THE ABRASIVE RESISTANCE OF WOOD AS DETERMINED WITH THE U. S. NAVY WEAR-TEST MACHINE

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THE ABRASIVE RESISTANCE OF WOOD AS DETERMINED WITH THE U. S. NAVY WEAR-TEST MACHINE

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Summary

This report presents the results of an investigation at the U. S. Forest Products Laboratory concerning the feasibility of using a newly designed Navy wear-test machine for determining the abrasive resistance of wood. Closely matched samples from 21 trees, representing 15 different species, were tested. The data obtained are analyzed both with respect to the testing procedures used and as to the validity of the data obtained.

Comparative tests of closely matched specimens indicate that the method of test used gives reproducible results. Further research on testing details will be required before this method of test can be standardized.

The data obtained give results which place the various species tested in about the order to be expected from actual experience. The actual order of species showing about the same amount of wear is probably not significant. The much greater wear resistance of end-grain surfaces is clearly indicated for all species tested. No clear, uniform relationship between wear resistance and specific gravity was found.

The results obtained indicate that this wear-test machine should be a valuable aid in making comparisons between new flooring materials and the wood species commonly used for flooring.

Introduction

The U. S. Forest Products Laboratory has long been interested in the abrasion resistance of wood as related to its use as a flooring material. The service

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

behavior of the species of wood commonly used for flooring can be predicted with some accuracy; this is not true, however, for other species of wood and various types of flooring materials. Actual service tests of flooring materials are expensive, difficult to duplicate, and require long periods of time for completion. Consequently, a simple abrasion test that would indicate the wear resistance of these materials would be of great value.

During the recent war, this Laboratory was called upon to assist the United States Navy in the development of a satisfactory substitute for teak as ship decking. As an aid in this work the Laboratory constructed a duplicate of the wear-test machine designed and built by the Navy Materials Laboratory.[2] This machine was used in an extensive investigation of the comparative wear resistance of teak and a large number of modified wood materials. The Navy wear machine was designed primarily for tests of ship walkway materials and no claims are made as to its suitability for tests of other materials.

After completion of the modified wood study, the Laboratory decided to investigate the possibility of using this wear-test machine as a wood-abrasion tester. The results of this investigation are outlined in this report.

Description of Material

Tests were made on some of the species of wood commonly used for flooring, together with other available species, included to provide a wide range in specific gravity. The following tabulation gives both the species and the number of trees represented.

Species (common and botanical names)	Number of trees represented
Hickory (Carya species)	1
Maple, sugar (Acer saccharophorum)	1
Ash, white (Fraxinus americana)	1
Oak (Quercus species)	1
Pine, southern yellow (Pinus sp.)	3
Beech (Fagus grandifolia)	1
Douglas-fir (Pseudotsuga taxifolia)	3
Birch, yellow (Betula lutea)	1
Spruce, Sitka (Picea sitchensis)	3
Poplar, yellow (Liriodendron tulipifera)	1
Baldcypress (Taxodium distichum)	1
Teak (Tectona grandis)	1
Khaya (Khaya sp.)	1
Pine, Eastern white (Pinus strobus)	1
Redwood (Sequoia sempervirens)	1

[2]Cizek., A. W., Kallas, D. H., and Nestlen, H., A New Machine for Measuring Wear Resistance of Walkway Materials, ASTM Bull. No. 132, Jan. 1945.

All of the specimens were obtained from air-seasoned or kiln-dried Laboratory stock that was relatively free from knots, checks, cross grain, or other growth characteristics that might influence direct comparisons between tests. Except for the beech and teak, all material was in plank form ranging in thickness from 3 to 4 inches with a minimum length of 5 feet. The beech was obtained from a board about 1 inch thick, while the teak specimens were obtained from 6-inch square stock 12 inches long.

Specimens cut from the dry material were conditioned at 70° F. and 64 percent relative humidity until they reached approximately constant weight.

Marking and Matching

Figure 1 shows the cutting method used to obtain matched specimens from 2- by 2- by 56-inch bolts. Each bolt provided sufficient material for two complete sets of specimens. Specimens of only the "A" series were used. The teak specimens were matched in a similar manner insofar as the limited amount of material would permit. The 1-inch thickness of the flat-sawn beech board made it necessary to edge glue side-matched material in order to obtain the required width for the radial and end-grain specimens.

As shown in figure 1, each specimen was marked with a code consisting of letters and numerals which identified it completely as to origin and intended use.

Methods of Test

The Navy wear-test machine used is shown in figure 2. The abrasive wear on the specimen is obtained by grinding against a revolving steel disk covered with a loose abrasive. The disk upon which the abrasive is distributed revolves clockwise at a uniform speed of approximately 23.5 revolutions per minute, while the specimen and specimen holder revolve clockwise at a uniform speed of approximately 32.5 revolutions per minute. The specimen is secured to the holder by means of two metal clamps. The holder is designed with a universal coupling in order to maintain uniform contact between the specimen surface and the revolving disk. Hardened steel cams and cam followers lift the specimen a distance of 1/16 inch and drop it back into contact with the abrading disk twice during each revolution of the specimen. A dead weight of 10 pounds is mounted on the top of the specimen holder.

The abrasive grit is distributed from the mechanically agitated hopper to the abrading disk at the rate of approximately 46 grams per minute. The grit used throughout all tests was a No. 80 commercial aluminum oxide. New abrasive was used for all tests.

A predetermining revolution counter automatically stopped the machine after the desired number of abrading-disk revolutions had been reached.

The amount of wear during a stated number of revolutions of the abrading-disk was determined by measuring both the loss in thickness in inches and the loss in weight in grams. The thickness was measured with a 0.001-inch dial gage at the five points shown in figure 3. The points of measurement were accurately located on the wearing face of the specimen by means of a template. The loss of weight was determined by weighing the specimen at stated intervals during the test. The lighter specimens were weighed to the nearest 0.001 gram while the heavier specimens and the specimens glued to metal plates were weighed to the nearest 0.01 gram.

Specimens in which the wear was relatively rapid were tested for a total of 500 revolutions, wear being measured after every 100 revolutions. All other specimens were tested for a total of 1,000 revolutions, with wear measured after every 200 revolutions.

In order to minimize the effects of changes in moisture content, all specimens were conditioned and tested in a room maintained at a temperature of 75° F. and a relative humidity of 64 percent.

Test Results

Individual test results are given in table 1. Specimens tested to 500 revolutions only are indicated by footnote [2]. The wear data shown for these specimens were obtained by doubling the values obtained at 500 revolutions. The coefficient of variation in wear within each group of four matched specimens is shown in column 6.

Table 2 shows the relative order of wear resistance and specific gravity of all samples tested. Test species are listed in the order of increasing wear as determined from tests on the tangential (flat-grain) surface. The respective order of wear on the radial (edge-grain) and end-grain surfaces is indicated numerically in columns 6 and 8. Column 10 shows the relative numerical order of the specific gravities, with the highest specific gravity having a value of 1.

Analysis of Results

Lacking comparative service test data with matched specimens, it was necessary to analyze the results of the abrading tests on the basis of their agreement with the abrasive resistance of wood as determined by practical experience. Wide acceptance of this method of determining the abrasion resistance of wood will depend on the development of a standardized method of test and obviously on the validity of the data obtained. The abrasion resistance data obtained were therefore analyzed with respect to both of these considerations.

Analysis of Test Methods

In order to determine the most satisfactory procedure, the amount of wear was determined by measuring both the loss in thickness in inches and the loss of weight in grams. A study of the data in table 1 indicates that loss of weight alone is not a reliable criterion of the abrasive resistance of wood. Test species varied considerably in density, and as a consequence equal weight losses do not necessarily represent equal losses of volume. This is illustrated in the following tabulation of data taken from table 1.

Species	Loss of weight after 1,000 revolutions of the abrading disk	Thickness loss after 1,000 revolutions of the abrading disk
	Grams	Inch
Sitka spruce (sample 3)	0.27	0.0116
Hard maple	.30	.0066
Yellow-poplar	.35	.0142
Sitka spruce (sample 1)	.35	.0167
Hickory	.37	.0056
Southern yellow pine (sample 3)	.50	.0088
Douglas-fir (sample 3)	.50	.0144
Douglas-fir (sample 1)	.52	.0143
White pine	1.56	.0386

These data indicate the necessity of considering the loss in weight in conjunction with the density of the material being tested. In tests of wood this is complicated by the fact that the average density of the test specimen does not always represent the density of the abraded surface. This is especially true of specimens abraded on the flat-grain surface, where the wear can be entirely in the dense summerwood, in the less dense springwood, or in any combination of the two. An attempt was made to correlate the loss of weight in grams with the specific gravity of the material worn away. This attempt was not successful, possibly due to the difficulty of measuring the small quantities involved.

The close agreement in the results of separate tests of matched specimens indicates that the results are rather closely reproducible whether loss of weight or thickness as measured. Minor variations in thickness loss within groups of matched specimens did not necessarily show similar variations in weight loss.

The methods of test used in this study were, in general, closely patterned after those developed by the designers of this testing machine, but others were selected arbitrarily. Further studies will be required before this abrasion test can be considered as a standardized test for wood.

Some of the items which require further study are outlined below.

1. Effect of allowable variations in the commercial abrasive used.
2. Effect of moisture content and temperature on the abrasive resistance of wood.
3. Effect of the rate of abrasive wear.
4. Effect of minor variations in the height through which the specimen is dropped.
5. Effect of wear on the steel abrading disk.
6. Establishment of a standard method of reporting the test results.

Analysis of Data

As previously mentioned, some specimens were only tested to 500 revolutions of the abrading disk and results doubled for the 1,000 revolution index in table 1. This method was used in view of the straight-line nature of most revolution -- wear-plot graphs. A few tests indicated that actual extrapolation of the data would change the tabulated data by only negligible amounts.

The data in table 1 allow comparison between four closely matched end-grain, tangential, or radial specimens. In all cases the end-grain specimens are significantly more resistant to wear than the radial or tangential specimens. Comparisons between the average values obtained for the four radial and tangential specimens of each species show that the radial wear is somewhat greater in the majority of the cases, but the trend is not uniform or well-defined. The relationship of wear to specific gravity for those species represented by samples from three different trees is also not consistent. Growth characteristics or structure variation may possibly cause some of these inconsistencies.

The data presented in this study are probably too limited to justify a statistical analysis, but in all cases except those of hard maple and white oak the coefficient of variation is greater for the tangential than the radial specimens. This appears to be in keeping with the more variable nature of the tangential surfaces.

The summary of average data in table 2 showing the relative order of wear resistance for all samples tested was included to facilitate wear-resistance comparisons between species and between the various surfaces abraded. The data in columns 4, 6, and 8 indicate a closer agreement in the relative order of wear resistance as determined by tests on the tangential and radial surfaces, than as determined by end-grain tests. The smaller numerical spread in the end-grain values probably accounts for some of these discrepancies. The data in column 10 indicate the general relationship between specific gravity and wear.

The straight-line nature of the wear caused by a given number of revolutions is shown for all species tested in figures 4, 5, and 6. Each point on these charts represents the averages of four individual tests.

Figure 7 shows the manner in which the abrasive wear in inches after 1,000 revolutions of the abrading disk varies with the specific gravity of the specimen. In general, the species of high specific gravity have the greatest wear resistance, while the specimens of low specific gravity have the least wear resistance. The teak and Sitka spruce specimens are notable exceptions to the general trend.

One possible use of a test of this kind would be as a flooring material acceptance test. A specification admitting only material showing a wear of less than 0.01 inch in 1,000 revolutions would thus admit end-grain hickory, hard maple, beech, yellow birch, white ash, white oak, some southern yellow pine, flat-grain hickory and maple, and also edge-grain hickory. A specification calling for a flat- or edge-grain material with a limiting wear factor of 0.02 inch would admit hickory, maple, ash, oak, beech, and possibly some southern yellow pine. Increasing this wear factor to 0.03 inch would also admit yellow birch, Douglas-fir, and possibly some Sitka spruce.

The data presented in figure 7 are shown in figure 8 in the form of a bar chart in which the species tested are placed in the order of wear resistance. The average specific gravity of each group of four specimens is shown directly above. In general, the wear resistance of each specimen tested is in the order that actual experience has shown to be proper. The chart again illustrates the fact that specific gravity values alone are not reliable criterions as to the abrasive resistance of wood.

Conclusions

The following conclusions are based on the results obtained in this preliminary investigation of the abrasive resistance of wood as measured by the Navy wear-test machine.

This method of test places the various species tested in about the order to be expected from actual experience. The actual order of the species showing about the same amount of wear is probably not significant.

Within each species tested it was found that the wear resistance of the end-grain surfaces was significantly higher than that of either the radial or tangential. In most instances the radial surfaces seem to be slightly less wear resistant than the tangential surfaces, but the trend is not well-defined.

The data show that, for most species tested, the results obtained from the four closely matched specimens abraded on the tangential surfaces are more variable than those from the specimens abraded on the radial faces.

No definite relationship was found to exist between wear resistance and specific gravity within the species represented by samples from three different trees.

The Navy wear-test machine appears to provide a ready means of measuring the comparative abrasion resistance of various species of wood. Further research would be required in order to interpret these results in terms of the wear resistance of wood in actual service. This research should also be directed towards the development of standard test procedures and standard methods of reporting the test results. This machine should prove useful in making comparisons between the wear resistance of newly developed flooring materials and that of the wood species commonly used for flooring.

Table 1.--Navy-machine wear data for 15 species of wood, based on 1,000 revolutions of the abrading disk

Surface abraded	Specimen	Specific gravity[1]	Loss in weight	Average wear	Coefficient of variation (wear)
(1)	(2)	(3)	(4)	(5)	(6)
	Number		Grams	Inch	Percent
Hard maple (Acer saccharophorum) (Average moisture content 11.8 percent)					
End grain...	M-1	0.64	0.24	0.0074	
Do.	M-2	.63	.28	.0060	
Do.	M-3	.63	.35	.0062	
Do.	M-4	.63	.31	.0066	
Average...		.63	.30	.0066	9.38
Tangential..	MT-1	.64	.52	.0096	
Do.	MT-2	.64	.44	.0088	
Do.	MT-3	.63	.48	.0086	
Do.	MT-4	.62	.46	.0088	
Average...		.63	.48	.0090	4.92
Radial......	MR-1	.66	.69	.0122	
Do.	MR-2	.64	.69	.0120	
Do.	MR-3	.64	.79	.0126	
Do.	MR-4	.64	.64	.0098	
Average...		.64	.70	.0116	10.84
White oak (Quercus sp.) (Average moisture content 11.9 percent)					
End grain...	O-1	.64	.62	.0096	
Do.	O-2	.64	.55	.0098	
Do.	O-3	.65	.53	.0094	
Do.	O-4	.65	.54	.0100	
Average...		.64	.56	.0097	2.66
Tangential..	OT-1	.64	1.13	.0168	
Do.	OT-2	.64	1.10	.0156	
Do.	OT-3	.66	1.16	.0176	
Do.	OT-4	.67	1.27	.0164	
Average...		.65	1.16	.0166	5.02
Radial......	OR-1	.65	1.30	.0188	
Do.	OR-2	.65	1.31	.0194	
Do.	OR-3	.68	1.17	.0174	
Do.	OR-4	.67	1.20	.0176	
Average...		.66	1.25	.0183	16.57

(Sheet 1 of 11 sheets)
Continued

Table 1.--Navy-machine wear data for 15 species of wood, based on 1,000 revolutions of the abrading disk (continued)

Surface abraded	Specimen	Specific gravity[1]	Loss in weight	Average wear	Coefficient of variation (wear)
(1)	(2)	(3)	(4)	(5)	(6)
	Number		Grams	Inch	Percent
		Yellow birch (Betula lutea) (Average moisture content 12.2 percent)			
End grain...	B-1	0.56	0.47	0.0092	
Do.	B-2	.56	.46	.0098	
Do.	B-3	.58	.45	.0080	
Do.	B-4	.58	.41	.0082	
Average...		.57	.45	.0088	9.65
Tangential...	BT-1	.61	1.36	.0260	
Do.	BT-2	.60	1.46	.0266	
Do.	BT-3	.60	1.47	.0286	
Do.	BT-4	.60	1.30	.0204	
Average...		.60	1.40	.0254	13.83
Radial......	BR-1	.59	1.53	.0238	
Do.	BR-2	.58	1.52	.0236	
Do.	BR-3	.59	1.50	.0216	
Do.	Br-4	.58	1.48	.0226	
Average...		.58	1.50	.0229	4.42
		White ash (Fraxinus americana) (Average moisture content 9.5 percent)			
End grain...	A-1	.60	.60	.0100	
Do.	A-2	.60	.65	.0080	
Do.	A-3	.66	.38	.0074	
Do.	A-4	.66	.39	.0086	
Average...		.63	.50	.0085	13.11
Tangential..	AT-1	.64	.83	.0128	
Do.	AT-2	.65	.74	.0114	
Do.	AT-3	.62	.78	.0142	
Do.	AT-4	.66	.78	.0124	
Average...		.64	.78	.0127	9.13
Radial......	AR-1	.65	1.10	.0180	
Do.	AR-2	.65	1.04	.0173	
Do.	AR-3	.65	1.10	.0178	
Do.	AR-4	.64	1.11	.0200	
Average...		.65	1.09	.0183	6.49

(Sheet 2 of 11 sheets)
Continued

Table 1.--Navy-machine wear data for 15 species of wood, based on 1,000 revolutions of the abrading disk (continued)

Surface abraded	Specimen	Specific gravity[1]	Loss in weight	Average wear	Coefficient of variation (wear)
(1)	(2)	(3)	(4)	(5)	(6)
	Number		Grams	Inch	Percent
		Hickory (Carya sp.) (Average moisture content 12.2 percent)			
End grain...	H-1	0.72	0.36	0.0042	
Do.	H-2	.72	.39	.0058	
Do.	H-3	.68	.32	.0064	
Do.	H-4	.68	.40	.0064	
Average...		.70	.37	.0056	16.84
Tangential..	HT-1	.70	.51	.0088	
Do.	HT-2	.75	.48	.0064	
Do.	HT-3	.73	.51	.0066	
Do.	HT-4	.70	.62	.0098	
Average...		.72	.53	.0079	21.13
Radial......	HR-1	.72	.56	.0090	
Do.	HR-2	.78	.54	.0072	
Do.	HR-3	.71	.66	.0110	
Do.	HR-4	.75	.58	.0078	
Average...		.74	.58	.0088	19.05
		Beech (Fagus grandifolia) (Average moisture content 9.8 percent)			
End grain...	Be-1	.59	.40	.0081	
Do.	Be-2	.59	.43	.0085	
Do.	Be-3	.60	.43	.0078	
Do.	Be-4	.60	.45	.0076	
Average...		.59	.43	.0080	4.90
Tangential..	BeT-1	.62	1.08	.0178	
Do.	BeT-2	.61	.95	.0153	
Do.	BeT-3	.63	1.40	.0201	
Do.	BeT-4	.66	1.97	.0265	
Average...		.63	1.35	.0199	24.13
Radial......	BeR-1	.61	1.72	.0272	
Do.	BeR-2	.62	1.76	.0271	
Do.	BeR-3	.63	1.65	.0249	
Do.	BeR-4	.61	1.75	.0281	
Average...		.62	1.72	.0268	5.07

(Sheet 3 of 11 sheets)
Continued

Table 1.--Navy-machine wear data for 15 species of wood based on 1,000 revolutions of the abrading disk (continued)

Surface abraded	Specimen	Specific gravity[1]	Loss in weight	Average wear	Coefficient of variation (wear)
(1)	(2)	(3)	(4)	(5)	(6)
	Number		Grams	Inch	Percent
		Khaya (*Khaya* sp.) (Average moisture content 11.2 percent)			
End grain...	AM-1	0.42	0.78	0.0202	
Do.	AM-2	.42	.80	.0216	
Do.	AM-3	.41	.72	.0204	
Do.	AM-4	.41	.71	.0226	
Average...		.42	.75	.0212	5.28
Tangential[2]	AMT-1	.40	3.50	.0782	
Do.	AMT-2	.41	3.50	.0776	
Do.	AMT-3	.40	3.12	.0708	
Do.	AMT-4	.42	3.06	.0604	
Average...		.41	3.30	.0718	11.53
Radial[2].....	AMR-1	.42	3.26	.0716	
Do.	AMR-2	.41	3.36	.0746	
Do.	AMR-3	.42	3.14	.0700	
Do.	AMR-4	.41	3.28	.0716	
Average...		.42	3.26	.0720	2.67
		Teak (*Tectona grandis*) (Average moisture content 9.0 percent)			
End grain...	T-1	.56	1.15	.0251	
Do.	T-2	.56	1.15	.0241	
Do.	T-3	.57	1.15	.0246	
Do.	T-4	.57	1.15	.0242	
Average...		.56	1.15	.0245	1.86
Tangential[2].	TT-1	.58	4.10	.0694	
Do.	TT-2	.57	4.08	.0672	
Do.	TT-3	.57	3.96	.0632	
Do.	TT-4	.55	3.98	.0668	
Average...		.57	4.02	.0666	3.86
Radial[2].....	TR-1	.58	4.88	.0782	
Do.	TR-2	.56	5.04	.0842	
Do.	TR-3	.56	5.10	.0854	
Do.	TR-4	.56	5.00	.0830	
Average...		.56	5.00	.0828	3.81

Table 1.--Navy-machine wear data for 15 species of wood, based on 1,000 revolutions of the abrading disk (continued)

Surface abraded	Specimen	Specific gravity[1]	Loss in weight	Average wear	Coefficient of variation (wear)
(1)	(2)	(3)	(4)	(5)	(6)
	Number		Grams	Inch	Percent
		Yellow poplar (Liriodendron tulipifera) (Average moisture content 9.9 percent)			
End grain...	P-1	0.46	0.33	0.0137	
Do.	P-2	.46	.37	.0136	
Do.	P-3	.47	.36	.0148	
Do.	P-4	.47	.34	.0146	
Average...		.46	.35	.0142	4.32
Tangential[2]	PT-1	.45	2.34	.0456	
Do.	PT-2	.42	3.42	.0778	
Do.	PT-3	.45	2.34	.0440	
Do.	PT-4	.42	2.40	.0456	
Average...		.44	2.62	.0532	30.80
Radial[2].....	PR-1	.45	2.96	.0592	
Do.	PR-2	.46	3.02	.0580	
Do.	PR-3	.44	3.06	.0612	
Do.	PR-4	.44	3.08	.0610	
Average...		.45	3.02	.0598	2.55
		Douglas-fir-1 (Pseudotsuga taxifolia) (Average moisture content 11.9 percent)			
End grain...	DFL-1	.43	.40	.0116	
Do.	DFL-2	.43	.47	.0154	
Do.	DFL-3	.44	.62	.0158	
Do.	DFL-4	.44	.57	.0143	
Average...		.44	.52	.0143	13.24
Tangential[2]	DFLT-1	.46	2.14	.0636	
Do.	DFLT-2	.39	1.92	.0448	
Do.	DFLT-3	.46	1.42	.0440	
Do.	DFLT-4	.41	1.64	.0420	
Average...		.43	1.78	.0486	20.72
Radial[2].....	DFLR-1	.42	1.60	.0332	
Do.	DFLR-2	.42	1.68	.0396	
Do.	DFLR-3	.43	1.60	.0408	
Do.	DFLR-4	.42	1.86	.0456	
Average...		.42	1.68	.0398	12.83

Table 1.--Navy machine wear data for 15 species of wood, based on 1,000 revolutions of the abrading disk (continued)

Surface abraded	Specimen	Specific gravity[1]	Loss in weight	Average wear	Coefficient of variation (wear)
(1)	(2)	(3)	(4)	(5)	(6)
	Number		Grams	Inch	Percent
Douglas-fir-2 (*Pseudotsuga taxifolia*) (Average moisture content 11.8 percent)					
End grain...	DFM-1	0.48	0.62	0.0128	
Do.	DFM-2	.48	.64	.0144	
Do.	DFM-3	.50	.52	.0118	
Do.	DFM-4	.50	.48	.0138	
Average...		.49	.56	.0132	8.66
Tangential..	DFMT-1	.50	.94	.0180	
Do.	DFMT-2	.49	1.64	.0350	
Do.	DFMT-3	.49	.85	.0152	
Do.	DFMT-4	.49	1.37	.0254	
Average...		.49	1.20	.0234	37.82
Radial......	DFMR-1	.48	1.56	.0308	
Do.	DFMR-2	.49	1.57	.0300	
Do.	DFMR-3	.48	1.52	.0302	
Do.	DFMR-4	.49	1.55	.0294	
Average...		.48	1.55	.0301	1.92
Douglas-fir-3 (*Pseudotsuga taxifolia*) (Average moisture content 11.4 percent)					
End grain...	DFH-1	.51	.52	.0160	
Do.	DFH-2	.51	.52	.0124	
Do.	DFH-3	.50	.47	.0150	
Do.	DFH-4	.50	.50	.0140	
Average...		.50	.50	.0144	10.66
Tangential[2]	DFHT-1	.52	1.18	.0184	
Do.	DFHT-2	.49	1.46	.0304	
Do.	DFHT-3	.51	2.14	.0412	
Do.	DFHT-4	.50	1.14	.0232	
Average...		.50	1.48	.0284	34.91
Radial[2]	DFHR-1	.49	2.20	.0452	
Do.	DFHR-2	.49	2.04	.0436	
Do.	DFHR-3	.48	2.16	.0440	
Do.	DFHR-4	.50	2.16	.0416	
Average		.49	2.14	.0436	3.43

Table 1.--Navy machine wear data for 15 species of wood, based on 1,000 revolutions of the abrading disk (continued)

Surface abraded	Specimen	Specific gravity[1]	Loss in weight	Average wear	Coefficient of variation (wear)
(1)	(2)	(3)	(4)	(5)	(6)
	Number		Grams	Inch	Percent
		Southern yellow pine-1 (Pinus sp.) (Average moisture content 12.4 percent)			
End grain...	SPL-1	0.66	0.76	0.0132	
Do.	SPL-2	.66	.76	.0146	
Do.	SPL-3	.60	.73	.0122	
Do.	SPL-4	.60	.59	.0124	
Average...		.63	.71	.0131	8.31
Tangential	SPLT-1	.64	2.31	.0300	
Do.	SPLT-2	.62	2.06	.0365	
Do.	SPLT-3	.63	2.20	.0270	
Do.	SPLT-4	.63	2.09	.0315	
Average...		.63	2.16	.0312	12.72
Radial......	SPLR-1	.62	2.18	.0331	
Do.	SPLR-2	.68	2.16	.0285	
Do.	SPLR-3	.62	2.25	.0334	
Do.	SPLR-4	.68	2.09	.0293	
Average...		.65	2.17	.0311	8.15
		Southern yellow pine-2 (Pinus sp.) (Average moisture content 12.7 percent)			
End grain...	SPM-1	.58	.72	.0126	
Do.	SPM-2	.58	.75	.0140	
Do.	SPM-3	.59	.75	.0126	
Do.	SPM-4	.59	.63	.0121	
Average...		.58	.71	.0128	6.39
Tangential..	SPMT-1	.59	1.64	.0241	
Do.	SPMT-2	.63	1.33	.0158	
Do.	SPMT-3	.58	1.55	.0224	
Do.	SPMT-4	.62	1.17	.0197	
Average...		.60	1.42	.0205	17.65
Radial......	SPMR-1	.60	1.88	.0298	
Do.	SPMR-2	.59	1.80	.0282	
Do.	SPMR-3	.62	1.91	.0294	
Do.	SPMR-4	.58	1.96	.0340	
Average...		.60	1.89	.0304	8.31

Table 1.--Navy-machine wear data for 15 species of wood, based on 1,000 revolutions of the abrading disk (continued)

Surface abraded	Specimen	Specific gravity[1]	Loss in weight	Average wear	Coefficient of variation (wear)
(1)	(2)	(3)	(4)	(5)	(6)
	Number		Grams	Inch	Percent
		Southern yellow pine-3 (*Pinus sp.*) (Average moisture content 12.5 percent)			
End grain...	SPH-1	0.62	0.56	0.0088	
Do.	SPH-2	.62	.50	.0072	
Do.	SPH-3	.62	.44	.0092	
Do.	SPH-4	.62	.48	.0102	
Average...		.62	.50	.0088	14.18
Tangential..	SPHT-1	.62	1.81	.0223	
Do.	SPHT-2	.63	1.58	.0178	
Do.	SPHT-3	.63	1.66	.0200	
Do.	SPHT-4	.62	1.54	.0172	
Average...		.62	1.65	.0193	12.02
Radial......	SPHR-1	.61	1.32	.0209	
Do.	SPHR-2	.61	1.21	.0186	
Do.	SPHR-3	.61	1.35	.0200	
Do.	SPHR-4	.61	1.35	.0194	
Average		.61	1.31	.0197	4.93
		Sitka spruce-1 (*Picea sitchensis*) (Average moisture content 11.6 percent)			
End grain...	SL-1	.33	.38	.0174	
Do.	SL-2	.33	.38	.0167	
Do.	SL-3	.32	.34	.0163	
Do.	SL-4	.32	.31	.0164	
Average...		.32	.35	.0167	2.98
Tangential[2]	SLT-1	.32	.96	.0318	
Do.	SLT-2	.36	.72	.0208	
Do.	SLT-3	.33	1.06	.0358	
Do.	SLT-4	.36	.96	.0318	
Average...		.34	.92	.0300	21.50
Radial[2]	SLR-1	.32	1.44	.0384	
Do.	SLR-2	.38	1.26	.0304	
Do.	SLR-3	.33	1.36	.0378	
Do.	SLR-4	.36	1.28	.0320	
Average...		.35	1.34	.0346	11.69

Table 1.--Navy-machine wear data for 15 species of wood, based on 1,000 revolutions of the abrading disk (continued)

Surface abraded	Specimen	Specific gravity[1]	Loss in weight	Average wear	Coefficient of variation (wear)
(1)	(2)	(3)	(4)	(5)	(6)
	Number		Grams	Inch	Percent
		Sitka spruce-2 (*Picea sitchensis*) (Average moisture content 11.5 percent)			
End grain...	SM-1	0.41	0.28	0.0106	
Do.	SM-2	.41	.30	.0123	
Do.	SM-3	.39	.28	.0129	
Do.	SM-4	.39	.27	.0120	
Average...		.40	.28	.0120	8.12
Tangential[2]	SMT-1	.42	1.70	.0424	
Do.	SMT-2	.38	1.34	.0336	
Do.	SMT-3	.42	1.24	.0270	
Do.	SMT-4	.37	1.36	.0352	
Average		.40	1.40	.0346	18.27
Radial[2]	SMR-1	.39	1.62	.0378	
Do.	SMR-2	.39	1.68	.0386	
Do.	SMR-3	.38	1.70	.0414	
Do.	SMR-4	.40	1.64	.0380	
Average		.39	1.66	.0390	4.28
		Sitka spruce-3 (*Picea sitchensis*) (Average moisture content 11.6 percent)			
End grain...	SH-1	.40	.28	.0112	
Do.	SH-2	.40	.27	.0111	
Do.	SH-3	.40	.26	.0124	
Do.	SH-4	.40	.27	.0115	
Average...		.40	.27	.0116	5.10
Tangential[2]	SHT-1	.40	1.68	.0376	
Do.	SHT-2	.39	1.82	.0462	
Do.	SHT-3	.40	1.78	.0346	
Do.	SHT-4	.39	1.56	.0360	
Average...		.40	1.70	.0386	13.51
Radial[2]	SHR-1	.41	1.98	.0450	
Do.	SHR-2	.40	2.04	.0478	
Do.	SHR-3	.40	1.94	.0438	
Do.	SHR-4	.40	2.00	.0456	
Average...		.40	1.98	.0456	3.68

(Sheet 9 of 11 sheets)
Continued

Table 1.--Navy-machine wear data for 15 species of wood, based on 1,000 revolutions of the abrading disk (continued)

Surface abraded	Specimen	Specific gravity[1]	Loss in weight	Average wear	Coefficient of variation (wear)
(1)	(2)	(3)	(4)	(5)	(6)
	Number		Gram	Inch	Percent
		Redwood (Sequoia sempervirens) (Average moisture content 11.4 percent)			
End grain...	R-1	0.33	0.75	0.0238	
Do.	R-2	.33	.76	.0265	
Do.	R-3	.31	.86	.0296	
Do.	R-4	.31	.83	.0293	
Average...		.32	.80	.0273	9.96
Tangential[2]	RT-1	.31	3.94	.1142	
Do.	RT-2	.33	3.86	.1104	
Do.	RT-3	.30	4.12	.1296	
Do.	RT-4	.32	4.46	.1292	
Average		.32	4.10	.1208	8.27
Radial[2]	RR-1	.32	5.14	.1446	
Do.	RR-2	.32	5.22	.1512	
Do.	RR-3	.31	5.34	.1588	
Do.	RR-4	.31	5.52	.1630	
Average...		.32	5.30	.1544	5.28
		White pine (Pinus strobus) (Average moisture content (9.3 percent)			
End grain...	WP-1	.38	1.52	.0372	
Do.	WP-2	.38	1.53	.0388	
Do.	WP-3	.38	1.57	.0392	
Do.	WP-4	.38	1.61	.0394	
Average...		.38	1.56	.0386	2.59
Tangential[2]	WPT-1	.39	4.48	.1088	
Do.	WPT-2	.40	4.28	.0996	
Do.	WPT-3	.38	5.00	.1240	
Do.	WPT-4	.37	5.42	.1352	
Average		.38	4.79	.1168	13.54
Radial[2]	WPR-1	.39	5.50	.1336	
Do.	WPR-2	.39	5.52	.1340	
Do.	WPR-3	.38	6.76	.1660	
Do.	WPR-4	.38	6.38	.1572	
Average		.38	6.04	.1476	11.14

Table 1.--Navy-machine wear data for 15 species of wood, based on 1,000 revolutions of the abrading disk (continued)

Surface abraded	Specimen	Specific gravity[1]	Loss in weight	Average wear	Coefficient of variation (wear)
(1)	(2)	(3)	(4)	(5)	(6)
	Number		Gram	Inch	Percent
		Baldcypress (*Taxodium distichum*) (Average moisture content 11.5 percent)			
End grain...	C-1	0.41	1.33	0.0308	
Do.	C-2	.41	1.32	.0322	
Do.	C-3	.40	1.24	.0311	
Do.	C-4	.40	1.25	.0297	
Average...		.40	1.28	.0310	3.32
Tangential[2]	CT-1	.42	2.34	.0548	
Do.	CT-2	.39	2.60	.0626	
Do.	CT-3	.42	2.26	.0518	
Do.	CT-4	.39	2.42	.0602	
Average		.40	2.40	.0574	8.59
Radial[2]	CR-1	.41	2.66	.0598	
Do.	CR-2	.40	2.36	.0540	
Do.	CR-3	.41	2.38	.0548	
Do.	CR-4	.40	2.52	.0564	
Average...		.40	2.48	.0562	4.57

[1]Based on weight when oven-dry and volume when tested. Oven-dry weights were computed from weights when tested and from a moisture determination of specimens G1 and G2 (fig. 1).

[2]These specimens were not abraded behond 500 revolutions. Actual test values were doubled to provide the comparative values listed at 1,000 revolutions.

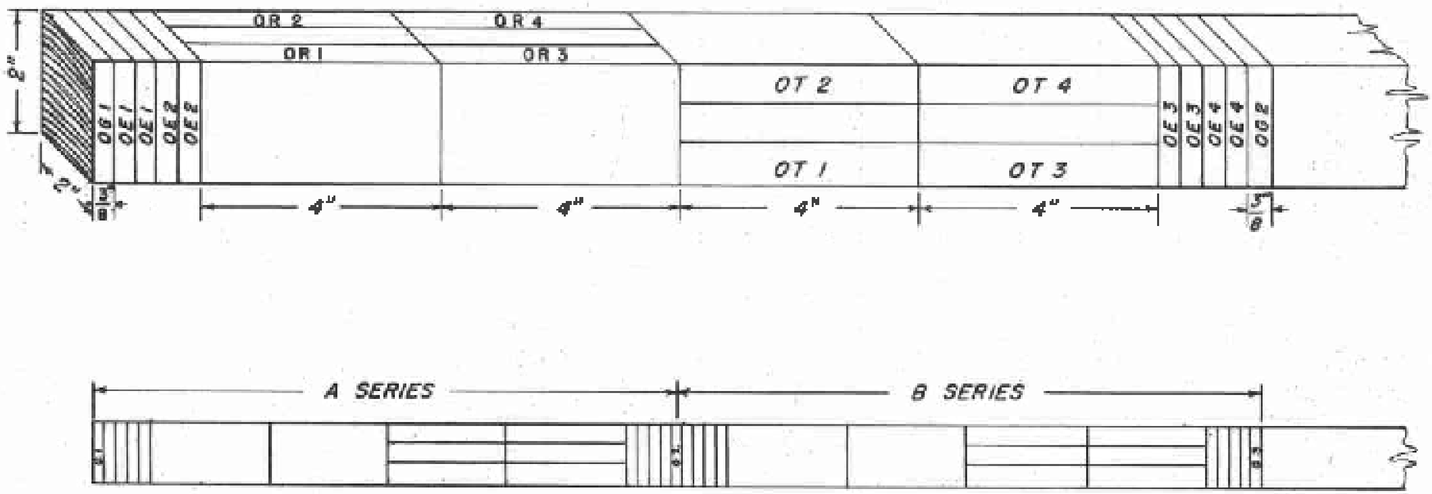
(Sheet 11 of 11)
Concluded

Table 2.--Relative order of average wear resistance and specific gravity among 15 species of normal wood

Species[1]	Sample	Tangential (flat grain) surface		Radial (edge grain) surface		End grain surface		Average specific gravity of end grain specimens	
		Wear in 1,000 revolutions	Relative order of wear resistance	Wear in 1,000 revolutions	Relative order of wear resistance	Wear in 1,000 revolutions	Relative order of wear resistance	Specific gravity	Relative order
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Number	Inch		Inch		Inch			
Hickory	1	0.0079	1	0.0088	1	0.0056	1	0.704	1
Hard maple	1	.0090	2	.0116	2	.0066	2	.632	5
White ash	1	.0127	3	.0183	3	.0085	4	.633	4
White oak	1	.0166	4	.0183	4	.0097	7	.646	2
Southern yellow pine	3	.0193	5	.0197	5	.0088	5	.619	6
Beech	1	.0199	6	.0268	7	.0080	3	.597	7
Southern yellow pine	2	.0205	7	.0304	9	.0128	10	.589	8
Douglas-fir	2	.0234	8	.0301	8	.0132	12	.490	12
Yellow birch	1	.0254	9	.0229	6	.0088	6	.574	9
Douglas-fir	3	.0284	10	.0436	14	.0144	15	.502	11
Sitka spruce	1	.0300	11	.0346	11	.0167	16	.328	20
Southern yellow pine	1	.0312	12	.0311	10	.0131	11	.634	3
Sitka spruce	2	.0346	13	.0390	12	.0120	9	.400	17
Sitka spruce	3	.0386	14	.0456	15	.0116	8	.395	18
Douglas-fir	1	.0486	15	.0398	13	.0143	14	.434	14
Yellow-poplar	1	.0532	16	.0598	17	.0142	13	.464	13
Baldcypress	1	.0574	17	.0562	16	.0310	20	.404	16
Teak	1	.0666	18	.0828	19	.0245	18	.566	10
Khaya	1	.0718	19	.0720	18	.0212	17	.416	15
White pine	1	.1168	20	.1476	20	.0386	21	.384	19
Redwood	1	.1208	21	.1544	21	.0273	19	.318	21

[1]Order of species based on average resistance to tangential wear.

CUTTING DIAGRAM



MARKING KEY

SPECIES - O=OAK; A=ASH; ETC.
RADIAL (EDGE-GRAIN) SPECIMENS - R
END-GRAIN SPECIMENS - E
TANGENTIAL (FLAT-GRAIN) SPECIMENS - T
SPECIFIC GRAVITY SPECIMENS - G

Figure 1.--Cutting method used to obtain matched abrasion and specific gravity specimens.

Z M 78836 F

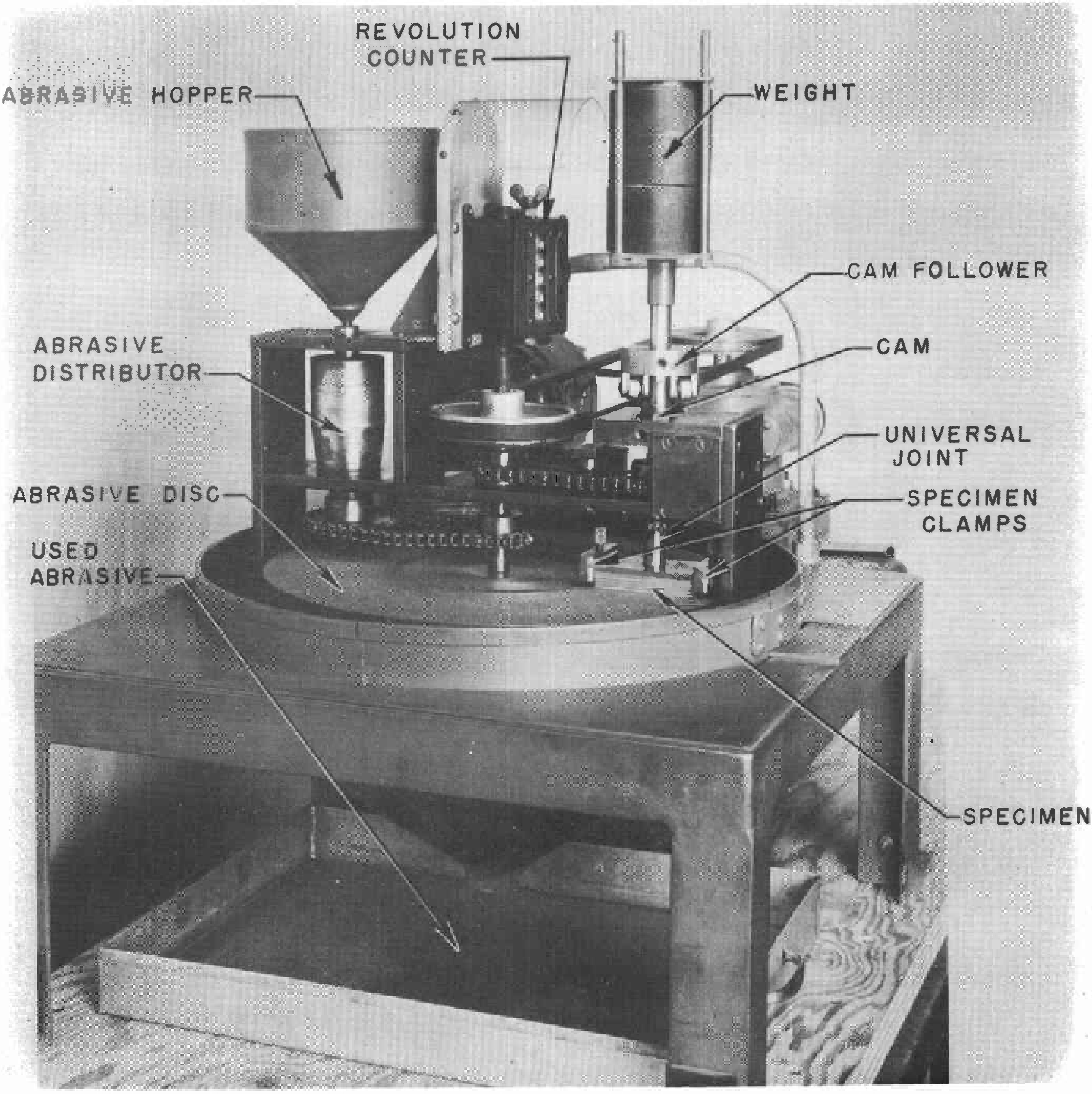


Figure 2.--Wear-test machine built in accordance with Navy plans and specification.

Z M 78949 F

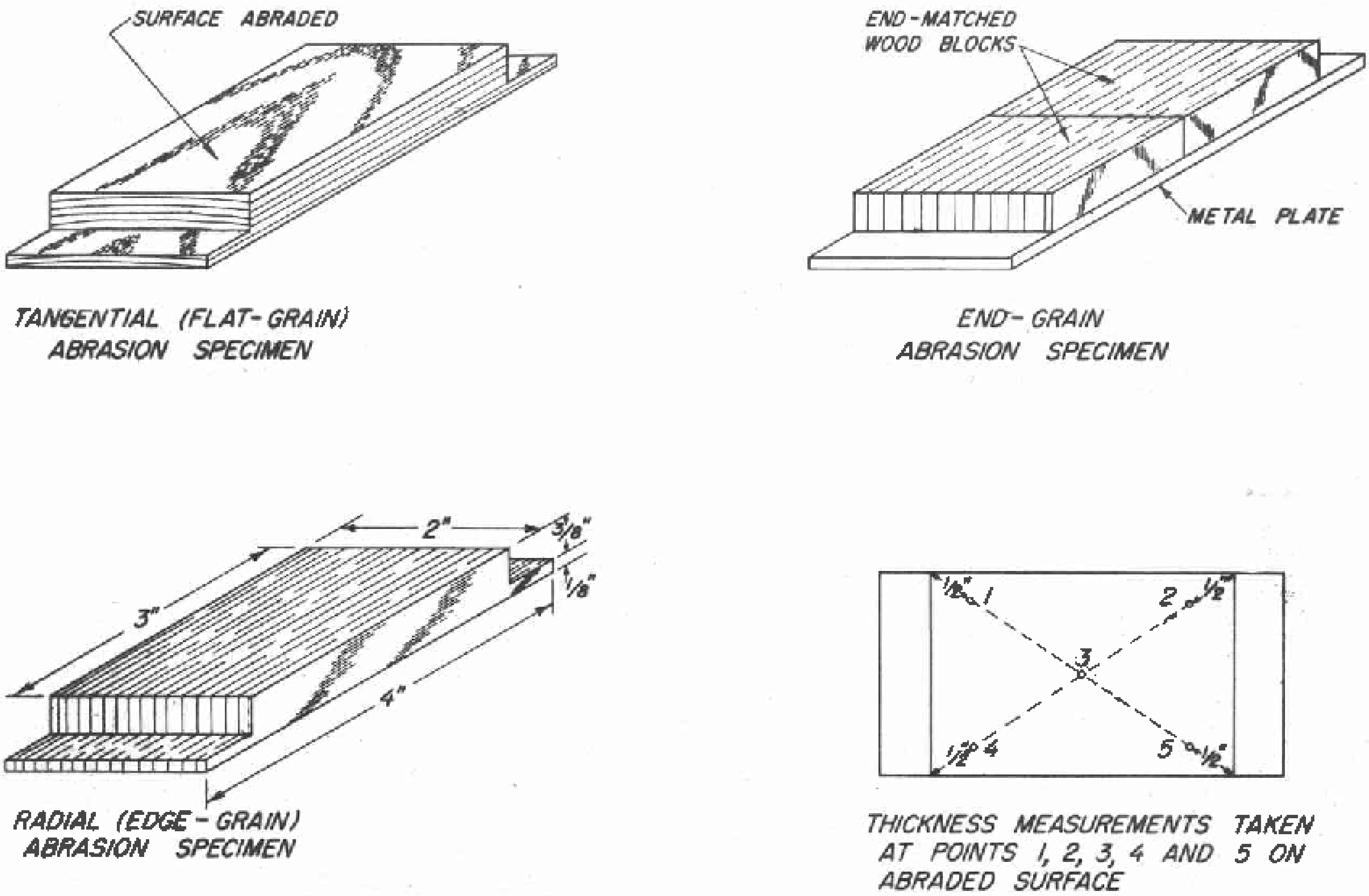


Figure 3.--Details of matched tangential, radial, and end-grain types of abrasion specimens. Abrasive wear was determined by successive thickness measurements at the points indicated.

Z M 78835 F

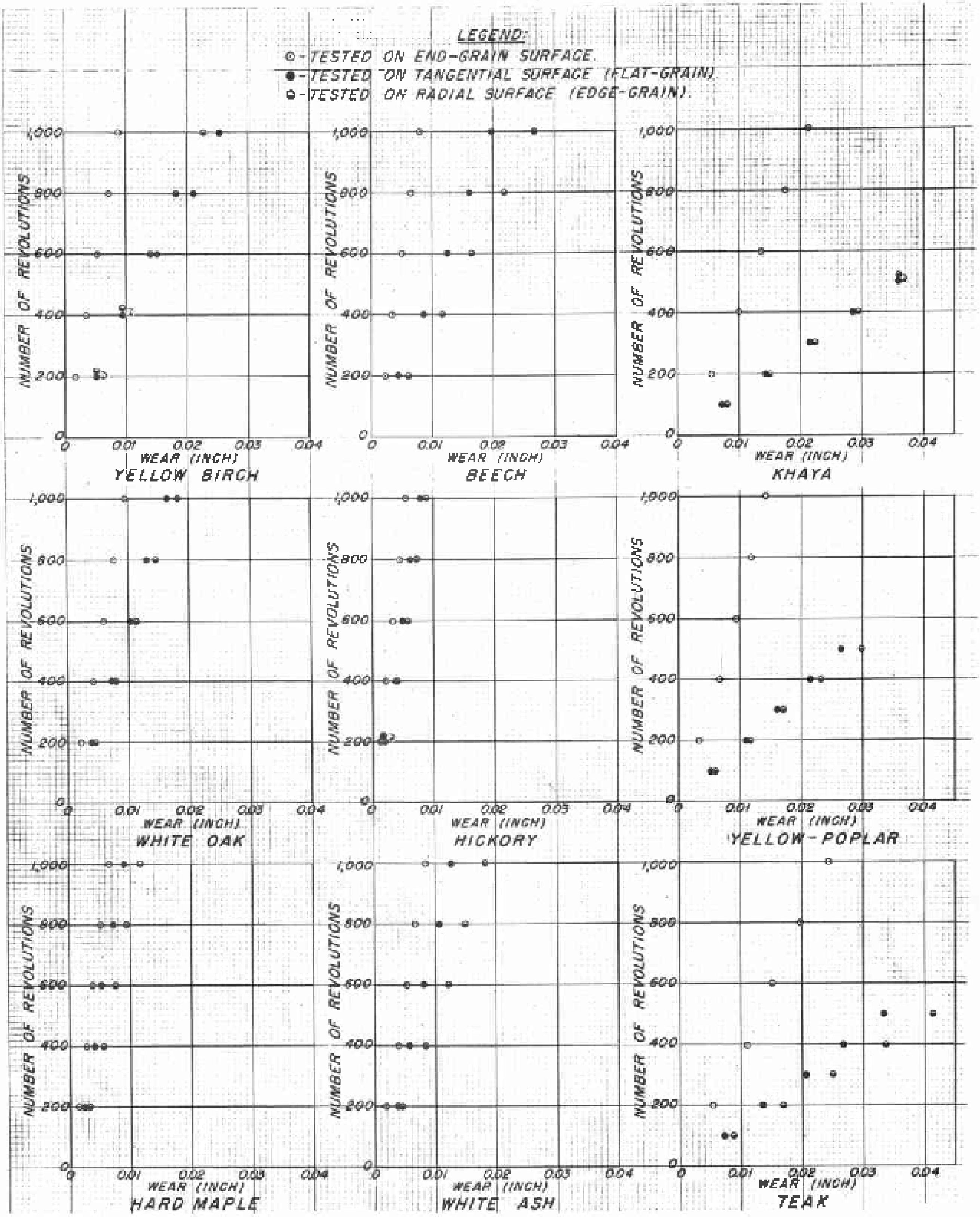


Figure 4.--Amount of abrasive wear for various hardwoods as related to number of revolutions of abrading disk. Each plotted point represents the average of four individual tests of matched specimens.

Z M 78839 F

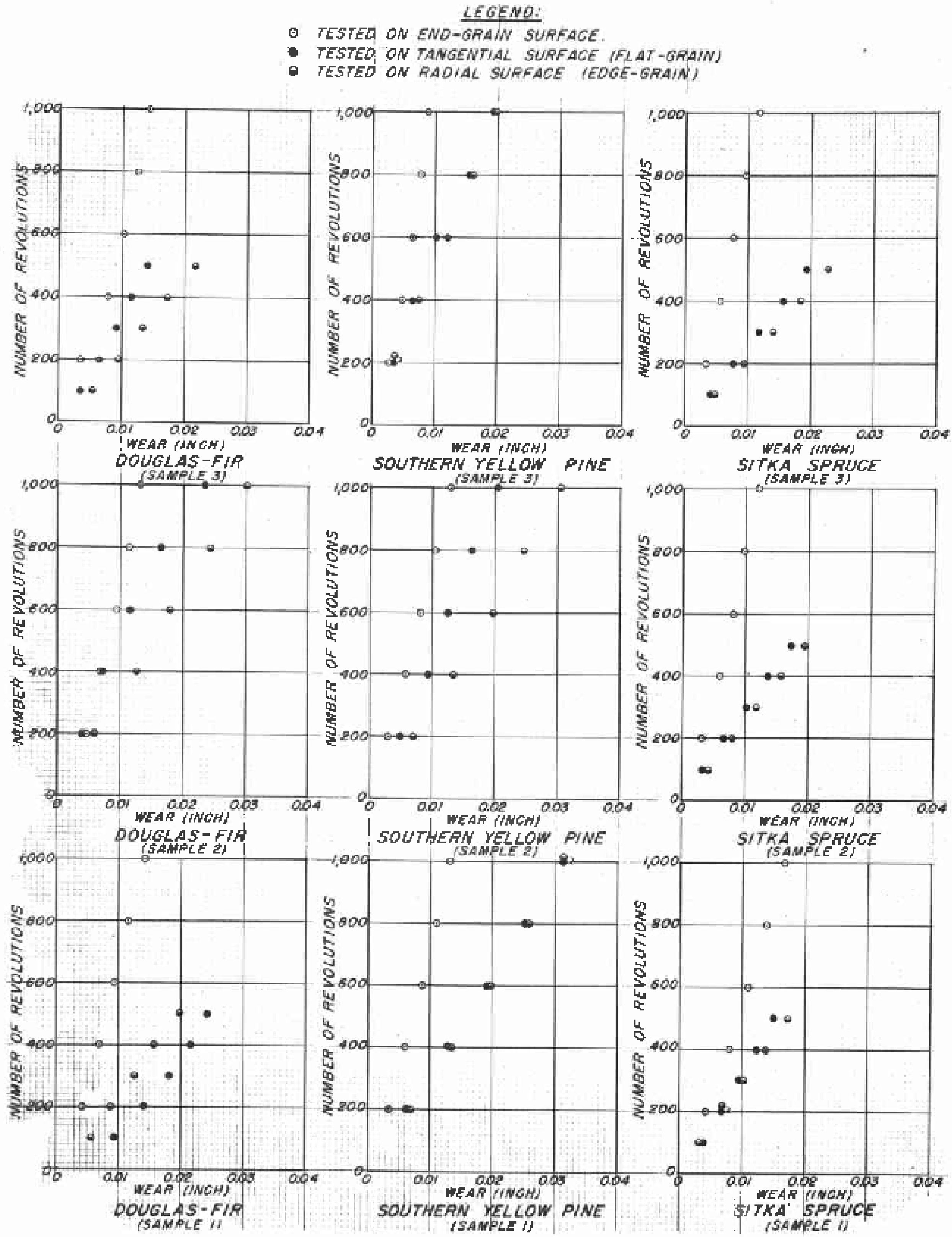


Figure 5.--Amount of abrasive wear as related to number of revolutions of abrading disk for three samples each of Douglas-fir, southern yellow pine, and Sitka spruce. Samples represent different trees. Each plotted point represents the average of four individual tests of closely matched specimens.

Z M 78839 F

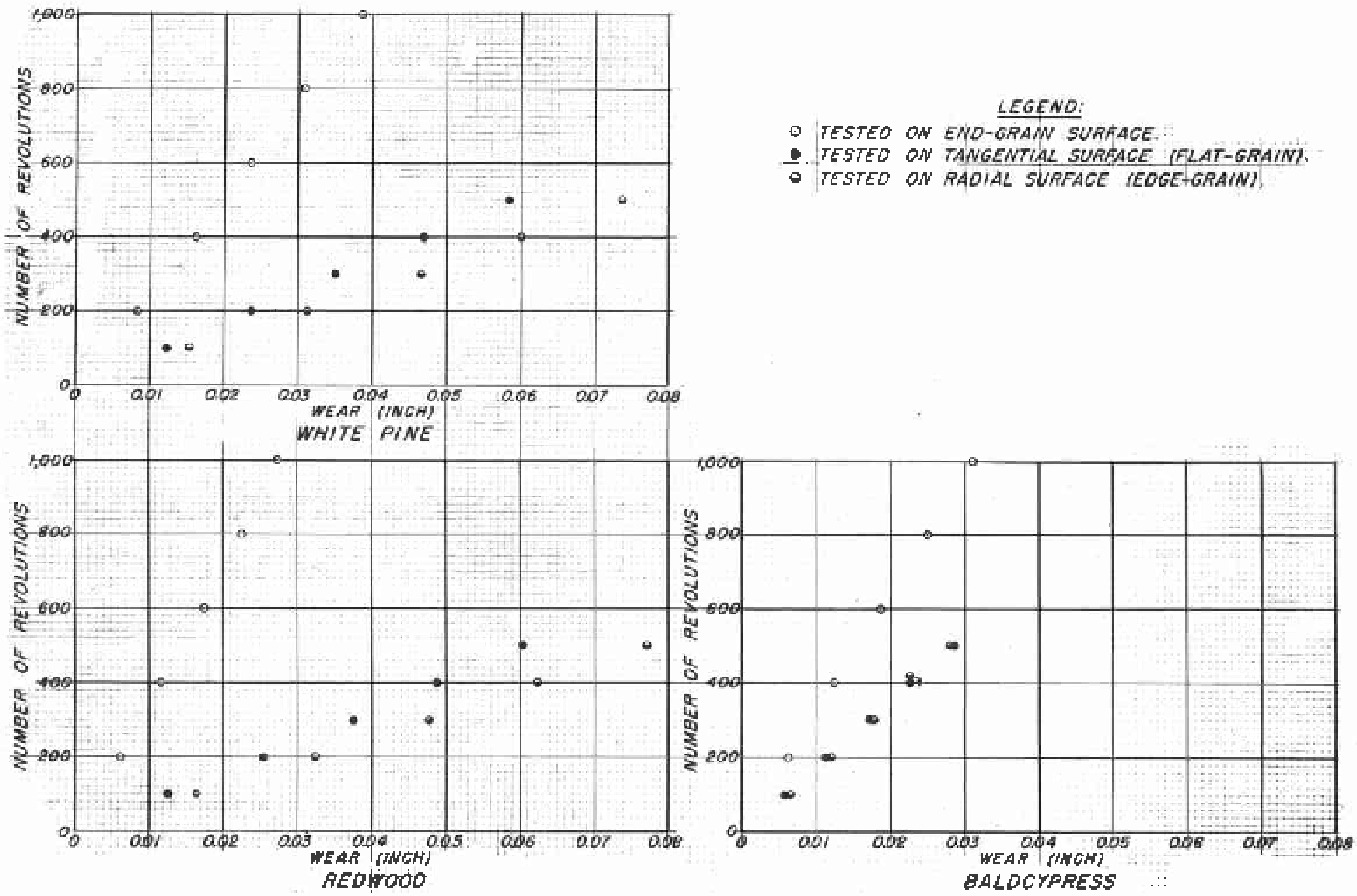


Figure 6.--Amount of abrasive wear as related to number of revolutions of abrading disk for white pine, redwood, and baldcypress. Each plotted point represents the average of four individual tests of matched specimens.

Z M 78840 F

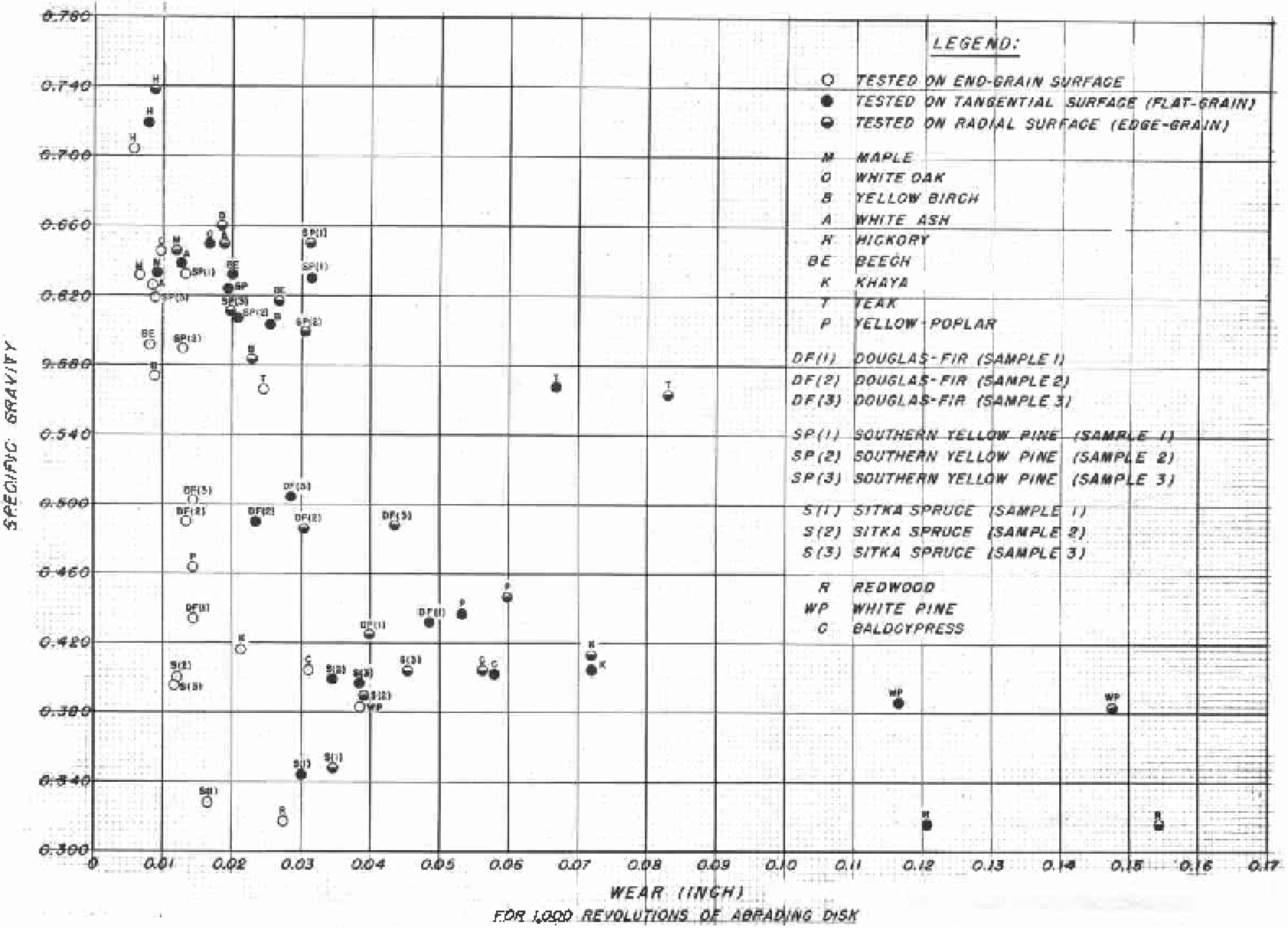


Figure 7.--Relationship between amount of wear at 1,000 revolutions of abrading disk and specific gravity. Each plotted point represents the average of four tests of matched specimens.

Z M 78837 F

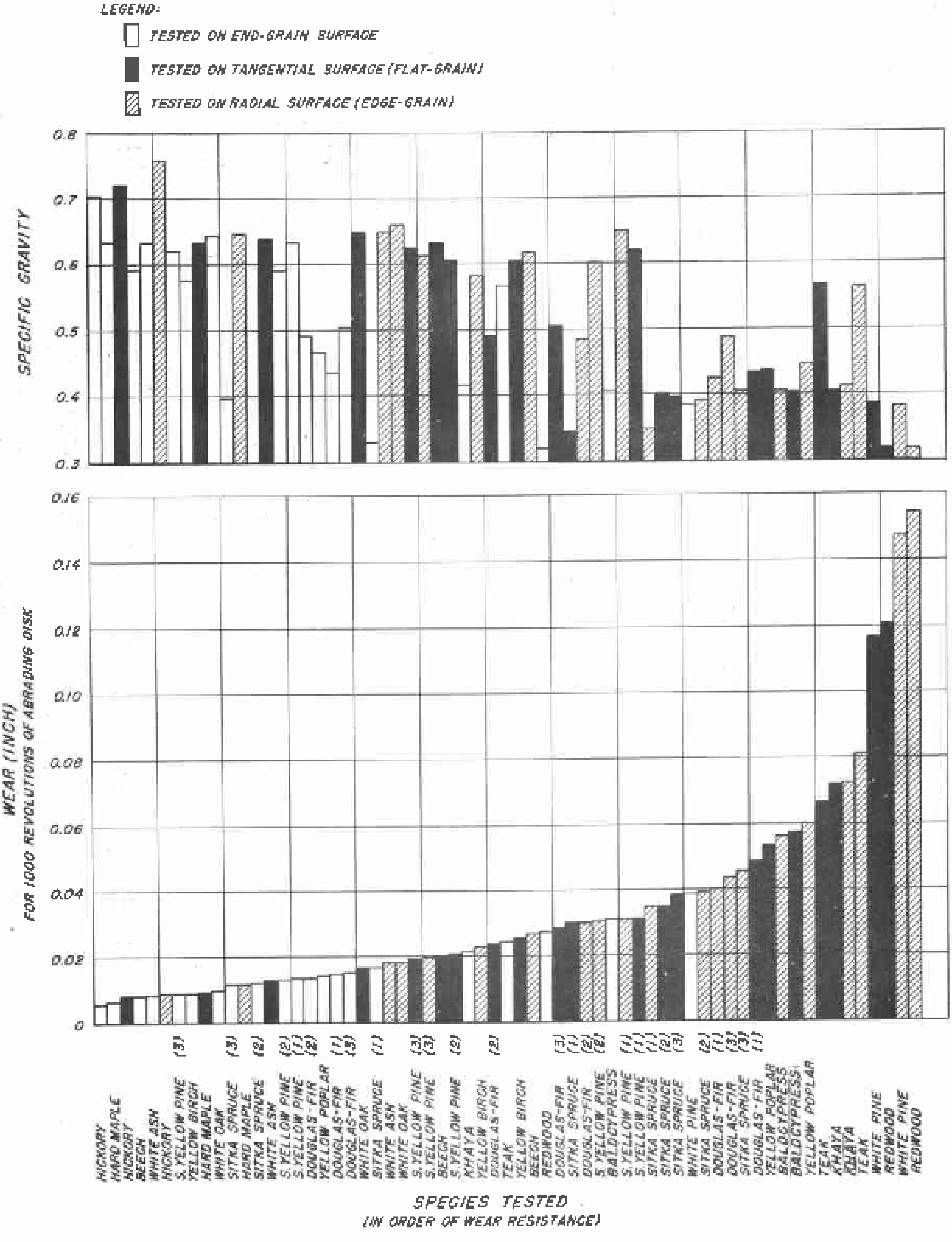


Figure 8.--Bar chart showing order of wear resistance of all species tested as determined by the amount of wear at 1,000 revolutions of the abrading disk. The average specific gravity of each species is shown directly above. Each bar represents the average of four tests of closely matched specimens.

Z M 78841 F