESS TEST METHODS[1]

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Summary

Two types of single-blow impact machines are in common use for testing small, clear specimens of wood. These are the simple pendulum impact machine, as embodied in the Amsler testing machine, and the Forest Products Laboratory toughness machine, which employs a linked chain operating over a drum at the axis of a pendulum. Previous studies have shown that results of tests with different sizes of specimens with any one machine are not directly convertible in unit energy values from one size to the other. In the interest of unifying test procedures, the same size specimen used for the pendulum impact (2 centimeters square in cross section) was adopted for the toughness test method. An extensive series of tests was made on matched material to determine the comparability of results by the two methods. The data show that, while each provides good comparative data among species and between other variables in test conditions, the pendulum impact method afforded generally lower average results than the Forest Products Laboratory

[1]For presentation at the Food and Agriculture Organization Fourth Conference on Wood Technology, Madrid, Spain, April 1958.

[2]Special acknowledgment is made to A. W. Dohr of the Forest Products Laboratory and Victor M. Goodman, former student assistant, for supervising and conducting tests and analyzing and reporting detailed data utilized in this report.

[3]Member FAO Technical Working Party on Testing of Mechanical Properties of Timber, FAO Conference on Wood Technology.

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

toughness test method. The average differences ranged from 4 to 27 percent. It does not appear from these data than an accurate conversion factor can be established to translate test values from one test method into directly comparable results of the other, even when the same size specimen is used. As a very broad, general approximation, however, average values from the pendulum impact method can be estimated as about 15 percent lower than values obtained by the toughness test method for comparable material.

Introduction

Two types of single-blow impact machines have been used for many years to evaluate the shock resistance of wood in bending. These comprise the pendulum impact method, as employed in the Amsler Universal Wood Testing Machine, and the Forest Products Laboratory Toughness Machine, which employs a chain operating over a drum at the axis of the pendulum.

Single-blow impact tests not only afford a basis for evaluating and comparing the shock resistance of wood species from specimens of small size, but also provide a basis for quality control in the selection of wood intended for exacting uses. Moreover, such tests also serve as a rapid and relaible means of evaluating the effect of deteriorating influences such as fungus attack or exposure to elevated temperature or chemical treatments. These important applications are made possible by the fact that the shock resistance is generally the first property affected or, at a somewhat more advanced stage of deterioration, is affected to a greater extent than are properties evaluated under static loading conditions.

Toughness Test Method

The toughness testing machine developed by the Forest Products Laboratory has been extensively used for measuring the shock resistance of wood. While this machine employs the principle of utilizing the energy of a falling pendulum, the load is applied by means of a chain operating over a rotating drum that has the same center of rotation as the pendulum (fig. 1).[2] In test, the specimen is conveniently supported horizontally, and the load is applied uniformly across the width of the specimen face at midlength by a cylindrical tup. To meet the wide range in properties of different woods, the capacity of the standard machine is adjustable to

[2]A complete description of the machine is given in Forest Products Laboratory Report No. 1308, "Forest Products Laboratory's Toughness Testing Machine."

any of fifteen different settings. This is accomplished by employing 3 different release positions of the pendulum (30°, 45°, and 60°) and 5 different weight positions. The difference between the initial and the final angle of the pendulum provides a measure of energy absorbed by the specimen. For tests of exceedingly tough material, a heavier weight is used to increase the capacity of the machine. For special studies involving material in smaller sizes, two smaller models of the machine have been developed.

Pendulum Impact Method

In the pendulum impact method, an impact bending load is applied to the specimen by a device attached to the pendulum near its center of percussion. The pendulum is weighted to provide the required capacity. The energy absorbed in breaking the specimen is determined by observing the extent to which the free fall swing of the pendulum is retarded. In the Amsler machine (fig. 2) only one capacity range was provided through a single fixed weight and a single initial pendulum release position.

Specimen Size

Specimens of a number of different sizes have been used with the toughness machine. Some of the earliest data were obtained with specimens having a 3/4-inch cross section. Later, a specimen 5/8 inch square by 10 inches in length, tested over an 8-inch span, was employed. A considerable amount of data obtained with specimens of these sizes is available. Subsequently, in the interest of unifying testing procedures, the 2-centimeter specimen was adopted as standard for toughness tests.[6]

Unfortunately, no fully satisfactory method has yet been devised for converting toughness data for one size of specimen to another, even when the same machine is used. Basically, it would appear that there might be a reasonably good theoretical relationship based on the energy absorbed per cubic volume of specimen between supports. Fairly extensive tests have shown, however, that such a relationship is not consistent.

[6] American Society for Testing Materials. Standard Methods of Testing Small Clear Specimens of Timber, ASTM Designation D143-52, Sections 71-76.

Machine Variables Affecting Impact Results

A number of factors that may affect the results of single-blow impact tests can be enumerated. These include friction of the pendulum at the bearing supports; elastic deformation of the machines, such as stretch in the loading chain of the toughness machine; the curvature of the loading tup and end supports, which influences the distribution of load on the specimen; the span-depth ratio, which determines the relation of shear and bending deformations; the extent to which the specimen overhangs beyond the end supports, which affects the relative proportion of specimens that pull through the supports without being completely ruptured; and the so-called toss factor, which refers to the unmeasurable energy losses that occur when a specimen is thrown from the machine after sudden failure. All such losses of energy are, of course, reflected in observed impact values.

Effect of Density and Moisture Content

It has long been evident that variations in specific gravity have a very pronounced effect on single-blow impact energy values. While, for most properties, strength varies with some power of specific gravity between 1.0 and 2.5, data now available indicate that single-blow impact energy may vary with a substantially higher power--apparently about the fourth power--of specific gravity. This, of course, means that very large differences in the recorded energy can be expected to occur within the rather broad range of specific gravity normally encountered in any one species.

Furthermore, the effect on impact resistance of differences in moisture content is not well established. Tests at several laboratories have clearly shown that toughness-moisture relations are decidedly different than strength-moisture relations for properties not involving shock resistance. Marked differences have been found among species. In general, toughness at normal temperature tends to decline as the moisture content is reduced from green levels to about 10 to 16 percent, and thereafter increases as the moisture content is further reduced. Thus, while it is often observed that toughness values of dry wood are essentially similar to those obtained from green wood, it cannot be assumed that toughness is not affected by moisture content. The actual relations are so complex, and differ to so great an extent among species, that no generally applicable procedure can be recommended for making adjustments to take into account differences in moisture content. Hence, it is apparent that studies directed toward the effect of test methods must be conducted in a way that will eliminate, as far as possible, any substantial differences in moisture content.

Scope

This report presents a brief summary of information obtained in two separate investigations[7] conducted at the Forest Products Laboratory to evaluate the comparability of data from carefully matched specimens of the current standard 2-centimeter size when tested by the pendulum impact method and the toughness test method. The tests were made on four species of wood, and included were carefully matched radial and tangential specimens tested in both the green and the dry condition.

Test Details

The specimens employed as a basis for this report were 2 centimeters (0.79 inch) square by 28 centimeters (11.0 inches) long, loaded at the center of a 24-centimeter (9.47-inch) span. Toughness tests were conducted in accordance with standard procedures.[6] The methods used in performing pendulum impact tests followed recommended procedure. No measurements were made of pressure exerted on the movable support.

Nomenclature

The definitions of three of the terms used in this report are as follows:

Tangential specimens are those to which the load is applied on a tangential face. Radial specimens are those to which the load is applied on a radial face.

Total energy is the total energy of rupture per specimen, measured as provided for in each type of machine. Energy values for the pendulum impact method were converted from kilogram-meters to inch-pounds for convenient comparison.

Test Material

Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Mirb.) Franco) included in these tests was obtained from seven different areas in the Rocky

[7]Tests of Douglas-fir, red oak, and yellow birch were conducted by Victor M. Goodman. The results were reported in detail in June 1956 as a partial fulfillment of the requirements for the Degree of Bachelor of Science at the University of Wisconsin. Tests of loblolly pine were under the direct supervision of A. W. Dohr. An unpublished detailed report of the work on that species was prepared in April 1954.

Mountain region. The samples, collected for limited standard property tests, consisted of a 3-foot length taken at about 16 to 19 feet above the stump from each of 10 trees at each location. The toughness specimens for this study were cut from one 3- by 4-1/2- by 30-inch stick (7.6 by 11 by 76 centimeters) taken from the outer portion of each such log section.

Red oak (Quercus rubra L.) specimens were obtained from 4 log sections 36 to 50 inches in length, each from a separate tree, that were available from another study. The height at which they had grown in the tree was not known. In contrast to Douglas-fir, in which only one stick was taken from each log section, as many sticks as possible of the size indicated for Douglas-fir were taken from each of the four oak log sections. A total of 39 oak specimen blanks was obtained.

Yellow birch (Betula alleghaniensis Britton) specimens were cut from 3 freshly cut logs, representing 3 trees, available at the Laboratory. As these were about 8 feet in length, each log was cut into 2 pieces about 4 feet long, and each such section was considered as an individual log. As in the case of red oak, the log sections were cut into as many 3- by 4-1/2- by 30-inch (7.6 by 11 by 76 centimeters) sticks as possible. A total of 49 sticks was obtained from the birch logs.

Loblolly pine test material was obtained from sections of 10 trees of loblolly pine (Pinus taeda L.) cut in the Crossett Experimental Forest near Crossett, Ark. Each tree section had grown at the height from 11 to 14 feet above the stump. A flitch 2-1/2 inches in thickness by 36 inches in length (6 by 91 centimeters) was cut from bark to bark, including the pith.

Matching

In each of the four species, specimens were provided for tests of green and dry material, loaded on either the radial or tangential face. In Douglas-fir, red oak, and yellow birch, the original sticks were cut longitudinally into 2 pieces about 1-1/2 by 4-1/2 by 30 inches (3.8 by 11 by 76 centimeters) in size for tests in the green and dry condition. The location of the test types was determined across the width of the sticks at random; that is, the test types were ring-matched. Radial and tangential specimens of the same type were randomly end-matched.

In loblolly pine, the three test types were end-matched and the radial and tangential specimens ring-matched. Specimens obtained from one radius were used for green tests and those from the opposite radius for dry tests.

In the final cutting, each specimen was oriented so that the annual rings were, as nearly as possible, tangential to two of the faces.

Conditioning

In each species, specimens designated for tests in the green condition were cut to final size and tested as promptly as possible to avoid changes in moisture content. Blanks from which dry specimens were to be cut were suitably end-coated and either air dried (Douglas-fir and loblolly pine) or kiln dried (red oak and yellow birch); a very mild kiln schedule was used. After drying, the specimen blanks were allowed to season in a conditioning room at 75° F. and 64 percent humidity, and individual specimens were cut to size and conditioned to essentially constant weight before being tested.

Data

Comparative average values and ratios of the total energy obtained from matched specimens tested by the pendulum impact method and the toughness test method are listed in table 1. The values tabulated for Douglas-fir and red oak are from specimens matched throughout in both the green and the dry condition. For yellow birch and loblolly pine, values are based on a closely matched group in the green condition and a somewhat different group, closely matched within itself, in the dry condition.

Table 2 shows the variability of specific gravity values obtained from the various groups of specimens tested by the two methods. Table 3 lists similar information for total energy.

Table 4 summarizes an analysis of variance of total energy as obtained by the pendulum impact method and the toughness test method for Douglas-fir, red oak, and yellow birch. An analysis of that type was not made for loblolly pine.

Discussion of Results

Reliability of Matching

Table 1 shows that, based on average values, the 16 groups representing green and dry specimens tested on radial and tangential faces by the toughness method were well matched to the corresponding 16 groups representing the pendulum impact method, for both moisture content and specific gravity.

For both test methods and moisture conditions, the radial and tangential specimens were also well matched for specific gravity.

Because specific gravity was based on volume at test, which differed as between green and dry specimens, specific gravity cannot be used to evaluate the adequacy of matching of specimens at the two moisture levels. Hence, comparisons of average energy values for green and dry material by the two test methods must be considered most reliable in Douglas-fir and red oak, where specimens representing the two moisture conditions were well matched within the same sticks.

Further evidence of the matching between related groups is offered in table 2. This table shows reasonable similarity not only of the mean specific gravity values of the green and dry, radial and tangential groups tested by both methods, but also of the variability around those mean values.

Variability of Test Results

Table 3 shows that the variability of the individual impact energy values around the means of the various groups was quite high. The coefficient of variation (standard deviation divided by the mean, expressed in percent) of modulus of rupture in static bending tests of green material has been found to average around 16 percent, while in these single-blow impact tests it was around 30 percent, or nearly twice as high.

It has been pointed out that variations in impact energy due to differences in specific gravity are a strongly contributing factor in producing the wide variability characteristic of single-blow impact tests. Thus, while the material in the various related groups of specimens was quite closely matched, on the average, with respect to specific gravity, individual specimens can be expected to depart from average trends. Moreover, impact strength is known to be very sensitive to deteriorating influences that may be present in a test specimen.

On the whole, the results of tests on dry material showed less variability than those on the green, and results of tests with the pendulum impact method tended to be somewhat more variable for both green and dry material than those obtained with the toughness test method. Ten of the fourteen groups listed in table 3 showed higher coefficients of variation in the groups tested with the pendulum impact method. Because of the generally high level of variability in test results for the green and dry material and in the results of radial and tangential tests of the four species, the differences in variability between the two test methods are probably not important.

Comparison of Pendulum Impact and Toughness Test Methods

Column 9 of table 1 lists the ratios of the average total energy obtained by the pendulum impact method to that obtained from closely matched groups of specimens tested by the toughness method. The ratios indicate that results obtained with the pendulum impact method may range from 4 to 27 percent lower, for similar material, than those obtained with the toughness test method. Because of this wide variation, a statistical analysis was undertaken to determine the significance of the differences obtained for Douglas-fir, red oak, and yellow birch.

The analysis of variance summarized in table 4 showed that the source of variation attributable to the difference in test methods (T) was very highly significant in Douglas-fir, highly significant in red oak, and highly significant in green yellow birch. For the latter species, the analysis was handled separately for green and dry tests, as the two groups contained different numbers of specimens.

The significant interaction between test method and moisture content (T x M) for Douglas-fir was examined by use of the "t" test to determine whether the relationship between test values obtained with the two methods was significantly affected by moisture content. The analysis showed that the average energy values for both green and dry material were significantly higher in tests made by the toughness method, but the difference between the two methods was more marked when the test material was dry.

An analysis of variance was not made for loblolly pine, but the very large differences in average values obtained with the two test methods leaves little doubt that the differences were highly significant.

No well-defined conclusions can be made as to the effect of moisture content or growth-ring orientation on the differences in test results obtained with the two methods of test. The ratios listed in column 9 of table 1 appear to indicate a trend toward smaller ratios in the dry tests--that is, larger differences between the two test methods--for both the radial and tangential orientations in Douglas-fir and red oak, where the specimens were well matched for the two moisture conditions. There appears also to be a trend toward smaller ratios (larger differences) for tests made on the radial face, particularly in the dry condition.

While the tests included in this study show that direct comparability of impact energy values cannot be assumed for tests made with the pendulum impact method and the toughness test method, the data also show that either method can be expected to provide good comparative data among species, or between various test conditions. For example, columns 10 and 11 in table 1 show the relative relationships among the 4 species included in these tests. Douglas-fir was chosen arbitrarily as the comparison base. While there are obvious discrepancies in the species ratios obtained with the 2 test methods, the relative rank of the 4 species is the same with the 2 test methods in 3 of the 4 groups representing different moisture conditions and growth-ring orientations.

From the data available, it is not possible to calculate a single conversion factor, or possibly several factors to take into account differences resulting from moisture condition and growth-ring orientation, that can be expected to relate average values from the two test methods with a high degree of accuracy. On the other hand, in the absence of specific data applicable to a particular species and test condition, it would appear reasonable to make a very broad, general approximation that average values from the pendulum impact method can be estimated as about 15 percent lower than values obtained by the toughness test method for comparable material. In the 16 groups included in these studies such an approximation would have yielded overestimates for 7 of the 16 groups ranging from 1 to 16 percent, and underestimates for 9 of the groups ranging from 1 to 12 percent of the measured average values from pendulum impact tests.

While a 15 percent adjustment factor cannot be considered an accurate estimator of the difference in energy values between the pendulum impact and toughness test methods, its use does provide a basis for making broad comparisons that are of the same general order of magnitude.

Effect of Growth-Ring Orientation

In the two softwood species tested, Douglas-fir and loblolly pine, impact energy values of both test methods were decidedly higher for specimens loaded on the tangential face than for those loaded on the radial face. Values for tangential specimens averaged about 40 percent higher in green material and about 60 percent higher in dry material. In the two hardwood species, red oak and yellow birch, tests of tangential specimens yielded values from 2 percent lower to 9 percent higher than the corresponding groups of radial specimens. There appeared to be no consistent relationship with moisture condition. It is evident that the relation of results between radial and tangential specimens depends on both species and moisture content, and the differences are less for the hardwoods. These findings are in agreement with the results of previous tests, which have shown that the effect of differences in ring placement on single-blow impact values are not nearly so important in hardwoods as in softwoods.

Effect of Moisture Content

The data from these tests substantiate earlier observations that energy values from single-blow impact tests tend to be consistently lower for material at about 12 percent moisture content than for material tested in the green condition. For the two hardwood species, the results of tests on specimens in the dry condition averaged about 7 percent lower than for those tested in the green condition, and did not appear to be affected consistently by the test method employed, the species, or the growth-ring orientation.

In the two softwood species, on the other hand, the test values for dry loblolly pine were substantially lower in relation to the green test values than was the case in Douglas-fir. Moreover, the ratio of dry to green test values of Douglas-fir was substantially lower for test values obtained with the pendulum impact method than for those obtained with the toughness test method. While the detailed effects of variation in moisture content on energy values were not a primary consideration in this study, these findings emphasize the fact that single-blow impact energy values are variously affected by differences in moisture content.

Conclusions

The comparative studies included in this report, covering 2 moisture conditions and 2 ring orientations for 4 species, show that impact energy values obtained with the pendulum impact method tend to be consistently and significantly lower than values for carefully matched material obtained with the toughness test method.

On the average, the difference in results obtained with the 2 test methods ranged from 4 to 27 percent, but the differences varied widely among species both as between the green and dry material and as between the 2 growth-ring positions. Thus, on the basis of data now available, establishment of an accurate adjustment factor that could be used to convert data obtained by one method to a reasonably exact equivalent for the other test method is not feasible. On the other hand, as a very broad, general approximation, the average values from the pendulum impact test can be estimated as about 15 percent lower than values for comparable material tested by the toughness method. The relationships of impact energy values among species and between various test conditions were quite similar for the two test methods.

These studies confirmed previous evidence that radial and tangential impact energy values do not differ greatly in hardwoods, but that softwood specimens loaded on the tangential face yield consistently higher results than those loaded on the radial face.

Table 1.--Values from comparative tests of Forest Products Laboratory toughness method and pendulum impact method

Species	Number of specimens	Toughness method: Moisture content	Toughness method: Specific gravity[1]	Toughness method: Total energy[2]	Pendulum impact method: Moisture content	Pendulum impact method: Specific gravity[1]	Pendulum impact method: Total energy[2]	Ratio of total energy[3]	Species ratios (total energy): Toughness method	Species ratios (total energy): Pendulum impact method
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
		Percent		In.-lb.	Percent		In.-lb.			
GREEN--RADIAL										
Douglas-fir	49	50.9	0.399	149.4	46.2	0.402	134.5	0.90	1.00	1.00
Loblolly pine	39	102.2	.489	322.4	103.8	.482	261.3	.81	2.16	1.94
Red oak	22	77.0	.531	281.0	78.0	.526	255.8	.91	1.88	1.90
Yellow birch	17	76.0	.554	422.5	76.2	.546	352.8	.84	2.83	2.62
GREEN--TANGENTIAL										
Douglas-fir	49	51.1	.401	204.8	49.2	.403	196.6	.96	1.00	1.00
Loblolly pine	39	100.4	.489	440.6	101.9	.485	345.4	.78	2.15	1.76
Red oak	22	77.2	.531	306.8	77.9	.531	271.6	.89	1.50	1.38
Yellow birch	17	77.7	.549	411.3	75.9	.547	382.2	.93	2.01	1.94
DRY--RADIAL										
Douglas-fir	49	13.9	.426	138.7	13.4	.428	104.4	.75	1.00	1.00
Loblolly pine	38	13.5	.531	199.9	13.3	.523	146.6	.73	1.44	1.40
Red oak	22	12.1	.579	277.1	11.7	.586	233.6	.84	2.00	2.24
Yellow birch	13	10.3	.638	374.6	10.1	.638	348.4	.93	2.70	3.34
DRY--TANGENTIAL										
Douglas-fir	49	13.9	.424	199.7	13.7	.423	171.4	.86	1.00	1.00
Loblolly pine	38	12.4	.528	323.4	13.2	.527	265.4	.82	1.62	1.55
Red oak	22	11.7	.580	284.3	11.6	.583	247.3	.87	1.42	1.44
Yellow birch	13	10.7	.633	371.8	10.3	.633	348.9	.94	1.86	2.04

[1] Based on weight when ovendry and volume at test.

[2] Specimens 2 centimeters (0.79 inch) square by 28 centimeters (11 inches) long center-loaded over a 24-centimeter (9.47-inch) span.

[3] Values obtained by the ratio: $\frac{\text{Pendulum impact method (col. 8)}}{\text{Toughness method (col. 5)}}$

Table 2.--Variability of specific gravity[1] of specimens used in comparative tests of Forest Products Laboratory toughness method and pendulum impact method

Species	Number of specimens	Toughness method				Pendulum impact method			
		Species mean specific gravity	Standard error	Standard deviation	Coefficient of variation	Species mean specific gravity	Standard error	Standard deviation	Coefficient of variation
					Percent				Percent
GREEN--RADIAL									
Douglas-fir	49	0.402	0.0067	0.0470	11.7	0.402	0.0071	0.0499	12.4
Loblolly pine	39	.481	.0072	.0448	9.3	.476	.0069	.0428	9.0
Red oak	22	.531	.0069	.0322	6.1	.526	.0053	.0249	4.7
Yellow birch	17	.554	.0080	.0330	6.0	.546	.0071	.0291	5.3
GREEN--TANGENTIAL									
Douglas-fir	49	.401	.0061	.0430	10.7	.403	.0067	.0466	11.6
Loblolly pine	39	.485	.0063	.0396	8.2	.479	.0069	.0431	9.0
Red oak	22	.531	.0063	.0296	5.6	.531	.0076	.0357	6.7
Yellow birch	17	.549	.0075	.0310	5.6	.547	.0076	.0315	5.8
DRY--RADIAL									
Douglas-fir	49	.426	.0074	.0518	12.2	.428	.0074	.0518	12.1
Red oak	22	.579	.0068	.0320	5.5	.586	.0061	.0286	4.9
Yellow birch	13	.638	.0147	.0530	8.3	.638	.0143	.0517	8.1
DRY--TANGENTIAL									
Douglas-fir	49	.424	.0076	.0533	12.6	.423	.0076	.0530	12.5
Red oak	22	.580	.0065	.0305	5.3	.583	.0070	.0326	5.6
Yellow birch	13	.633	.0153	.0550	8.7	.633	.0131	.0473	7.5

[1] Based on weight when ovendry and volume at test.

Table 3.--Variability of total energy[1] values obtained in comparative tests of Forest Products Laboratory toughness method and pendulum impact method

Species	Number of specimens	Toughness method				Pendulum impact method			
		Species mean total energy	Standard error	Standard deviation	Coefficient of variation	Species mean total energy	Standard error	Standard deviation	Coefficient of variation
		In.-lb.	In.-lb.	In.-lb.	Percent	In.-lb.	In.-lb.	In.-lb.	Percent
GREEN--RADIAL									
Douglas-fir	49	149.4	6.00	41.97	28.1	134.5	5.85	40.96	30.5
Loblolly pine	39	323.0	13.76	85.95	26.6	267.4	10.30	64.35	24.1
Red oak	22	281.0	17.87	83.81	29.8	255.8	14.66	68.75	26.9
Yellow birch	17	422.5	33.41	137.76	32.6	352.8	34.62	142.74	40.5
GREEN--TANGENTIAL									
Douglas-fir	49	204.8	9.64	67.50	33.0	196.6	11.76	82.33	41.9
Loblolly pine	39	440.3	17.88	111.66	25.4	345.0	14.62	91.27	26.5
Red oak	22	306.8	21.44	100.58	32.8	271.6	14.91	69.94	25.8
Yellow birch	17	411.3	25.72	106.06	25.8	382.2	29.12	120.05	31.4
DRY--RADIAL									
Douglas-fir	49	138.7	4.39	30.75	22.2	104.4	4.40	30.78	29.5
Red oak	22	277.1	15.53	72.85	26.3	233.6	15.01	70.42	30.1
Yellow birch	13	374.6	24.50	88.34	23.6	348.4	27.61	99.55	28.6
DRY--TANGENTIAL									
Douglas-fir	49	199.7	10.88	76.13	38.1	171.4	8.65	60.53	35.3
Red oak	22	284.3	12.18	57.15	20.1	247.3	13.67	64.14	25.9
Yellow birch	13	371.8	18.60	67.08	18.0	348.9	18.77	67.69	19.4

[1] Total energy of specimens 2 centimeters (0.79 inch) square by 28 centimeters (11 inches) long center-loaded over a 24-centimeter (9.47-inch) span.

Table 4.--Analyses of variance of total energy values obtained in comparative tests of Forest Products Laboratory toughness method and pendulum impact method

Species	Source[1] of variation	Degrees of freedom	Sum of squares	Mean squares	"F"	Significance[2]
Douglas-fir	T	1	44,991.429	44,991.429	29.94	***
	M	1	30,861.927	30,861.927	20.54	***
	G	1	369,284.180	369,284.180	245.75	***
	T x M	1	9,474.744	9,474.744	6.31	*
	T x G	1	973.665	973.665	.65	N.S.
	G x M	1	676.068	676.068	.45	N.S.
	T x G x M	1	2.985	2.985	.002	N.S.
(Treatment total)		7	456,264.998			
	R	48	749,170.882	15,607.727	10.39	***
	Error	336	504,908.342	1,502.703		
	Total	391	1,710,344.222			
Red oak	T	1	54,570.573	54,570.573	8.60	**
	M	1	14,620.096	14,620.096	2.30	N.S.
	G	1	10,765.638	10,765.638	1.70	N.S.
	T x M	1	1,122.615	1,122.615	.18	N.S.
	T x G	1	32.046	32.046	.01	N.S.
	G x M	1	1,175.761	1,175.761	.19	N.S.
	T x G x M	1	739.230	739.230	.12	N.S.
(Treatment total)		7	83,025.959			
	R	21	570,528.281	27,168.013	4.28	*
	Error	147	932,511.111	6,343.613		
	Total	175	1,015,537.070			
Yellow birch[3]						
Green	T	1	41,481.180	41,481.180	15.25	**
	G	1	1,410.501	1,410.501	.52	N.S.
	T x G	1	7,019.747	7,019.747	2.58	N.S.
	R	16	909,639.958	56,852.497	20.90	**
	Error	48	130,575.780	2,720.329		
	Total	67	1,090,127.166			
Dry	T	1	7,847.412	7,847.412	2.73	N.S.
	G	1	18.720	18.720	.006	N.S.
	T x G	1	36.893	36.893	.01	N.S.
	R	12	218,006.838	18,167.236	6.32	**
	Error	36	103,533.070	2,875.919		
	Total	51	329,442.933			

[1]T is between tests; M is moisture, green and dry; G is growth ring orientation, radial and tangential; R is replications.

[2]N.S. is not significant; * is significant at the 5 percent level; ** is significant at the 1 percent level; *** is significant at the 0.1 percent level.

[3]Comparison between green and dry was made by using the pooled standard error in a "t" test.

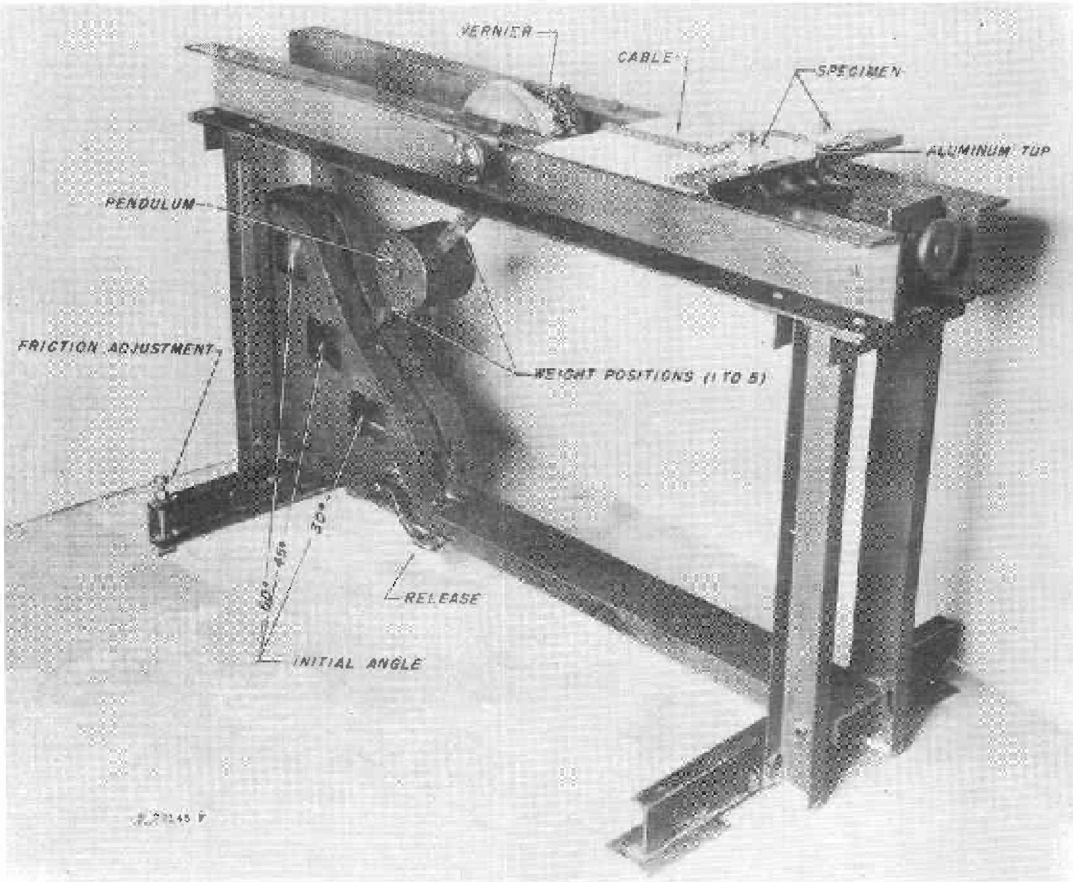

Figure 1.--Forest Products Laboratory Toughness Machine.

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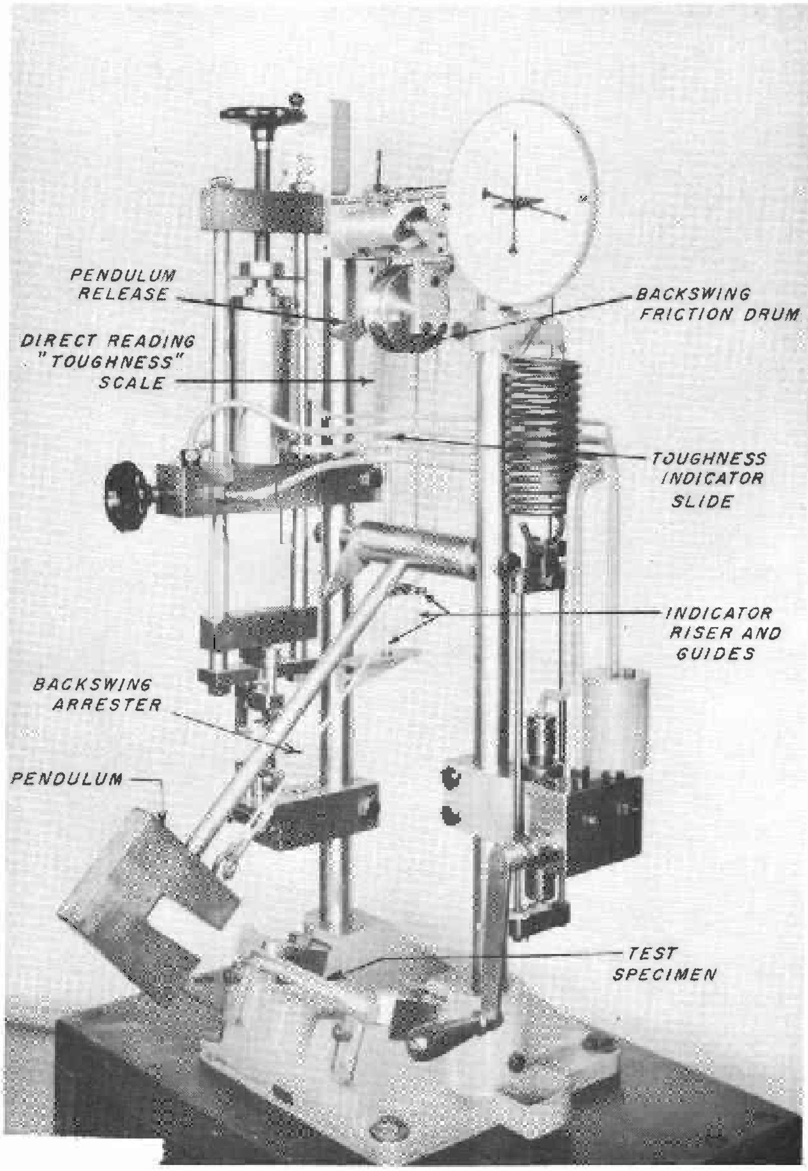

Figure 2.--Amsler Universal Wood-Testing Machine.

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