U.S. Department of Commerce, Bureau of Standards

RESEARCH PAPER RP640

Part of Bureau of Standards Journal of Research, Vol. 12, February 1934

WEAR OF CARPETS

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ABSTRACT

The nature of the wear on the wool fibers was studied microscopically. The wool fibers from a worn carpet are frayed at the tips and spindle-shaped fibrils whose dimensions correspond to cortical cells are worn off. Some of the fibers are fractured, others are broken off near the base by the repeated bending and compression. The carpet wear test furnishes a new and easy means of obtaining and isolating the cortical cells of the wool fiber.

A wear index which is applicable to all ordinary kinds and qualities of pile carpets and which is believed to give a good representation of their relative durability in service has been selected and used in this paper.

The effect of the quality of pile wool, height of pile, density of pile, type of pile anchorage, and carpet underlays on the durability was studied. The density of the pile appears to be the predominant factor of a carpet which affects wear. The height of pile is a factor of lesser importance. The quality of pile wool has a measurable effect. The types of pile anchorage studied have no appreciable effect. In general, the wear index is approximately proportional to the product of pile density squared and pile height.

All underlays increased the durability of the carpets. The increase in wear index depends upon the underlay and the carpet. The composition, thickness, density, and compressibility of underlays are factors which contribute to their effectiveness. An underlay appears to be more effective when it is used with carpets of short pile than when it is used with carpets of long pile.

CONTENTS

I. INTRODUCTION

Since the publication of Research Paper No. 315 describing a "Carpet Wear Testing Machine", [1] numerous tests of the wear of carpets have been made at the Bureau of Standards. Attention has been given to the nature of the wear on the wool fibers. The effect on the durability of carpets of quality of pile wool, height of the pile, density of the pile, type of pile anchorage, and the effect of carpet underlays have been studied.[2] The results obtained indicate that

[1] Schiefer, H. F. and Best, A. S., Carpet Wear Testing Machine, B.S. Jour. Research, vol. 6 (RP315) pp. 927-936, June 1931.

[2] By "pile" is meant the face or nap of the carpet. See figure 9. By "underlay" is meant the layer of material which is frequently placed underneath the carpet to reduce slipping on the floor and to increase the softness and durability.

the wear produced by the machine is similar to that produced in service and they indicate a direct correlation between serviceability and the machine wear index.

The results should be of interest to both manufacturer and user of carpets because they suggest, on the one hand, ways to improve carpets to meet the varying requirements of the customers, and on the other, a basis for the selection of carpets with reference to relative durability.

II. TEST PROCEDURE

The testing machine is shown in figure 1. A circular sample of the carpet to be tested is fastened to a turntable which is brought to bear against two leather-covered pulleys. One of the pulleys is driven by a motor and in turn drives the turntable. The other pulley is used as a brake to produce slipping of both pulleys on the carpet as it rotates. A vacuum cleaner removes the material which is worn off. The wear is evaluated by measuring the change in thickness of the pile as the test proceeds.

The tests were made under the following conditions:

Downward force at each pulley	135 lb.
Brake load	15 lb.
Speed of turntable	80 rpm.
Relative humidity	65 percent.
Temperature	70 F.

Thicknesses were measured with the gage shown in figure 2, having a circular foot 1 inch in diameter and exerting a pressure of 0.75 lb/sq in. The total thickness of the carpet was determined before wear and at intervals during the test. The measurements were made at 8 points spaced 45° apart on the circular worn portion of the carpet and the results averaged. The thickness of the backing of the carpet was determined by pulling out the pile tufts from a sufficiently large area to permit measurements in several places. The thickness of the pile was then obtained by subtracting the thickness of the backing from the thickness of the carpet. When a carpet was tested with an underlay, the carpet was removed from the testing turntable to another turntable for thickness measurements. The thickness of the underlay was measured while the underlay was still in its undisturbed position on the testing turntable.

A test was discontinued when the pile had been worn down to one fourth of the original pile thickness. Discontinuing the tests at this point protected the leather from rapid deterioration by contact with the coarse backing and kept the surface smooth. Under these conditions the pulleys had to be refaced with new leather at intervals of approximately 1,500,000 revolutions of the turntable.

III. RESULTS

1. WEAR INDEX

The number of thousands of revolutions of the turntable required to wear the pile of a carpet down to one fourth of the original pile thickness was taken as the wear index of the carpet. This index was selected after consideration of other methods of evaluating wear. It has the advantage of being applicable to all ordinary kinds and qualities of pile carpets. The wear indices correlate well with the

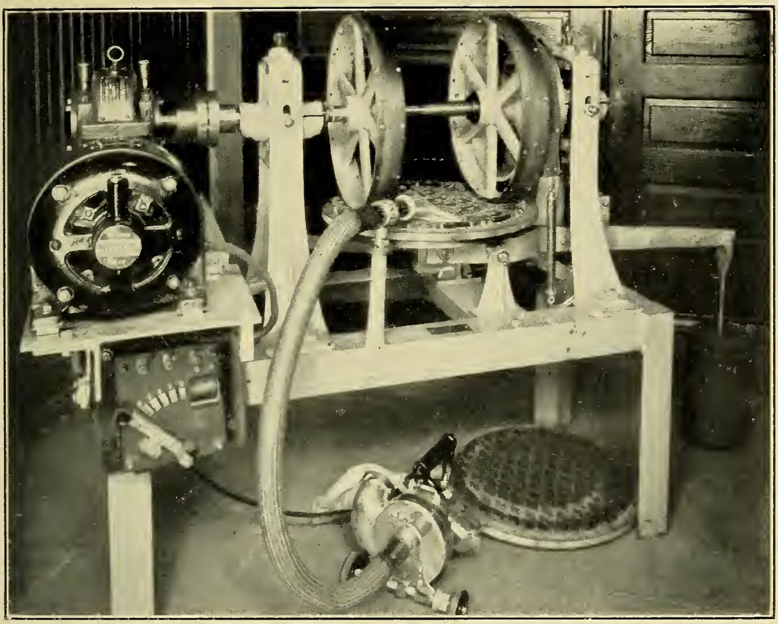

FIGURE 1.—*Carpet wear-testing machine.*

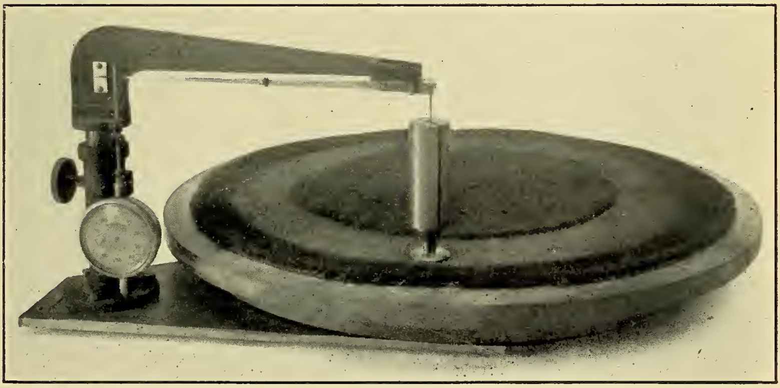

FIGURE 2.—*Gage for measuring thickness of carpet.*

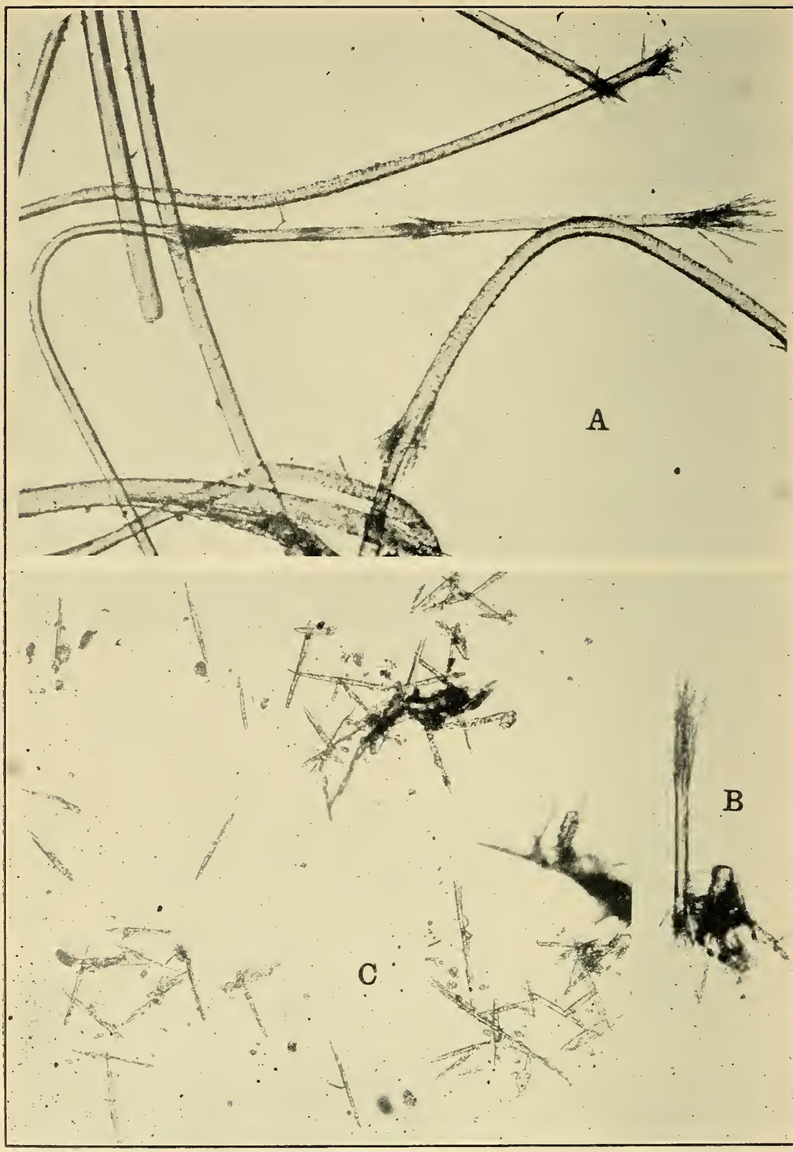

FIGURE 4.—*Nature of accelerated wear on wool fibers.*

A, Wool fibers removed from worn track of carpet. Fibers show characteristic fraying and partial fractures. Magnification about 50.

B, Segment of fractured wool fiber removed from worn track of carpet by vacuum. Segment shows characteristic fraying at both ends. Magnification about 50.

C, Fibrils removed from worn track of carpet by vacuum cleaner. They have the characteristic spindle-shaped appearance of cortical cells of wool fibers and correspond to them in dimensions. Magnification about 200.

available manufacturer's wear indices, which are based upon the reputation of the carpets in service. In figure 3 are plotted the laboratory wear indices of 4 axminster carpets against the manufacturer's wear indices. The linear relationship between the two indices indicates that the laboratory wear index gives a good representation of the relative durability of these carpets in service.

2. WEAR ON FIBERS

The nature of the accelerated wear on the individual fibers is shown in figure 4. Microscopic examination of fibers taken from carpets after several years in service show similar wear. The tips of the fibers are frayed and split. Some of the fibers are fractured in one or more places. The fibrils at the tips and segments of the fibers are broken off during a test.

The splitting off of the fibrils at the tips constitutes a slow process of wear and is probably produced mainly by the slipping action of the machine. The breaking off of the fibers near the anchorage constitutes a rapid process of wear and is probably produced mainly by the bending and compressive actions of the machine. The slight twisting action of the machine contributes to both wearing processes.

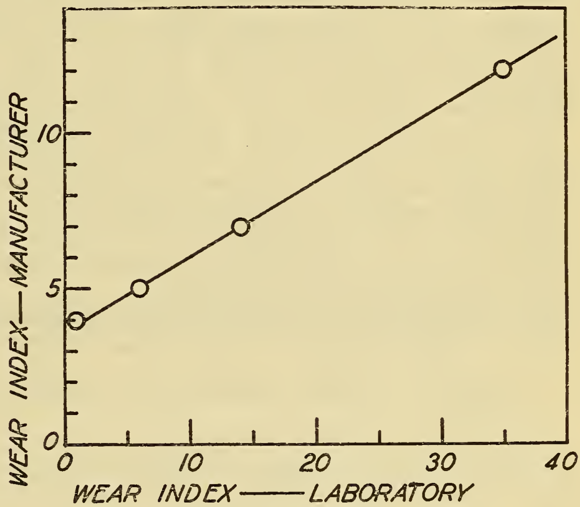

FIGURE 3.—*Correlation between wear indices of 4 axminster carpets based upon laboratory tests and the reputation of the carpets in service.*

The characteristic spindle-shaped appearance of the fibrils shown in figure 4 (*C*) indicates the cellular structure of the wool fiber. The fibrils are arranged with their long axes parallel to the length of the fiber as shown by *A* and *B* of figure 4. The length and maximum thickness of 30 fibrils were measured. The lengths varied from 25 to 58 microns and the maximum thicknesses from 2.5 to 5.0 microns. According to Matthews [3] the lengths of the spindle-shaped cortical cells of wool vary from 36 to 64 microns and the thicknesses from 13 to 17 microns. The dimensions given by Matthews are based upon measurements of cells which were isolated by swelling the wool fiber in an alkali. The swelling takes place mainly in the thickness and little in the length. The amount of swelling of the cells is not known. A determination of it presupposes known values for the dimensions of the cells. It is not surprising therefore, that the thicknesses reported by Matthews are 3 to 5 times those shown in figure 4 (*C*). The close

[3] Textile Fibers, 4th edition, p. 93, 1924.

correspondence in appearance and dimensions identifies the fibrils in figure 4 (*C*) with the cortical cells of the wool.

The carpet wear test furnishes a new and easy means of obtaining and isolating the cortical cells of the wool fiber. This makes it possible to study the behavior of the cortical cells under various conditions. It would be interesting, for example, to determine whether or not the cortical cells aline themselves in a definite fashion when they are suspended in solutions of different pH to which are applied electric or magnetic fields. The method used by Harris [4] in observing the mobility of particles of the wool fiber in the electrophoresis cell could probably be used for such a study.

Gabriel [5] has examined cortical cells of different kinds of wool. He found that the cortical cells of extremely fine Australian Merino fibers were remarkably similar to those of the coarse Lincoln fibers. He noted slight differences in average length, variation from the average, and in general appearance. The cortical cells for his study were obtained by inoculating the fibers with a bacterium isolated from pink rotted wool. The resulting action causes the fibers to disintegrate into free cortical cells after a period of about 10 days.

The wool fiber is known to consist of micelles which are long in comparision to their thickness.[6] They are probably lamellar in shape, their thickness does not exceed 200 angstroms or two millionths of a centimeter, and they are arranged with their axes parallel to the length of the fiber. It is of interest to note that the average maximum thickness of the fibrils shown in figure 4 (*C*) is approximately 160 times the thickness of the micelles.

E. M. Scheid has recently published photographs of worn wool fibers of carpets similar to those shown in figure 4 (*A*).[7]

3. EFFECT OF THE DENSITY AND HEIGHT OF THE PILE [8]

Two series of 12 velvet carpets each were obtained for a study of the effect on the durability of carpets of the density and height of the pile. The two series differed only in the yarn used in the pile. The yarn of series A was stock dyed and the average weight was 0.3 grain per inch length. The yarn of series B was skein dyed and the average weight was 0.28 grain per inch length. The carpets in each series were made in 3 different pile densities by using 3 pitches, namely, 7, 8, and 8.75. Pitch refers to the number of pile tufts per inch of width. The carpets in each series were made in 4 different pile heights for each pitch by varying the height of the wires over which the pile loops are formed before they are cut by withdrawal of the wires. The heights of the wires were 0.114, 0.205, 0.290, and 0.500 inch. The rows, that is, the number of pile loops or wires per inch of length, were kept constant for the two series, namely, at 9 rows per inch.

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[4] The Isoelectric Point of Wool, Milton Harris, B.S. Jour. Research, vol. 8, pp. 779–786, 1932.

[5] The Cortical Cells of Merino, Romeny and Lincoln Wools, M. T. Gabriel, Jour. Textile Institute, vol. 23, no. 8, pp. T171–T176, August 1932.

[6] The Constitution of the Keratin Molecule, Speakman and Hirst, Transaction of the Faraday Society vol. 29, part I, pp. 148–164, January 1933.

[7] Ein neues Schnellverfahren zur Prüfung der Haltbarkeit von Teppichen, E. M. Scheid, Melliand Textilberichte, Band 14, Lieferung 6, Seite 287, Juni 1933.

[8] "Pile height" is the length of the pile tuft projecting above the back. It is measured with a steel scale. "Pile thickness" is the thickness of the pile obtained according to the procedure described under part II. Since the measurements are made under a pressure of 0.75 lb/sq in., pile thickness is less than the pile height. It is used in the evaluation of the durability of the carpet. "Wire height" is a term used by the manufacturer to denote the size of the wire over which the pile loops are formed and is approximately equal to the pile height.

In figure 5 are plotted curves for the series of carpets made from pile yarn A. The thicknesses of the pile are plotted as ordinates

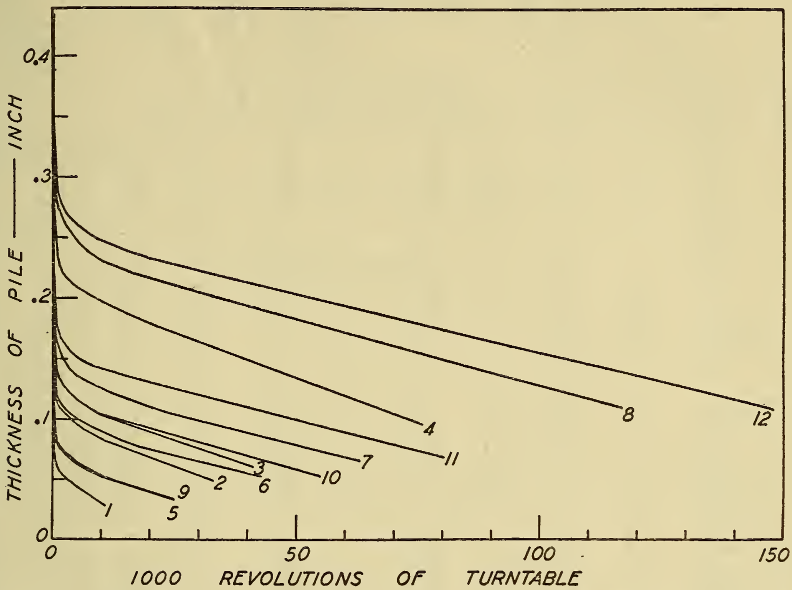

FIGURE 5.—*Curves showing the change in pile thickness with the number of revolutions of the turntable for velvet carpets made from pile yarn A. The numbers are the carpet numbers given in table 1.*

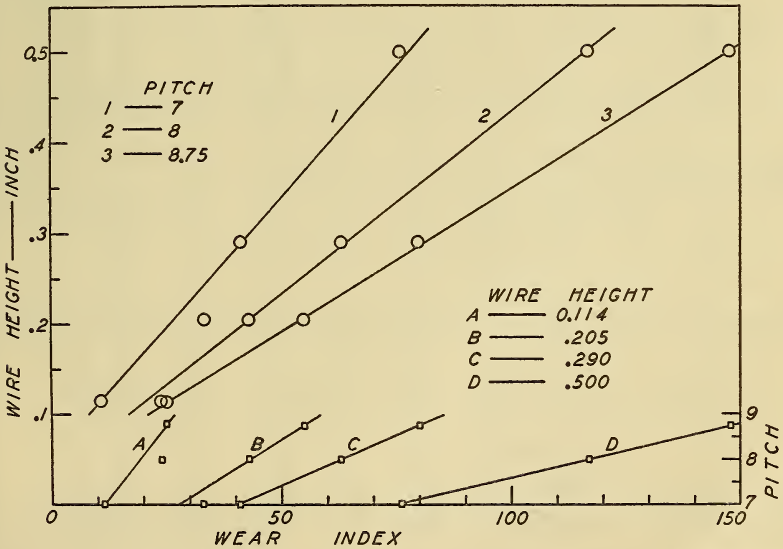

FIGURE 6.—*Correlations of wear index with wire height and pitch for series of velvet carpets made from pile yarn A.*

and the revolutions of the turntable as abscissas. The curves are typical of all of the carpets tested. They show the rate of wear of the pile as judged by change in thickness of the pile.

TABLE 1.—*Analysis of carpets and test results*

No.	Weave	Pile yarn	Rows per inch R	Pitch per inch P	Weight per tuft w	Length of tuft l	Weight of tuft per inch length	Height of pile [1] h	Thickness of pile [2] t	Wear index I	(Density)[2] (Pile height) $4R^2P^2w^2l^{-2}h$
					Grains	*Inches*	*Grains*	*Inch*	*Inch*		
1	Velvet	A	9.3	6.7	0.112	0.38	0.295	0.13	0.115	11	175
2	do	A	9.3	6.7	.173	.56	.309	.23	.194	33	341
3	do	A	9.3	6.7	.211	.69	.306	.27	.238	41	392
4	do	A	9.3	6.7	.329	1.10	.299	.48	.389	76	667
5	do	A	9.3	7.8	.113	.37	.305	.14	.140	24	275
6	do	A	9.3	7.8	.164	.54	.303	.23	.209	43	447
7	do	A	9.3	7.8	.205	.69	.297	.27	.258	63	502
8	do	A	9.3	7.8	.314	1.11	.283	.50	.432	117	844
9	do	A	9.3	8.4	.112	.38	.295	.14	.137	25	297
10	do	A	9.3	8.4	.168	.57	.295	.22	.213	55	468
11	do	A	9.3	8.4	.205	.70	.293	.28	.276	80	588
12	do	A	9.3	8.4	.320	1.10	.291	.49	.436	148	1014
13	do	B	9.3	6.7	.112	.40	.280	.14	.128	9	170
14	do	B	9.3	6.7	.163	.58	.281	.22	.174	18	270
15	do	B	9.3	6.7	.204	.71	.287	.25	.232	30	321
16	do	B	9.3	6.7	.317	1.09	.291	.47	.387	55	617
17	do	B	9.3	7.8	.106	.39	.272	.13	.126	12	202
18	do	B	9.3	7.8	.152	.56	.271	.22	.187	38	341
19	do	B	9.3	7.8	.189	.69	.274	.27	.246	59	427
20	do	B	9.3	7.8	.306	1.06	.289	.44	.385	109	772
21	do	B	9.3	8.4	.109	.41	.266	.15	.136	19	260
22	do	B	9.3	8.4	.168	.56	.300	.22	.207	44	484
23	do	B	9.3	8.4	.194	.72	.269	.28	.274	68	498
24	do	B	9.3	8.4	.319	1.08	.295	.46	.410	134	960
25	do	C	8.8	7.9	.103	.37	.278	.14	.127	15	210
26	do	C	8.8	7.9	.155	.55	.282	.22	.212	44	338
27	do	C	8.8	7.9	.200	.66	.303	.28	.272	73	498
28	do	C	8.8	7.9	.243	.82	.296	.36	.342	129	613
29	do	C	8.8	7.9	.301	1.09	.276	.48	.451	178	707
30	do	D	10.0	8.0	.101	.47	.215	.18	.166	21	213
31	do	E	9.0	9.5	.080	.37	.216	.14	.137	22	192
32	do	F	9.9	8.0	.110	.53	.207	.19	.157	25	215
33	do	G	9.0	9.5	.101	.50	.202	.19	.174	29	227
34	do	H	8.8	9.6	.081	.39	.207	.16	.133	29	198
35	do	I	9.0	8.0	.141	.47	.300	.19	.176	34	354
36	do	J	9.0	9.4	.087	.31	.281	.14	.135	35	316
37	do	K	9.2	7.8	.134	.47	.285	.17	.152	37	284
38	do	L	9.0	9.5	.142	.69	.205	.28	.276	59	347
39	do	M	8.8	7.1	.195	.65	.300	.27	.240	73	381
40	do	N	8.8	7.9	.203	.66	.308	.28	.275	85	513
41	do	O	9.0	8.0	.201	.65	.309	.27	.267	89	534
42	Axminster.	P	6.7	7.0	.138	.66	.209	.22	.124	1.7	85
43	do	Q	6.7	7.0	.124	.69	.180	.23	.143	2.4	65
44	do	R	6.7	7.0	.129	.66	.195	.20	.157	2.9	67
45	do	S	6.7	7.0	.133	.69	.193	.24	.123	4.9	79
46	do	T	5.8	7.0	.136	.72	.189	.25	.140	3	59
47	do	U	5.5	7.0	.174	.78	.223	.30	.173	6	89
48	do	V	7.3	7.0	.144	.78	.185	.25	.183	8	88
49	do	W	7.3	6.9	.182	.84	.217	.31	.190	14	148
50	do	X	5.7	7.0	.262	.87	.301	.28	.200	16	161
51	do	Y	5.7	7.0	.233	.75	.311	.28	.200	16	172
52	do	Z	9.6	7.0	.147	.75	.196	.28	.201	23	194
53	do	a	7.0	7.0	.280	.94	.298	.32	.244	26	273
54	do	b	7.1	7.0	.253	.75	.337	.28	.250	30	315
55	do	c	11.8	7.0	.120	.54	.222	.19	.175	35	266
56	Wilton	d	8.8	8.8	.071	.48	.148	.19	.146	11	100
57	do	e	8.9	9.2	.051	.41	.124	.19	.155	14	93
58	do	f	8.9	9.3	.078	.34	.229	.14	.131	16	203
59	do	g	10.3	9.4	.094	.50	.188	.19	.142	31	252
60	do	h	13.4	9.4	.093	.45	.207	.19	.151	34	515
61	do	i	8.9	9.5	.204	.91	.224	.34	.289	35	488
62	do	j	13.2	9.4	.082	.49	.167	.19	.173	55	327

[1] Height of pile is measured with a steel scale.
[2] Thickness of pile is measured with a gage having a circular foot 1 inch in diameter and exerting a pressure of 0.75 lb/sq in.

The analyses and wear indices of the two series of carpets are given in table 1, numbers 1 to 24, inclusive. Judged by wear indices, series A is slightly superior to series B. This is mainly due to the heavier pile yarn used in series A.

For a given pile yarn and pitch the wear index is approximately proportional to the wire height, and for a given pile yarn and wire height the wear index is approximately proportional to the pitch (see fig. 6). The wear index may therefore be expressed by the general equation

$$I=(a\,P+b)\ (c\,W+d)+e$$

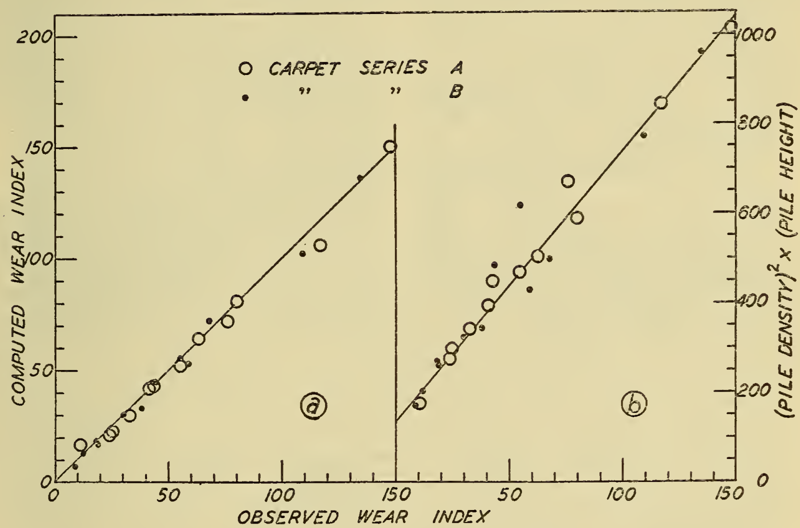

FIGURE 7.—*Correlation curves.*

(*a*) Correlation between observed and computed wear indices; (*b*) Correlation between observed wear index and product of pile density squared and pile height, for the two series of velvet carpets.

where I, P, and W are wear index, pitch, and wire height, respectively, and a, b, c, d, and e are constants. This is the equation for the hyperbolic paraboloid. It may be reduced to the form

$$I=a'PW+b'P+c'W+d'$$

and the constants determined empirically. The data are represented fairly close by the following equations:

$$I=106\,PW-9\,P-600\,W+64 \quad \text{for pile yarn A, and}$$

$$I=107\,PW-7\,P-625\,W+42 \quad \text{for pile yarn B.}$$

For comparison, the indices computed from these equations are plotted against the observed wear indices in figure 7(*a*) which shows a good linear relationship.

It is to be noted that the wear index increases more rapidly with increase in pitch (density) than with increase in pile height (wire

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height). There is a fairly good correlation between the wear index and the product of pile density squared and pile height. This product is equal to 4 R^2 P^2 w^2 $l^{-2}h$, where R is rows per inch, P is pitch per inch, w is weight per tuft in grains, l is length of tuft in inches, and h is height of pile in inches. The products are given in the last column of table 1. They are plotted against wear indices in figure 7(*b*) which shows a fairly good linear relationship.

The important conclusion to be drawn from these tests is that the density of the pile is the predominant factor which affects the rate of wear of the pile. The height of the pile is a factor of lesser importance. In other words, the durability of a carpet is increased by a greater amount when the pile density is increased by a given percentage than when the pile height is increased by the same percentage. The difference in durability may be accounted for readily from a consideration of the nature of the wear on the wool fibers.

4. EFFECT OF THE QUALITY OF PILE WOOL

The effect of the quality of pile wool is shown by the results for the four axminsters, nos. 42, 43, 44, and 45. These four carpets are similar to one another except for the quality of wool used in the pile. The analyses and wear indices of these carpets are given in table 1. Photographs of the wool fibers are shown in figure 8. It is to be noted that the diameters of the fibers in no. 42 range from small to large values with a preponderance of fine fibers. Nos. 43 and 44 contain very coarse fibers. The range of diameters and the average diameter of the fibers is greater for no. 43 than for no. 44. The diameters of the fibers of no. 45 do not vary over a great range. The fibers are of medium diameters compared to the fine and coarse fibers contained in nos. 42, 43, and 44. No. 45 has a wear index of 4.9 compared to 1.7 for no. 42. The wear indices for nos. 43 and 44 are 2.4 and 2.9 respectively.

The pile consisting of fine fibers is readily compressed and many of the weak fibers are probably broken off during the early part of the test by the slipping and twisting actions of the machine. This undoubtedly accounts for the low wear index of no. 42. The pile consisting of very coarse fibers is not readily compressed. The coarse, stiff fibers are probably readily fractured near the anchorage by the repeated bending action of the machine. This may account for the low wear indices of nos. 43 and 44. The fibers of medium diameters on the other hand are strong enough to better withstand the slipping and twisting actions and are flexible enough to better resist fracturing due to the bending actions. This accounts for the high wear index of no. 45. The quality of the wool used in the pile appears to have a direct influence on the nature and rate of wear of the wool fibers.

Ashcroft has published results showing the rate of wear of the pile as it is affected by the boiling of the yarn in the dyeing process.[9] His results indicate that the rate of wear increases almost directly with the time of boiling. This probably accounts for the uneven wear which the authors observed in carpets in which the pattern consisted of several colors. Yarns of certain colors were observed to wear more rapidly than adjacent yarns of other colors.

[9] Melliand Textile Monthly, vol. 4, no. 12, pp. 721–724, March 1933.

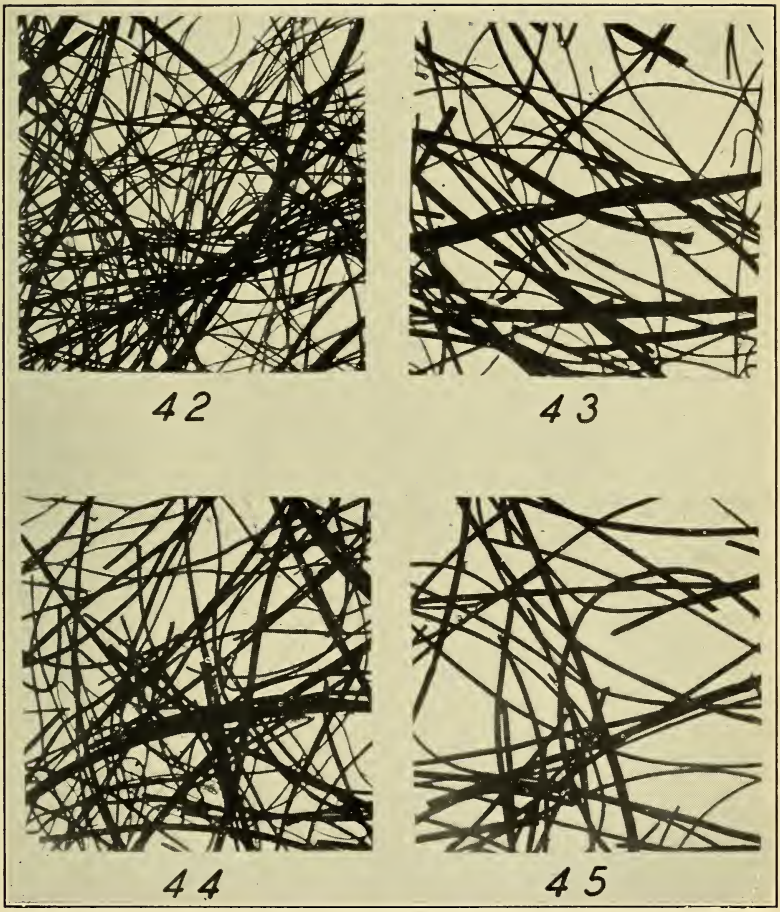

FIGURE 8.—*Photographs of wool fibers showing variations in diameter.*

The numbers indicate the carpets in table 1 in which the wool is used as pile.

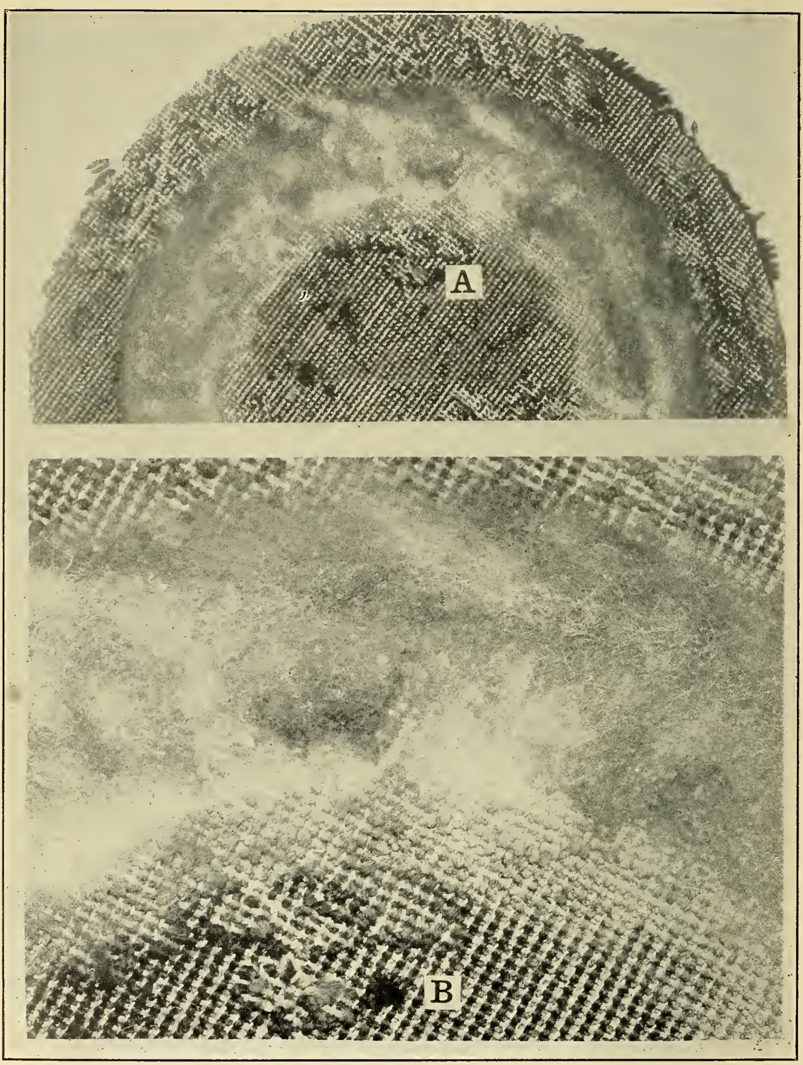

FIGURE 10.—*The back of a carpet, which had its pile through-to-the-back, after a test.*
B is a portion of A magnified 2.6 times.

These results suggest the importance of the fiber blend and the quality of the pile wool and indicate a fruitful field for further study.

5. EFFECT OF THE TYPE OF PILE ANCHORAGE

It is difficult to determine the effect of the pile anchorage on the durability. Carpets usually differ greatly in other factors, such as pitch, rows, pile heights, and yarn size, which have a greater effect on the durability and which mask the effect of the type of pile anchorage.

Typical pile anchorage are shown in figure 9. Tests made on a five-frame wilton carpet and on a velvet carpet, which were specially woven alike in all respects except anchorage of pile, showed no difference in the rate of wear.

It is worth while to note the effect of the wear test on a carpet having the pile tufts exposed on the back. When this carpet was

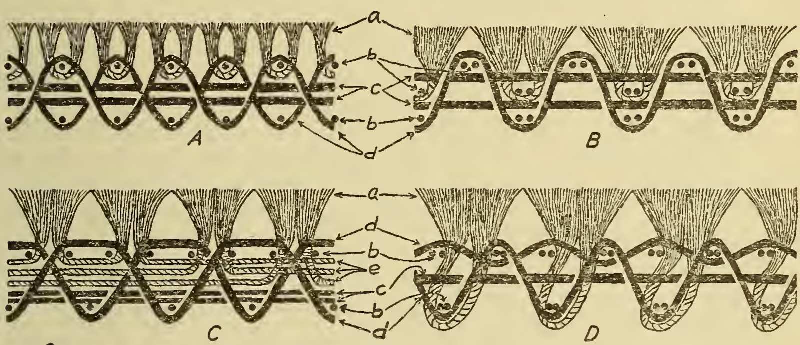

FIGURE 9.—*Diagrammatic cross sections of carpets.*

Type:
- *A.* Velvet, double-chain, two-shot with two stuffers.
- *B.* Axminster, single-chain, three double shots with two stuffers.
- *C.* Wilton, double-chain, three-shot, three-frame with two stuffers.
- *D.* Axminster, pile-through-to-the-back, double-chain, three double shots with one stuffer.

Parts:
- *a.* Pile, the face or nap of the carpet.
- *b.* Weft or woof, the threads that run crosswise of the carpet. (Shots, the number of times the weft thread is shot across to bind each row of pile.)
- *c.* Stuffers or fillers, extra threads laid lengthwise and crosswise of a carpet to increase bulk, weight, and stiffness.
- *d.* Chain, the longitudinal threads that bind the weft into the body of the carpet. These constitute a part of the warp threads which are the threads that run lengthwise of the carpet.
- *e.* Frames, the number of pile threads in a cross-section of a Wilton or Brussel carpet.

tested, the wool fibers gradually worked through to the back where they became matted together. This condition produced very irregular wear on the pile. The appearance of the back after a test is shown in figure 10. Ashcroft has called attention to a similar effect both in laboratory and service tests.[10]

In addition to the data on the velvet and axminster carpets referred to under sections 3 and 4, there are also given in table 1 similar data on wilton and several other axminster and velvet carpets. The general conclusion that the wear index is approximately proportional to the product of pile density squared and pile height is valid for all the carpets tested. In other words a given percentage increase in density of the pile produces a greater increase in the durability than the same percentage increase in height of pile. The results are shown in figure 11 for all tests on the three weaves. No specific conclusions can be drawn with reference to a particular weave. There is con-

[10] See footnote 9.

siderably more scattering than was the case with the velvet carpets discussed under section 3, figure 7 (*b*). This greater scattering is undoubtedly due to variables which were controlled in the special series of velvet carpets.

6. EFFECT OF UNDERLAYS

To show the effect of carpet underlays on the durability, a number of carpets were tested in combination with underlays. The underlays included: (*a*) three of jute; (*b*) two of animal hair and jute; (*c*) one of

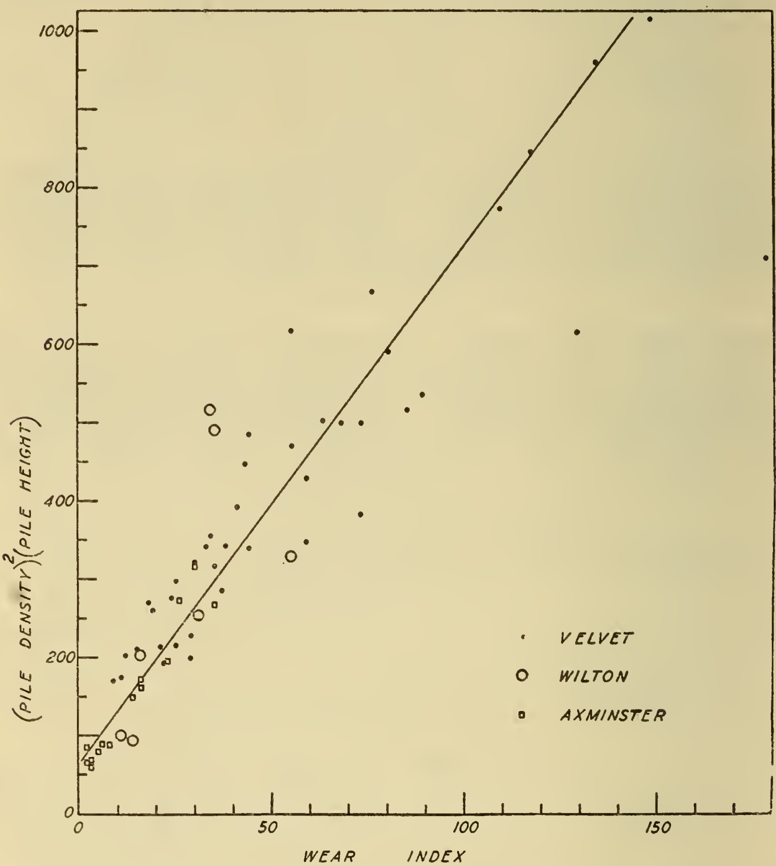

FIGURE 11.—*Correlation of wear index with product of pile density squared and pile height.*

cotton and paper; and (*d*) two of rubber. The carpets which were tested with underlays included velvets, axminsters, wiltons, and a domestic oriental having a long pile. The results are given in table 2.

In group I, specimens of one carpet were tested with the eight different underlays. All underlays increased the wear index of the carpet. The increases varied between 73 and 146 percent. It is to be noted that for the jute underlays, which were greatly compressed during the tests, the wear index is increased when the thickness of the underlay is increased from 0.29 to 0.37 inch, and that it is slightly decreased when the thickness is further increased to 0.47 inch. This is in substantial agreement with service tests conducted by A. C. Nielson Engineering Co. in the lobby of one of Chicago's largest theaters.[11]

In group II, specimens of seven different carpets were tested with specimens of one underlay. The wear index of each carpet was increased. The increase varied from 7 percent for the domestic oriental with a long pile to 146 percent for the velvet with a short pile. It appears that the underlay is more effective when it is used with carpets of short pile than when it is used with carpets of long pile.

In group III a specimen of carpet was tested with a sponge-rubber underlay, and then the test was repeated on another specimen of the carpet but the same piece of underlay was used underneath it. Similar tests were made with a jute underlay and specimens from the same carpet. In figure 12 the thickness values of the pile and of the underlays, measured at intervals during the tests, are plotted against the number of revolutions of the turntable. The thickness of the sponge-rubber underlay changed little during the tests. The two specimens of carpet which were tested with the same specimen of sponge-rubber underlay had the same increase in wear index, namely, 67 percent. The thickness of the jute underlay decreased greatly during the first test, but the further decrease in thickness during the second test was small. This difference in inelastic compression had a marked effect on the rate of wear. The wear index of the first specimen of carpet tested with the specimen of jute underlay was increased 67 percent, while the wear index of the second specimen tested with the same specimen of jute underlay was increased only 29 percent. These tests indicate that an underlay which is permanently compressed during use becomes less effective. Since rubber is likely to become hard and brittle with age, it is quite possible that the effectiveness of the rubber underlay may also be materially lessened with age.

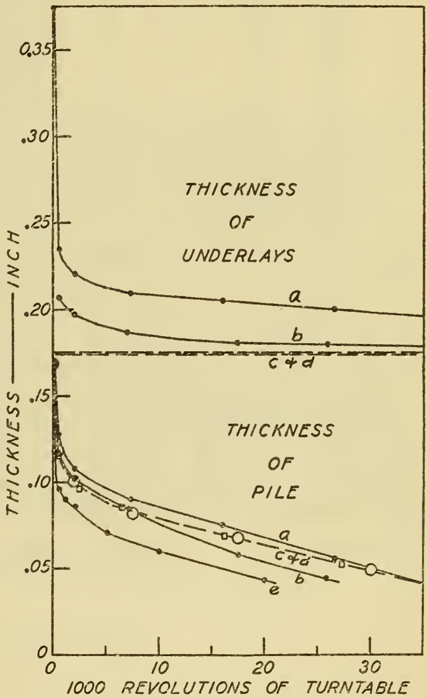

FIGURE 12.—*Curves showing changes in thickness of pile and underlay when two specimens of the same carpet are tested with one specimen of an underlay.*

(a) Carpet no. 30 tested with jute underlay B, first test.
(b) Same as (a) for second test.
(c) Carpet no. 30 tested with sponge-rubber underlay B, first test.
(d) Same as (c) for second test.
(e) Carpet no. 30 tested without an underlay.

[11] Letter from Western Felt Works dated May 15, 1931.

Table 2.—*Results of tests on carpets and underlays*

Group	Carpet			Underlay				Wear index		
	No.	Weave	Height of pile	No.	Description	Thickness: Before test	Thickness: After test	Carpet	Carpet and underlay	Increase
			Inch			*Inch*	*Inch*			*Percent*
I	63	Velvet	0.15	1	Jute A	0.29	0.15	11	19	73
	63	do	.15	2	Jute B	.37	.19	11	26	136
	63	do	.15	3	Jute C	.47	.27	11	24	118
	63	do	.15	4	Jute and hair	.42	.24	11	26	136
	63	do	.15	5	Hair and jute	.30	.20	11	21	91
	63	do	.15	6	Cotton and paper	.24	.14	11	19	73
	63	do	.15	7	Sponge rubber A	.31	.24	11	19	73
	63	do	.15	8	Sponge rubber B	.23	.23	11	27	146
II	63	do	.15	8	do	.23	.23	11	27	146
	30	do	.18	8	do	.17	.17	21	35	67
	35	do	.19	8	do	.23	.23	34	56	65
	55	Axminster	.19	8	do	.18	.18	35	57	63
	65	Wilton	.30	8	do	.22	.22	22	31	41
	47	Axminster	.30	8	do	.21	.21	6	8	33
	64	Domestic oriental	.55	8	do	.19	.19	56	60	7
III	30	Velvet	.18	8	Sponge rubber B, 1st test.	.17	.17	21	35	67
	30	do	.18	8	Sponge rubber B, 2d test.	.17	.17	21	35	67
	30	do	.18	2	Jute B, 1st test	.39	.20	21	35	67
	30	do	.18	2	Jute B, 2d test	.21	.18	21	27	29

The authors express their appreciation to the 17 manufacturers who have supplied samples of carpets and underlays. We are also indebted to G. E. Hopkins, technical director, Bigelow Sanford Carpet Co., for his personal interest in the tests and in arranging for the weaving of the series of carpets of special constructions.

Washington, October 30, 1933.