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Improved Single-Unit Schiefer Abrasion Testing Machine[1,2]

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A greatly improved single-unit Schiefer abrasion testing machine and a number of new abradants were developed. The abrasive wear on a variety of materials was found to be extremely uniform over the abraded area. On woven fabric the wear was similar to that observed in actual service. The effect of the amount of plasticizer in plastics and the effect of yarn and cloth construction in textiles on the resistance to abrasion were readily shown by the results obtained with the machine. A quantitative method for measurement of the amount of abrasion, based upon the change in electrical capacitance of the specimen, was developed for textiles, and a quantity that is a measure of destruction or ruin was defined. This method was applied to obtain an isoriun map of a large area of a trouser leg and clearly indicated a number of areas at which excessive abrasive wear had occurred in service.

I. Introduction

The experimental machine initially constructed to produce uniform abrasive action over a surface and from every direction in the plane of the surface, in accordance with the mathematical solution [3] for obtaining uniform abrasion, demonstrated very definitely the soundness of this type of machine. It was found desirable, however, to construct a much more rigid machine in order to maintain parallel alinement of the two axes of rotation. In redesigning the machine, several other improvements were made that facilitate testing, adapt the machine for testing a greater variety of materials, and increase the range of testing conditions. The new machine described in this paper meets these requirements very well.

II. Description of Machine

The general appearance of the improved single-unit [4] Schiefer abrasion testing machine is shown in figures 1 and 2. The specimen is in constant contact with the abradant during a test. The specimen and the abradant rotate in the same direction and with approximately the same angular velocity, 250 rpm, each about its own axis. These axes are spaced 1 in. apart and are parallel. The framework of the machine is a single heavy rigid casting. Ample interior space is provided for gears, which can be inserted through small openings in the rear of the casting. The schematic drawing in figure 3 shows the arrangement of the gears and the several rotating shafts to produce the rotation of the specimen and the abradant. Each shaft rotates in two ball bearings. The gears of one shaft are primed, thereby making the shafts rotate at slightly different speeds. This speed difference prevents one and the same element of the abradant from acting on one and the same area of the specimen during each rotation.

Different kinds of abradants, *A*, can be attached to the bottom of the abradant shaft, *B*. The abradant surface lies in a plane perpendicular to the shaft axis. This shaft has two keyways cut lengthwise for the entire length of the shaft. It can be moved vertically through a bushing, which forms a rotating shaft of the gear that is driven by a gear fastened to the auxiliary drive shaft. To the top of the abradant shaft is attached, through radial and thrust ball bearings, an aluminum cap, *C*, which serves as support for

[1] Permission to publish this paper was granted by the Office of the Quartermaster General, War Department, which sponsored and supported this work as part of a broad and long-term fundamental program of research on abrasion.

[2] This paper will also appear in the Textile Research Journal.

[3] Herbert F. Schiefer, Solution of problem of producing uniform abrasion and its application to the testing of textiles, J. Research NBS **39**, 1 (1947) RR1807.

[4] A four-unit Schiefer abrasion testing machine has recently been constructed and will be described in a subsequent paper.

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adjustable weights, *D*, to produce constant pressure of the abradant on the specimen throughout the test. A yoke, *E*, actuated by a cam, *F*, is provided for raising or lowering the abradant. A key on the inside of the aluminum cap can slide in a vertical keyway, *G*, of the main casting and keeps the cap and weights from rotating.

To the top of the specimen shaft is attached a presser foot, *H*, which fixes the area of the specimen, *I*, that is abraded. Different sizes, *H'*, and shapes can be used. In the upper portion of the specimen shaft are cut two keyways. A conical clamp seat, *J*, with the two keys is fitted to the specimen shaft and rotates with it. It can freely move vertically on the shaft. A cam, *K*, is provided at the bottom with two ball-bearing contacts for raising the conical clamp seat. The clamp, *L*, holding the specimen fits on the conical seat and can be fastened to it by two lock pins, *M*, by merely rotating the clamp slightly. The clamp and specimen can be removed quickly in the same simple manner for examination and measurement of the amount of wear. The specimen can then be returned to the machine without disturbing its position in the clamp and the abrasion test continued. The textile specimen, *I*, is mounted in the clamp in a relaxed state under reproducible conditions. When the specimen clamp is locked to the conical clamp seat and the conical clamp seat is lowered by turning the cam, the combined weight of the conical clamp seat and specimen clamp is suspended by the specimen over the presser foot fastened to the top of the shaft. This places the specimen under constant tension throughout the test with take-up of any stretch of the specimen. Different tensions can be obtained by varying the weight of the conical clamp seat or by the addition of auxiliary weights. It is apparent that the shaft, presser foot, conical clamp seat, specimen clamp, and specimen rotate as one unit under the described conditions.

The successive steps for mounting a circular textile specimen are shown from *A* to *E* in figure 4. A specimen, a template, and the three component parts of the clamp are shown in *A*. The lower half of the clamp is placed over a template with a hub projecting a given distance, which is adjustable, through the center of the clamp, *B*. The circular specimen is placed centrally over the hub, *C*, and the annular conical ring is placed on top of the specimen, so that the recess cut in the rim of the ring registers with a pin in the lower half of the clamp, *D*. The upper half of the clamp is then screwed to the lower half, thereby clamping the specimen evenly and securely, *E*. When the clamp is lifted from the template, the specimen is in the prescribed relaxed state. The two-fold reason for mounting the specimen in this relaxed state is to obtain even circumferential tension on the specimen and to provide enough material so that the portion of the specimen that is in contact with the presser foot projects sufficiently above the clamp for the abrasion test. It is obvious that other types of specimen clamps can be used for testing nontextile materials. Figure 5 shows clamps for testing small cylindrical specimens of plastics and other solid materials.

III. Abradants

Different abradants may be used interchangeably in the machine. The abradant, *A*, in figure 2 consists of closely spaced parallel spring steel blades, the edges of which have been ground to lie in the same plane. The abradant in figure 6, A, is similar except that notches were cut in the blades. The abradant in figure 6, B, is similar to the latter, except that thicker blades of high-speed tungsten tool steel were used. The abradant in figure 6, C, consists of 397 small rods of carboloy, the ends of which were ground to lie in the same plane. A similar abradant was used in some tests in which Pyrex rods were used in place of carboloy. It is planned to make others in which rods of high-speed tungsten tool steel and synthetic sapphires will be used. Figure 2 shows an adapter, *A'*, in which duck, cloth, sandpaper, emery-paper, and similar abrasives may be used. The successive steps for mounting such abrasives are shown from *A* to *E* in figure 7. The final step places the abrasive under uniform tension and in a plane at right angles to the axis of rotation. Obviously, many other types of abradants can be used, depending upon the kind of test desired and upon the kind of material being tested.

IV. Typically Worn Specimens

Typically worn specimens of woven fabric, fleeced knitted fabric, pile fabric, coated fabric, coated glass fabric, graph paper, leather, plastic, and printed enamel floor covering are shown in figure 8. The wear on all of these materials is extraordinarily uniform over the abraded area. The woven fabrics are of special interest. The tests on them were discontinued when one set of threads (warp or filling) was completely worn away, with the other set of threads still intact as shown in figure 9. Figure 10 shows abraded areas above the knee of two trouser legs. A higher magnification of the abraded area in figure 10, B is shown in figure 11. Examination of worn garments indicated that the wear shown by these trouser legs is typical of the abrasive wear of woven fabrics in service. The striking similarity of the abrasion obtained with the machine and in service is evident.

A special application of the machine described is for evaluating the effect of wet cleaning solutions on printed enamel felt-base floor coverings. The specimen is placed at the bottom of a shallow cylindrical cup, and the cleaning solution is placed on it. The abradant used is a nylon-bristle brush. Some of the floor coverings tested had good resistance to washing with soap and soda solution at 45° C. Others, like the one shown to the right of figure 12, were poor in this respect.[5]

V. Quantitative Method for Measuring Abrasion of Fabrics

Consideration was given to a quantitative measurement of the amount of abrasion during a test. This measurement should not disturb nor affect the specimen and should be simple, rapid, and sufficiently sensitive. The capacitance method described below seems to meet these requirements.

A capacitor,[6] shown in figure 13, A, was attached to a capacitance test set that is normally used to measure the capacitance between the electrodes of vacuum tubes. This set operated at a frequency of 465,000 cycles/sec. The capacitor is of the guard-ring type. The island electrode, *a*, is 1 cm in diameter. The outside diameter of the annular guard ring electrode, *b*, is 3 cm. The island and guard ring were so constructed that the specimen clamp, *c*, from the abrasion machine could be readily inserted in the capacitor in such a manner that the clamp was suspended by the worn area of the specimen over the island and guard electrodes, *d* of figure 13, B. The third electrode, *e*, is mounted in a heavy hinged lid, *f*, which can be swung down to a fixed stop, *g*, after the specimen and clamp are inserted as in figure 13, C. This third electrode forms part of a micrometer head, *h*, for adjusting the distance between it and the island electrode to precise known values. The construction of the capacitor is very heavy and rigid.

The measuring procedure consists in adjusting the distance between the electrodes to a value slightly in excess of the thickest specimen to be tested. The capacitance C_o with the unworn specimen in the capacitor is measured and also the capacitance C_a of the air without a specimen. The specimen is then abraded for R rotations against the abradant in the abrasion machine, and the capacitance C_R of the abraded specimen is measured. The value Q is then computed by means of the formula,

$$Q=\frac{C_o-C_R}{C_o-C_a}\times 100.$$

It can be taken as a measure of destruction or ruin by abrasion, expressed as a percentage. If a number of values of Q are obtained for various values of R, a wear curve can be obtained by plotting Q against R, as shown for fabrics A and B in figure 14. For comparative testing, some function of R such as $\log_{10} R_{50}$, where R_{50} is the number of rotations for which Q is 50 percent, is suggested as a suitable criterion or wear index. It is believed that this index would correlate well with the service test results. This confirmation will, of course, have to wait until adequate service and laboratory wear test results are available. The supplier of fabrics A and B stated that fabric B was definitely superior to fabric A, according to service performance of these two fabrics.

The application of the capacitance measurement for evaluating quantitatively the abrasive wear of garments is of special interest. The trouser leg shown in figure 10, B, was opened along the inside seam, and a very large number of capacitance measurements were made of the area shown in figure 10, B. For each measurement a value of Q was computed, using as a value of C_o that which was obtained for the least worn area. These values of Q were accurately

[5] This photograph was obtained from George G. Richey, who carried out this research at the National Bureau of Standards.

[6] Charles Moon of the National Bureau of Standards suggested the essential design features of this capacitor.

plotted according to the position of each measurement. From these plotted values of Q it was very easy to chart the isoruin lines of the parameter Q as shown in figure 15. By comparing this isoruin map with the actual photograph in figure 10, B, it can be seen that Q closely approximates the value of 50 percent in several areas where the one set of threads is practically worn away. The comparison is, of course, much more striking and convincing by a direct comparison of this isoruin map and the actual fabric. It is worth mentioning that a simple capacitance device could be arranged for obtaining the isoruin map of trousers without the necessity of opening any of the seams. This would allow the trousers to be worn again after each evaluation of the amount of wear from the isoruin map.

The isoruin map technique can also be used to explore the uniformity of a fabric, especially of the distribution of moisture-sensitive finishing agents in a fabric. In figure 16 are plotted the cumulative frequency distributions of C_o-C_a for three unworn cotton fabrics. It can be readily seen that these three fabrics contain areas for which C_o-C_a departs considerably above and below the average. The different values of C_o-C_a for areas 1 cm in diameter within fabrics arise from variations in the yarn number, ends and picks per inch, twist of the yarns, and amount of sizing. These factors affect the weight of the fabric in 1-cm diameter areas and also the amount of moisture contained in these areas. Changes in the latter greatly affect the values of C_o-C_a.

In connection with the foregoing, the following data are of interest. In figure 17 are plotted the weights in ounces per square yard of many unabraded specimens taken from 69 different cotton fabrics against C_o-C_a. The scattering of the points is attributed primarily to the nonuniformity within each of these fabrics. Another contributing cause is the fact that the weight was determined on an area of fabric that was 90 times the area used in the capacitance measurement. However, in view of the very large number of values plotted in figure 17, it is evident that for the over-all data the quantity C_o-C_a is directly proportional to the weight, ounces per square yard. It is reasonable to conclude, therefore, that when the value of C_o-C_R in an abrasion test is one-half of the value of C_o-C_a, that is, when Q is 50 percent, then the weight per unit area of the abraded portion of the specimen is one-half of the weight before the abrasion. A specimen that is abraded to this degree should have approximately one set of threads destroyed, as was indicated by a number of abraded areas in figure 15.

Another quantitative measurement that can be made on the worn area without disturbing or affecting the specimen is air permeability. The percentage increase in air permeability of the two fabrics referred to in figure 14 was measured immediately after each capacitance measurement. The specimen clamp from the abrasion machine was inverted and placed directly in the air permeability apparatus,[7] and the air flow was measured at a pressure differential of 0.5 in. of water across the specimen. The percentage increase in air permeability over the unabraded specimen is plotted against the number of rotations of abrasion in figure 18. It can be seen that the percentage increase in air permeability increases rapidly with the number of rotations of abrasion. The percentage increase at the number of rotations that corresponds to the value of 50 percent for Q in figure 14 is 68 percent for both fabric A and fabric B. There is no reason for this coincidence and it is not expected that this relationship would be found generally for other fabrics. The percentage increase in air permeability may have merit as a quantitative measurement of abrasion of some fabrics.

VI. Application for Evaluating the Effect of Plasticizer on Resistance to Abrasion of Plastics

Small cylinders of cellulose acetate butyrate containing various percentages of dibutyl sebacate were abraded using the abradant shown in figure 6, A. The cylinders were ½ in. long and were machined to a diameter of 0.450 in. The specimen holder shown in figure 5 was used. The weight and thickness (length of cylinder) were measured before the test and at regular intervals during the abrasion test. The decrease in weight is plotted in figure 19, and the decrease in thickness is plotted in figure 20 against the number of rotations the specimen was in contact with the abradant. The effect of the amount of plasticizer on

[7] Herbert F. Schiefer and Paul M. Boyland, An improved apparatus for measuring the air permeability of fabrics, J. Research NBS 28, 637 (1942) RP1471.

the resistance to abrasion was readily measured. The decrease in weight and in thickness per 100 rotations is plotted against the amount of plasticizer in figures 21 and 22. They show that the rate of abrasion increases directly with the amount of plasticizer. The decrease in weight of all of the separate measurements is plotted against the corresponding decrease in thickness in figure 23. The points lie very close to a straight line. This indicates that for these plastics the rate of abrasion is equally well measured by change in thickness and change in weight.

VII. Effect of Abrasion Tests on the Abradant

Some abradants are considerably affected or changed during an abrasion test. This is particularly true when abrasive papers, abrasive cloths, and fabrics are used as abradants and is shown by the results for 17 fabrics in table 1. Five successive tests were made of each fabric with the same piece of silicon carbide waterproof abrasive paper. This procedure was repeated four more times. A value in the second column, 58 ±3, for example, is the average number of rotations to destruction and standard error of five specimens of fabric 1, each tested with a new piece of abrasive paper. A value in the third column, 110±5, for example, is the average number of rotations to destruction and standard error of five specimens of fabric 1, each tested with a piece of abrasive paper that had already been used for testing a specimen of this fabric. A value in the fourth column, 127 ±7, for example, is the average number of rotations to destruction and standard error of five specimens of fabric 1, each tested with a piece of abrasive paper that had already been used for testing two specimens of this fabric. The values in the fifth and sixth columns were similarly obtained. In other words, before the fifth specimen of a fabric was tested with a piece of abrasive paper, the piece of abrasive paper had been used for a number of rotations that was equal to the sum of the number of rotations of the first, second, third, and fourth tests. The great decrease in the abrasive power of a piece of this abrasive paper is at once obvious, especially at the beginning of a test with a new piece of abrasive paper, as can be seen by comparing the values in the second and third columns. Because of this great change in the abrasive character of these types of abradants, it is customary to test only one specimen with each piece of abradant. In some work, where a test lasts a long time, the piece of abradant is periodically replaced by a new one, or the abradant surface is redressed with a more severe abradant. Although this procedure may seem best under these conditions, actually the results obtained may be misleading. For example, it would be erroneous to conclude that fabric 8 is twice as resistant to abrasion as fabric 1. It is clear from the values for fabric 1, that, after 58 rotations for the first test, the abrasive power has dropped to about one-half, so that 110 rotations are required for the second test. The same change in this abradant is produced for each of the other 16 fabrics. Also it can be seen from the standard error that the variability of the abrasive power of a piece of abrasive paper increases with use, the standard error for the second test is on the average more than twice as great as for the first test. The change in the abrasive power of the abradants during a test probably is the primary cause for the erratic results frequently reported in interlaboratory testing and conducted under otherwise similar testing conditions.

TABLE 1.—*Effect of five successive tests with same silicon carbide waterproof abrasive paper on abrasion result of different fabrics*

Fabric Number	Rotations of abradant to destroy specimen				
	First test	Second test	Third test	Fourth test	Fifth test
1	58±3	110±5	127±7	133±7	132±5
2	77±5	134±16	186±19	187±13	196±15
3	84±3	127±5	147±11	166±12	149±6
4	90±6	158±9	174±10	193±12	189±19
5	92±6	181±17	213±18	230±10	215±14
6	104±5	221±20	260±17	292±26	306±48
7	110±4	252±20	301±26	278±27	322±55
8	115±4	252±7	278±9	290±7	290±9
9	126±9	228±18	276±33	302±21	287±16
10	135±4	253±6	274±11	272±12	281±11
11	135±10	311±29	354±32	401±38	398±29
12	138±4	299±8	345±14	371±10	395±7
13	143±4	298±18	335±8	342±9	391±22
14	145±13	500±73	708±166	887±125	1105±279
15	152±5	417±20	505±23	540±40	591±22
16	193±6	494±27	563±22	686±76	866±71
17	475±29	1231±145	2106±229	2119±105	2747±760

The spring steel blade abradant shown in A of figure 2 has been used for over a million rotations on a large number of cotton fabrics. It was found that in these tests the action of the abradant changed less than 3 percent in over a hundred thousand rotations, which was much less than the variation between specimens taken from any one of these fabrics. For comparative testing of several fabrics this abradant can be considered to remain constant.

It is of interest to report the results of an entirely opposite effect on the abradant that was observed with one fabric. Instead of the usual decrease in the abrasive power of the abradant, in this case the abrasive power was greatly increased, that is, successive specimens were worn to destruction in fewer rotations, as shown in figure 24. The first specimen tested required over 8,000 rotations, and the second one required less than 2,000. After the third specimen the rate of abrasion was nearly constant and about ten times the initial rate. It was found that a resinous substance on the fibers stuck to the surface of the abradant. This substance was thermoplastic and apparently very sticky, so that the frictional force between this substance on the abradant and the fibers of the specimen was many times greater than that between the clean abradant and specimen and, therefore, increased the rate of abrasion. The coating on one blade of the abradant is shown in figure 25, A. In figure 25, B, the coating on this blade was removed. The same result was obtained when the Pyrex rod abradant was used. The appearance of the end of a coated and an uncoated Pyrex rod is shown in figure 26. Although the effect described cannot be ascribed to a faulty operation of the abrasion machine or of the abradant, nevertheless it is apparent that erroneous conclusions can be drawn if the operator of the machine is not an alert and critical observer.

VIII. Summary

An improved single-unit Schiefer abrasion testing machine was developed. It can be adapted for testing a great variety of materials under a wide range of test conditions. Different types of specimen holders and abradants can be used with the machine. Both the pressure and tension on the specimen can be fixed at selected values and maintained constant throughout the test period. A variety of materials including woven, knitted, and coated fabrics, plastics, paper, leather, and other materials were abraded with the machine. The abrasive wear of each material was found to be extremely uniform over the abraded area. The effect of the amount of plasticizer on the resistance to abrasion of plastics was readily measured. The rate of abrasion was directly proportional to the amount of plasticizer present. The abrasive wear in tests of woven fabrics appeared very similar to that which occurred in service. A quantitative method based upon the change in electrical capacitance of the specimen with abrasion was described for evaluating the amount of abrasion. A quantity that is a measure of abrasive destruction or ruin was defined. This quantity was used to obtain an isoruin map of a large area of a trouser leg. This isoruin map showed very clearly a number of areas at which excessive abrasive wear in service had occurred. The change of the abradant during abrasion tests was discussed. Silicon-carbide paper, a generally used abradant, decreased very greatly in abrasive power. The spring steel blade abradant remained essentially constant, although in testing one resin-finished fabric the surfaces of this abradant became coated with the resinous substance, which greatly increased the abrasive power.

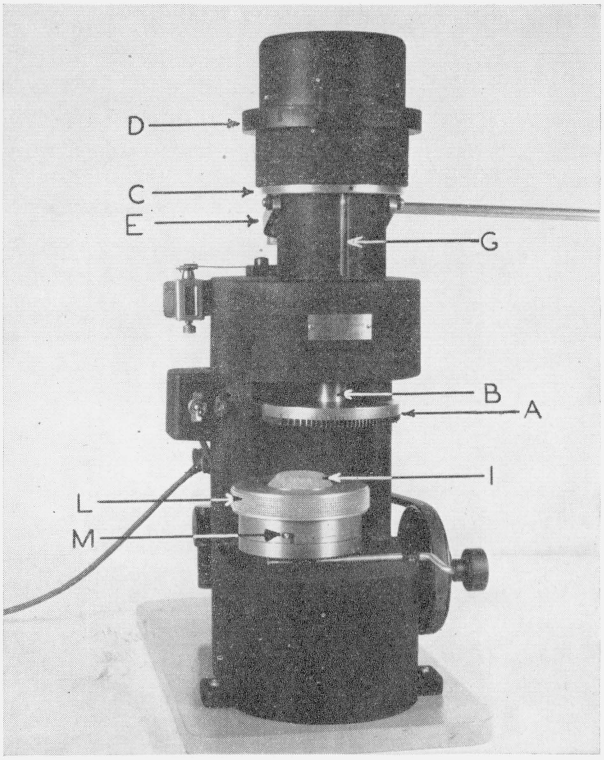

FIGURE 1. *Schiefer abrasion testing machine ready for a test.*

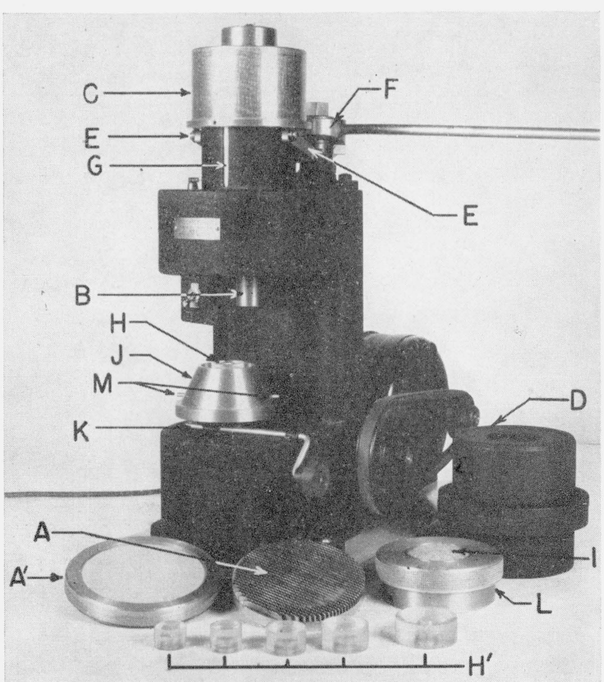

FIGURE 2. *Component parts of Schiefer abrasion testing machine.*

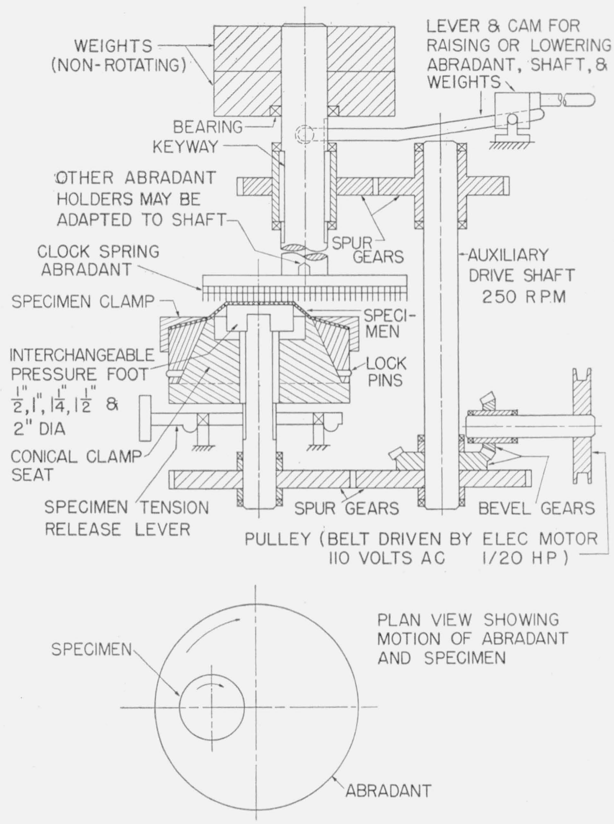

FIGURE 3. *Schematic drawing of Schiefer abrasion testing machine.*

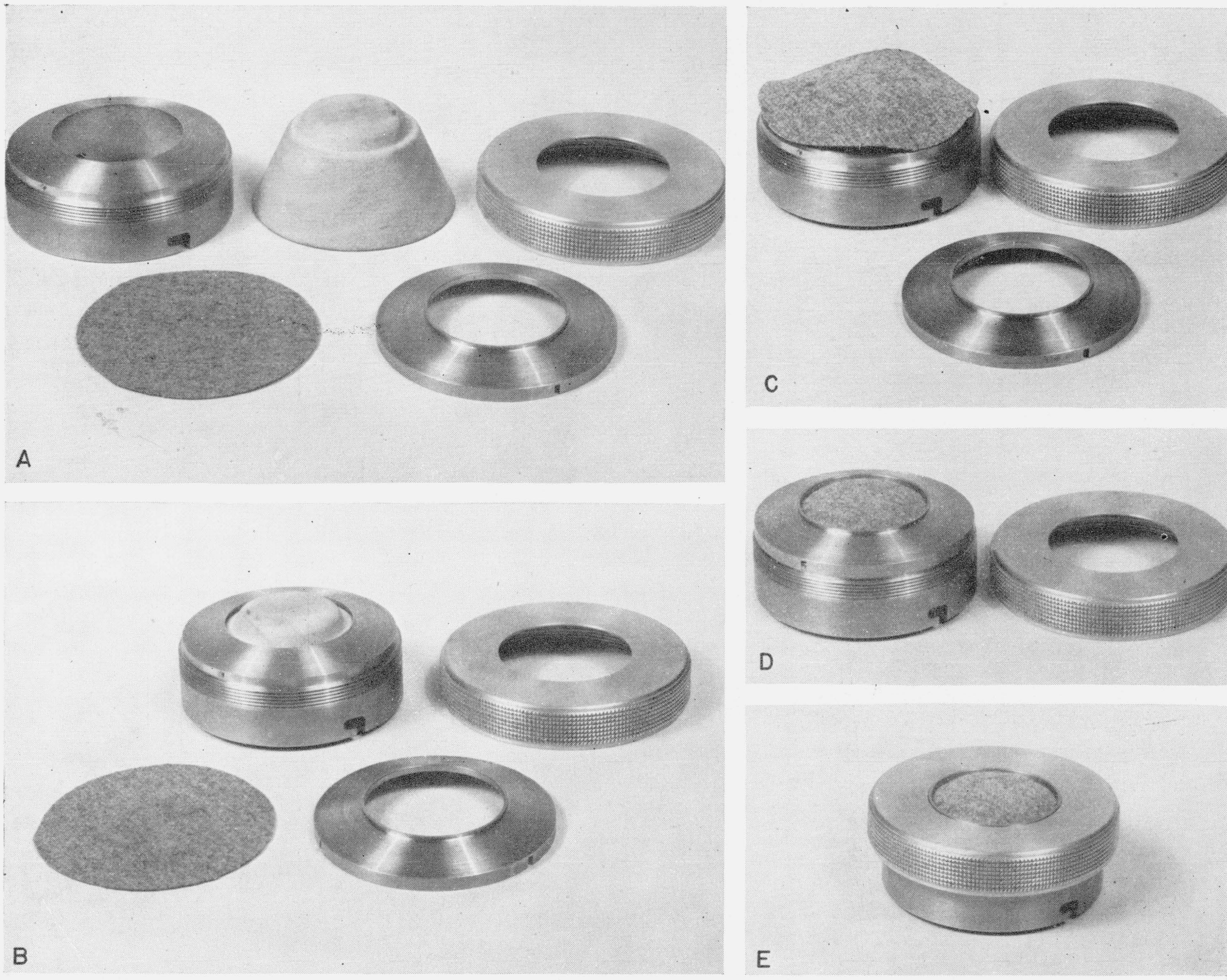

Figure 4. *Successive steps, A to E, in mounting a textile specimen for an abrasion test.*

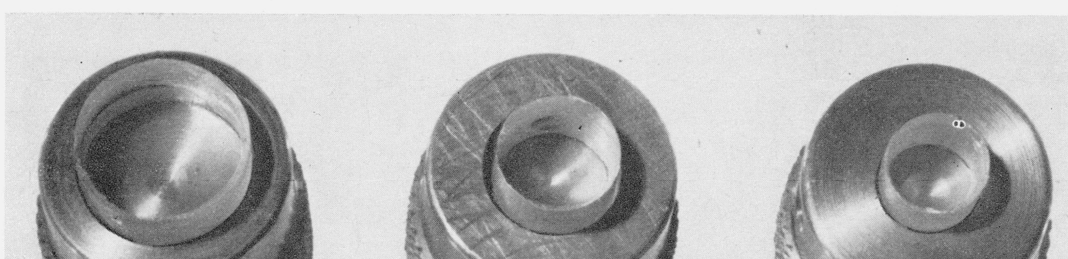

Figure 5. *Specimen clamps for testing plastic cylinders.*

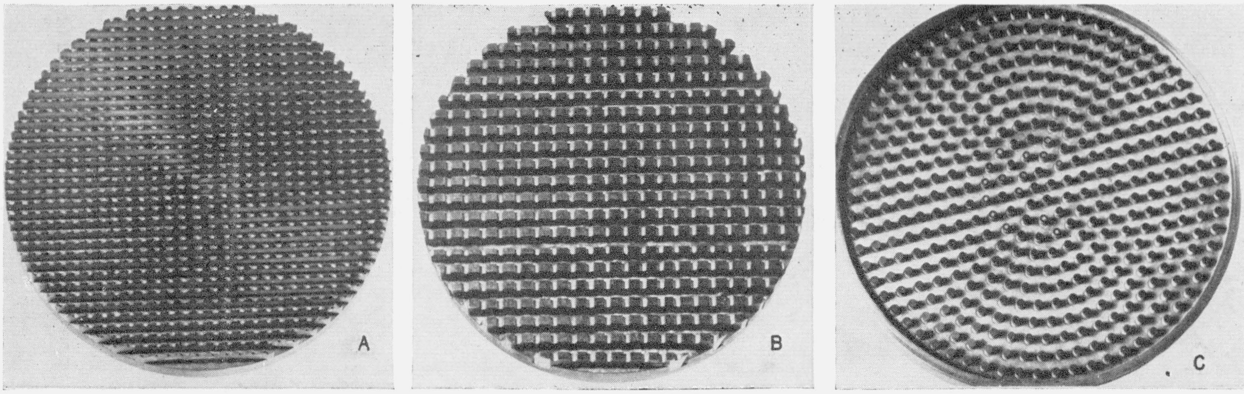

FIGURE 6. *Interchangeable abradants.*

A, Cross-cut spring steel blade abradant; B, cross-cut high-speed tungsten tool steel abradant; C, carboloy rod abradant.

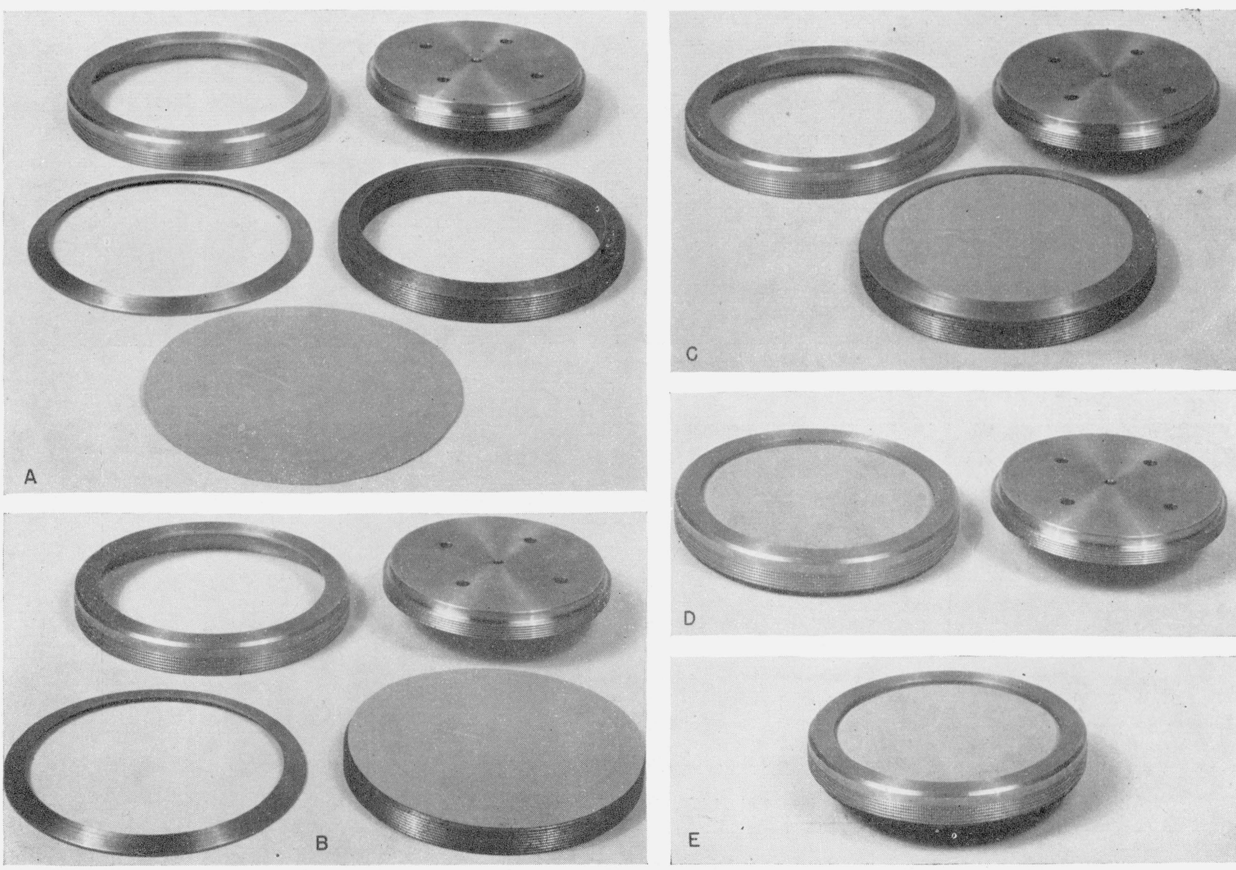

FIGURE 7. *Successive steps, A to E, in mounting a piece of abrasive paper or cloth as abradant in adapter.*

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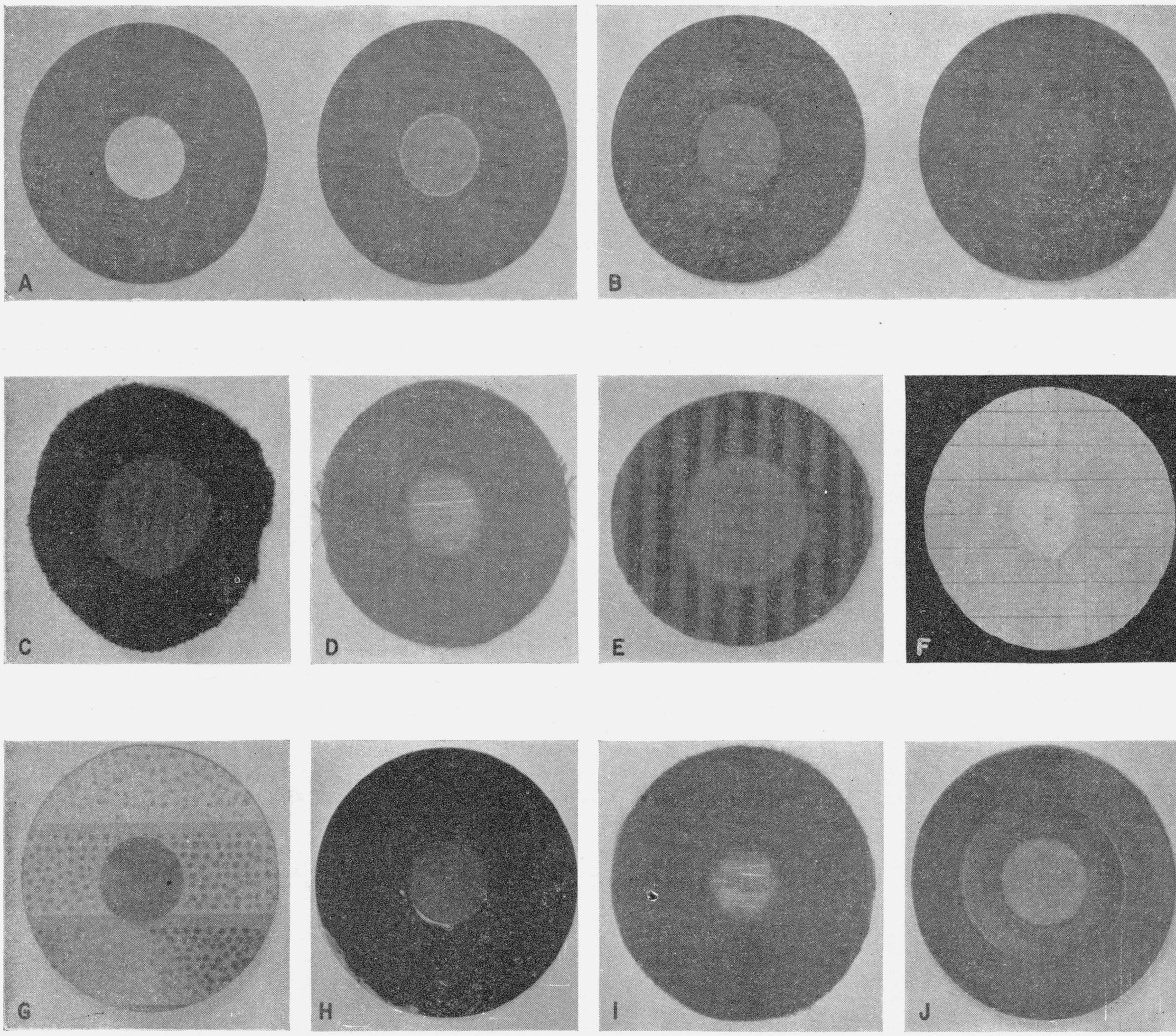

FIGURE 8. *Typically abraded specimens.*

A, Coated glass; B, coated fabrics; C, knitted; D, wool; E, pile; F, paper; G, floor covering; H, plastic; I, nylon; J, leather.

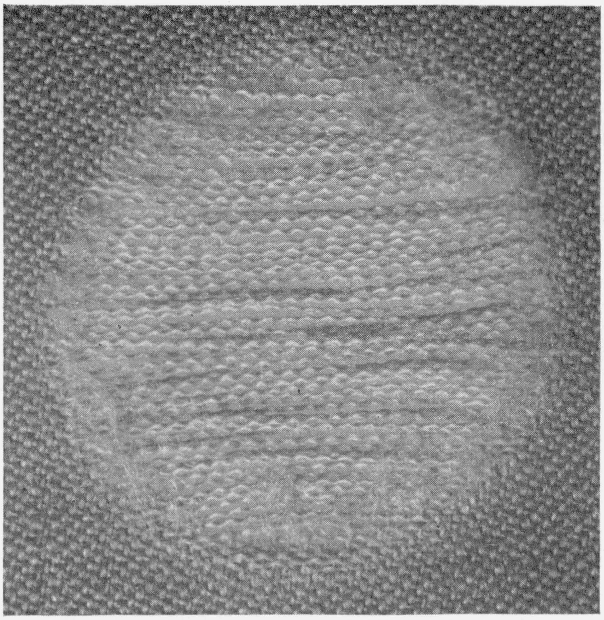

FIGURE 9. *Magnified appearance of an abraded woven specimen.*

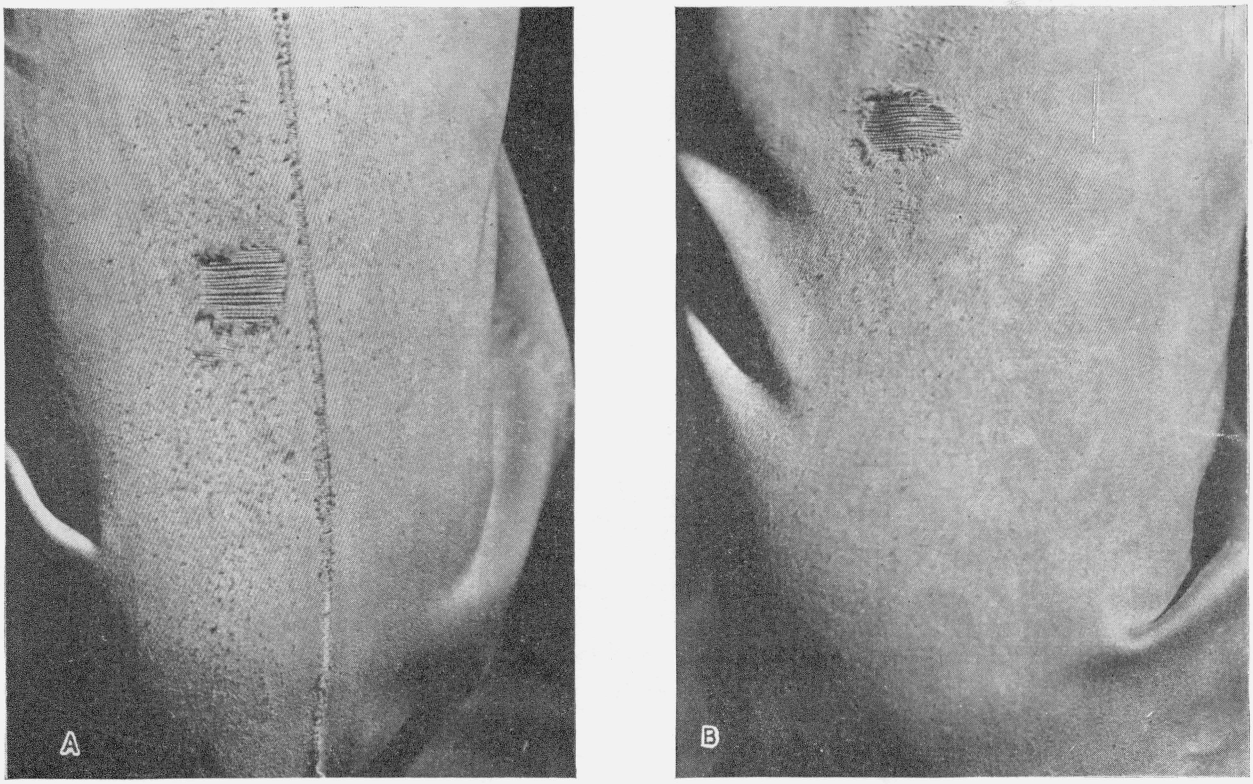

FIGURE 10. *Abraded areas of two trouser legs.*

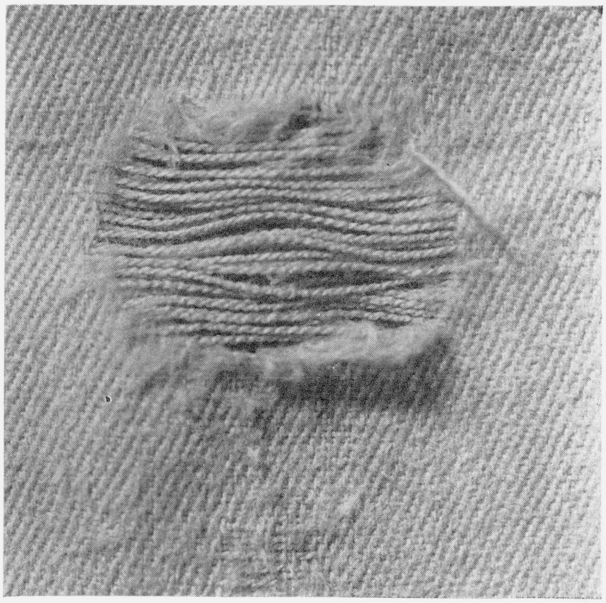

FIGURE 11. *Magnified appearance of abraded area of the trouser leg shown at B in figure 10.*

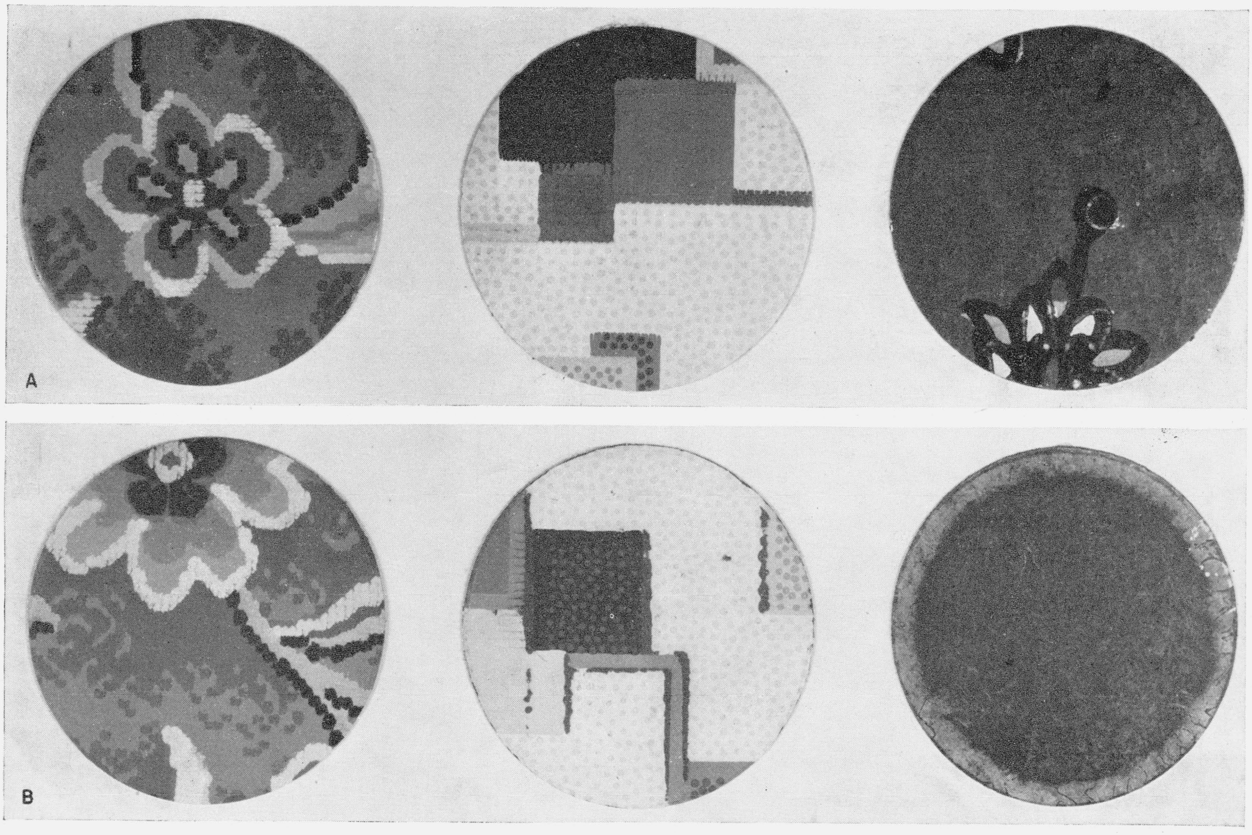

FIGURE 12. *Specimens of printed enamel felt base floor covering before and after test for resistance to detergents.*

A, Original; B, tested 9000 rotations.

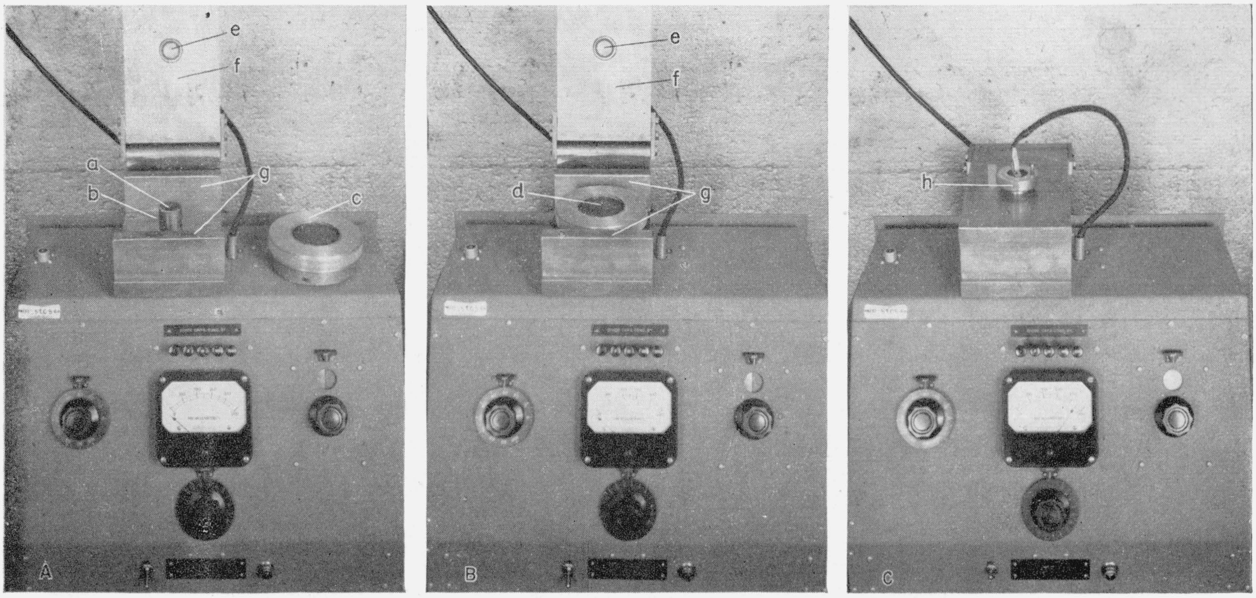

FIGURE 13. *A, Capacitor mounted in capacitance test set; B, abraded specimen suspended over electrode in capacitor; C, capacitor, showing micrometer head for adjusting distance between electrodes.*

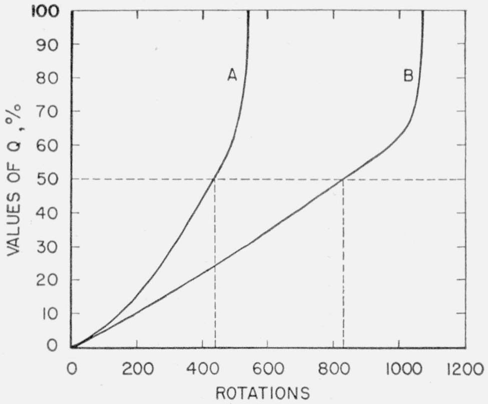

FIGURE 14. *Change in the parameter Q with rotations of abrasion for two fabrics.*

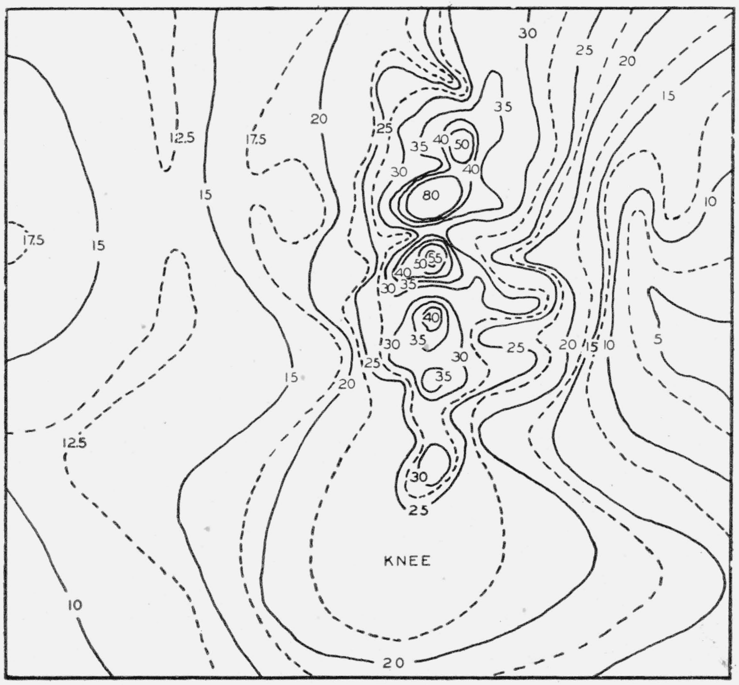

FIGURE 15. *Isoruin map of the worn trouser leg shown at B in figure 10.*

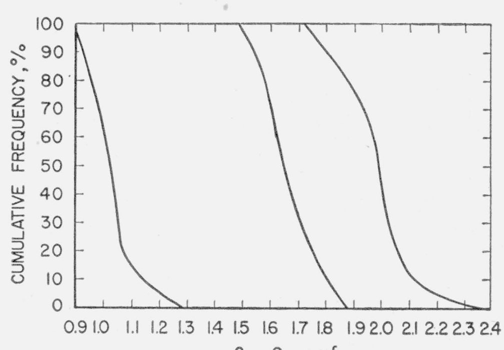

FIGURE 16. *Cumulative frequency curves of capacitance showing variations within three cotton fabrics.*

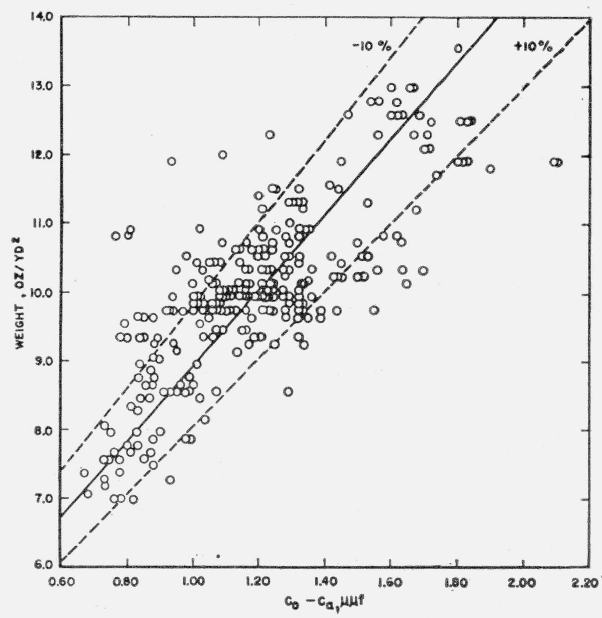

FIGURE 17. *Relation between weight and capacitance of cotton fabrics.*

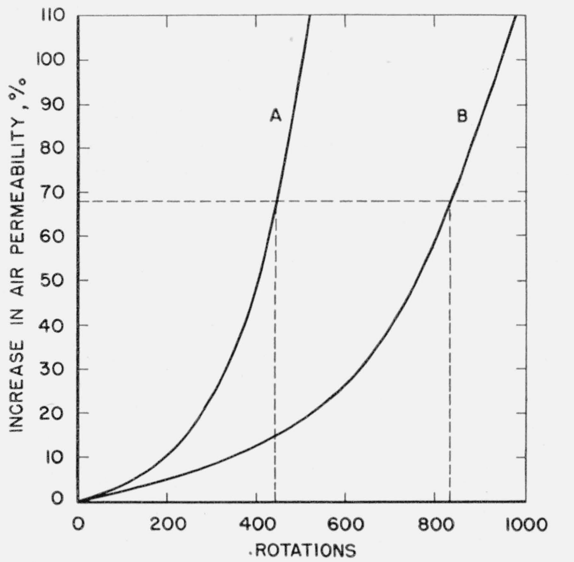

FIGURE 18. *Change in air permeability of two fabrics with rotations of abrasion.*

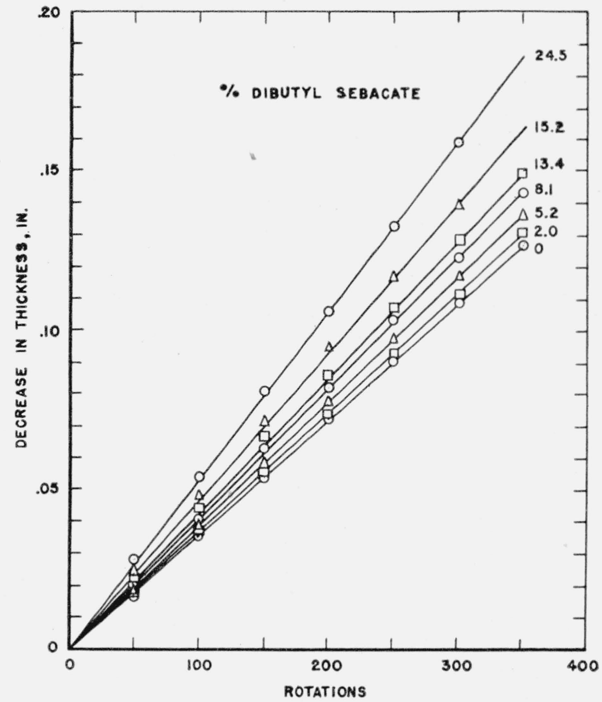

FIGURE 20. *Relation between decrease in thickness and rotations of abrasion of cellulose acetate butyrate containing varying amounts of plasticizer.*

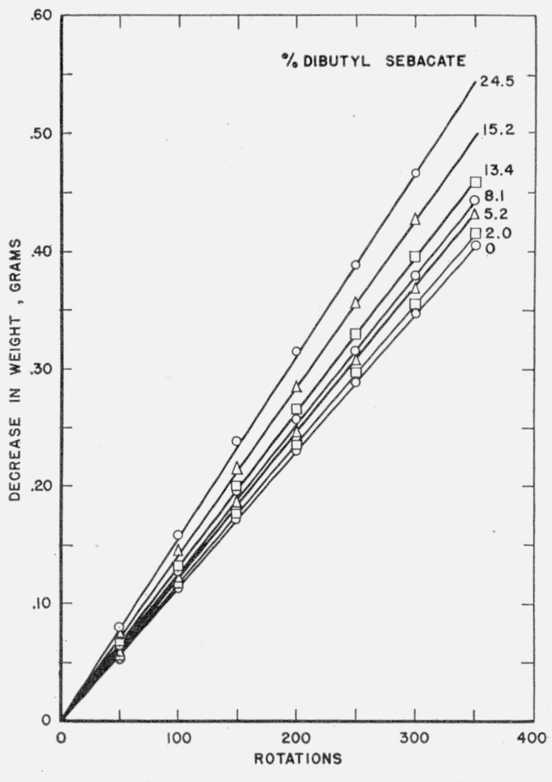

FIGURE 19. *Relation between decrease in weight and rotations of abrasion of cellulose acetate butyrate containing varying amounts of plasticizer.*

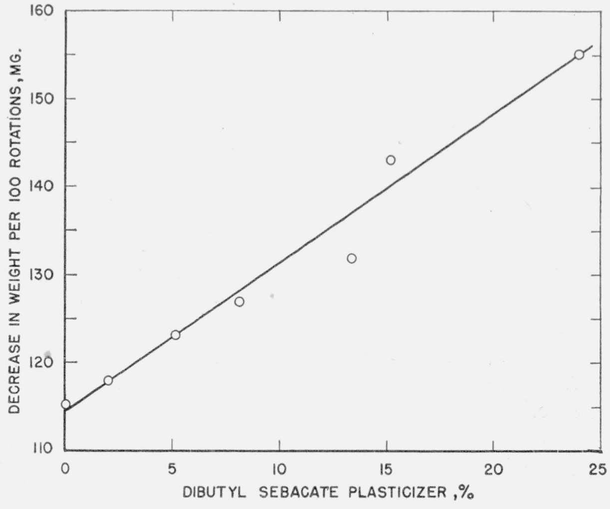

FIGURE 21. *Rate of abrasion of cellulose acetate butyrate as measured by change in weight per 100 rotations.*

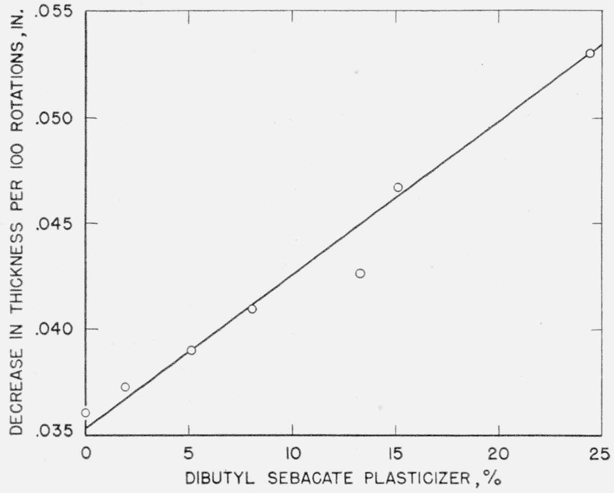

FIGURE 22. *Rate of abrasion of cellulose acetate butyrate as measured by change in thickness per 100 rotations.*

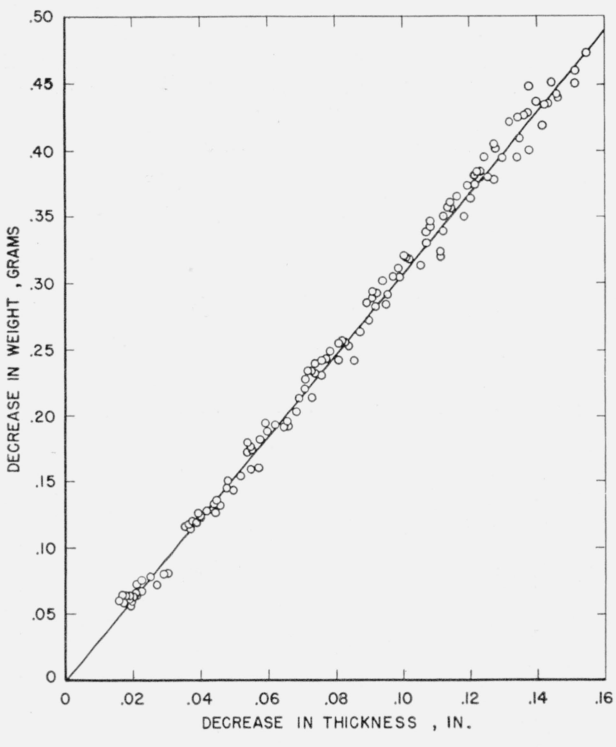

FIGURE 23. *Relation between decrease in weight and decrease in thickness of cellulose acetate butyrate in abrasion tests.*

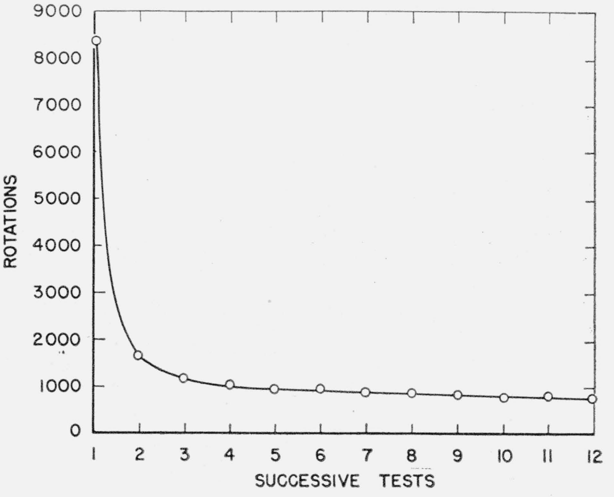

FIGURE 24. *Curve showing increased rate of abrasion in successive tests owing to deposit of resin finish on abradant.*

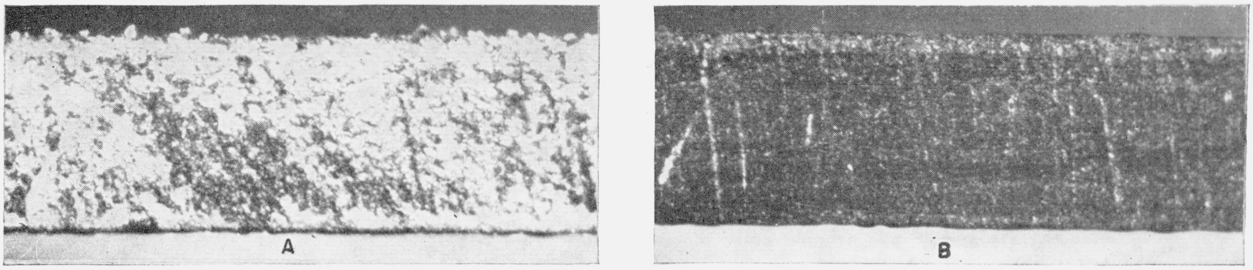

Figure 25. *A, Surface of an abradant blade coated with resin finish in abrasion test; B, resinous coating removed from the abradant blade.*

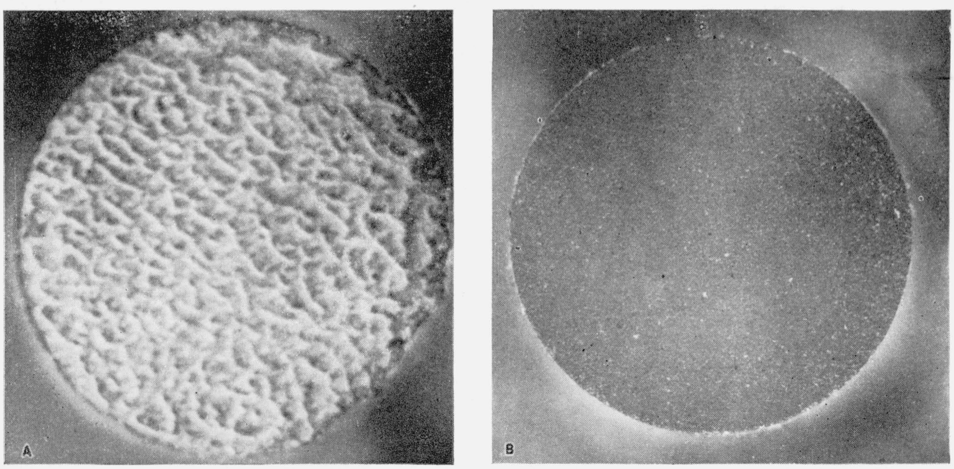

Figure 26. *A, Surface of a Pyrex rod of abradant coated with resin finish in abrasion test; B, surface of a Pyrex rod of abradant without the resinous coating.*

Washington, December 17, 1948.