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# EFFECT OF NUMBER OF WARP AND FILLING YARNS PER INCH AND SOME OTHER ELEMENTS OF CONSTRUCTION ON THE PROPERTIES OF CLOTH

By Herbert F. Schiefer, Daniel H. Taft, and John W. Porter

ABSTRACT

Series of plain-weave and 3/3 basket-weave cloths were woven from 80s (67.2 typp) cotton yarns, varying the number of warp and filling yarns per inch from 80 to 120, and the twist multiplier of the filling yarns from 2.48 to 5.64. The cloths were tested for weight, thickness, air permeability, elongation at rupture, breaking strength, fabric assistance, and tear resistance. The effects of the variations in construction on these properties are reported and discussed. Experimental data are given on the effect of abrasion of the yarns during weaving on the breaking strength and fabric assistance of cloths woven from 2/140 (2/117.6 typp) mercerized-cotton yarns in which the number of warp yarns per inch was kept constant at 114 and the number of filling yarns per inch varied from 30 to120.

CONTENTS



## I. INTRODUCTION

The work reported in this paper is a part of the general program undertaken for the purpose of providing systematic data on the effect of changes in the construction of cloth on its properties.[1] It is concerned with the effect of changes in the number of warp and filling yarns per inch on the weight, thickness, air permeability, elongation at rupture, breaking strength, fabric assistance, and tear resistance of plain weave and 3/3 basket-weave cloths woven from 80s (67.2 typp) cotton yarns. The effect of changes in the twist of the filling yarns, which supplements the study reported in Research Paper RP 861, also received consideration.

A somewhat similar study has been made by Essam [2] who used 50s yarn, spun from fine Sakellaridis cotton, for cloths woven in

[1] Other papers include the following: Herbert F. Schiefer, Richard S. Cleveland, John W. Porter, and Joshua Miller, *Effect of weave on the properties of cloth*, BS J. Research **11**, 441 (1933) RP600; Herbert F. Schiefer and Daniel H. Taft, *Mechanical properties of cotton yarns*, J. Research NBS **15**, 237 (1935) RP826; Herbert F. Schiefer and Daniel H. Taft, *Effect of yarn twist on the properties of cloth*, J. Research NBS **16**, 131 (1936), RP861.

[2] John M. Essam, *The physical properties of fabrics: The effect of yarn and weaving structure*, J. Textile Inst. **19**, T37 (1928); **20**, T275 (1929).

4 different weaves. The cloths of the 4 weaves were each woven with 4 different numbers of yarns per inch, using the same number of yarns per inch in the warp and filling.

The strength of a cloth can be correlated with that of the yarns from which it is made only by taking account of the effect on the yarn of abrasion during weaving, and of the fabric assistance, i. e., the contribution of the warp yarns to the filling breaking strength, and of the filling yarns to the warp breaking strength of the cloths. These effects were studied on some cloths woven from 2/140 (2/117.6 typp) mercerized cotton yarns and are discussed in this paper.

## II. PREPARATION OF CLOTHS

A series of cloths was woven from 80s (67.2 typp) cotton yarns whose properties are described in a previous paper.[3] The cloths were woven in the plain and the 3/3 basket weaves. In both weaves the number of warp yarns per inch of cloth was 80, 100, and 120, respectively. For each of the three warp constructions the number of filling yarns per inch of cloth was 80, 90, 100, 110, and 120, respectively. The twist multiplier of the warp yarn in these cloths was 3.33, and the twist multiplier of the filling yarn was 2.93.

A second series of cloths was woven from the same 80s yarns with 100 yarns per inch of cloth in the warp and with 96 in the filling. The twist multiplier of the warp yarn was 3.33, as before. This series varied with respect to the twist multipliers of the filling yarns, which were 2.48, 2.93, 3.33, 4.07, and 5.64.

A third series of plain-weave cloths was woven in which the warp and filling yarns were 2/140 (2/117.6 typp) mercerized cotton. The cloths were woven with 114 yarns per inch of cloth in the warp, and with 30, 40, 50, 60, 70, 80, 90, 100, and 120 yarns per inch, respectively, in the filling. In connection with the weaving of each cloth, the loom was operated to weave a length of 3 inches with an empty shuttle to provide material for the determination of the effect of loom abrasion on the breaking strength of the warp yarns, and also the effect of interlacing the warp yarns with filling yarns on the warp breaking strength and fabric assistance. In another portion of the cloths the warp yarns were cut out for a width of 3 inches to provide material for the determination of the effect of interlacing the filling yarns with warp yarns on the filling breaking strength and fabric assistance.

The relative humidity of the atmosphere was maintained at approximately 65 percent during the weaving of the cloths.

The effect of changes in construction on the appearance of the cloths is shown in the photographs reproduced in figures 1 and 2.

## III. TEST PROCEDURE

Atmospheric humidity.—All tests were made on material in equilibrium with an atmosphere having a relative humidity of 65 percent and a temperature of 70° F.

Weight.—Five specimens, each 2 inches square, were cut with a die from each cloth and weighed on an analytical balance. The weight of the 5 specimens, expressed in ounces per square yard, is reported in this paper for each cloth.

[3] Herbert F. Schiefer and Daniel H. Taft, *Mechanical properties of cotton yarns*, J. Research NBS **15**, 237 (1935) RP826.

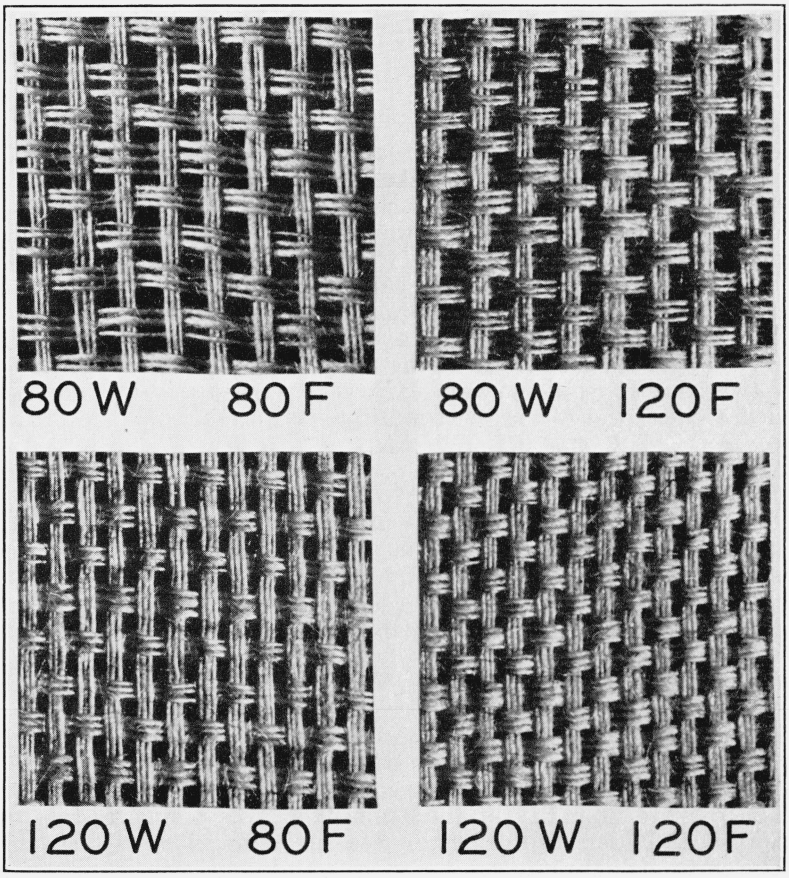


FIGURE 1.—*Effect of number of warp and filling yarns per inch on the appearance of 3/3 basket-weave cloth woven from 80s cotton yarn.*

The number of yarns per inch are indicated. W and F refer to the warp (vertical) and filling (horizontal) yarns, respectively. Magnification about 6.5.

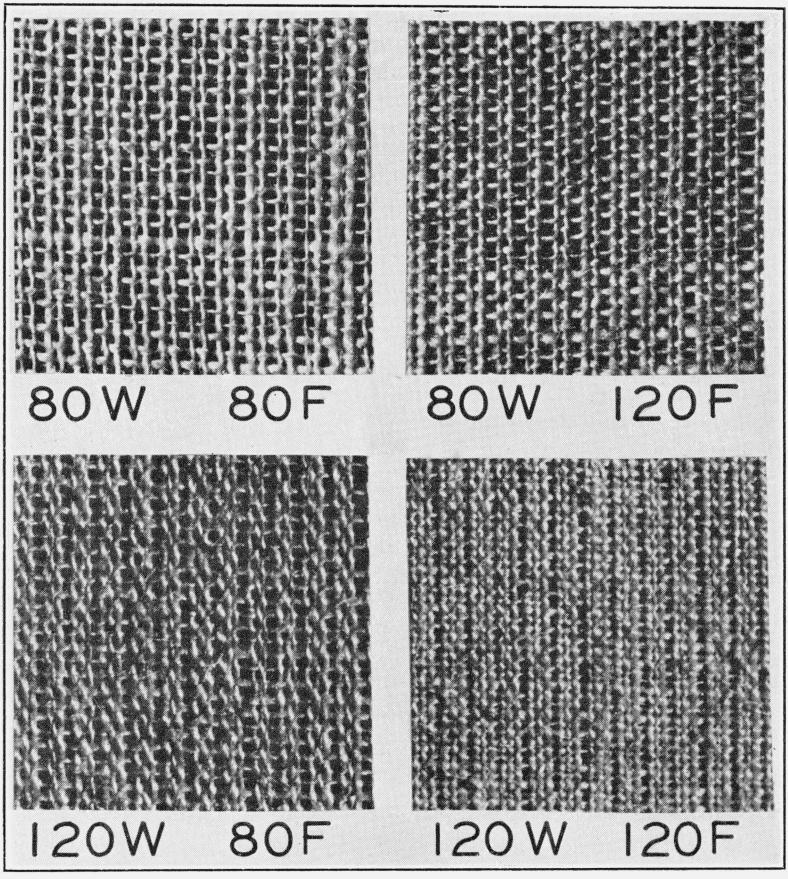


FIGURE 2.—*Effect of number of warp and filling yarns per inch on the appearance of plain-weave cloth woven from 80s cotton yarn.*

The number of yarns per inch are indicated. W and F refer to the warp (vertical) and filling (horizontal) yarns, respectively. Magnification about 6.5.

Thickness.—The thickness of each cloth was measured at 10 areas with the compressometer,[4] using a circular foot 1 inch in diameter and exerting a pressure of 1 lb/in$^2$. The average of the 10 determinations on each cloth is reported to the nearest 0.0005 inch.

Air permeability.—Three air-permeability determinations were made on each cloth according to the method described by Schiefer and Best.[5] The average result of the 3 tests on each cloth, expressed in cubic feet per minute per square foot of cloth at a pressure drop of 0.5 inch of water across the cloth, is reported in this paper.

Breaking strength and elongation at rupture.—The cloths were tested for breaking strength and elongation at rupture by the standard strip method.[6] Five determinations were made in the warp and five in the filling direction of each cloth. The tests were made on a machine of the pendulum type having a capacity of 55 pounds.

In the third series of cloths, strips 1 inch in width and about 12 inches in length were taken from the warp and filling in such a manner that the strips included the portions in which the warp (or filling) yarns were not interlaced with filling (or warp) yarns. One-half of each strip was tested for breaking strength of the cloth while the other half was tested for the breaking strength of the yarns which had been subjected to the actions of the loom. The breaking strengths of the warp and filling yarns were also determined by the multiple-strand method.[7]

Fabric assistance is computed from the difference in breaking strength of the cloth and the breaking strength of the yarns tested by the multiple-strand method. In the third series of cloths fabric assistance is also computed from the difference in breaking strength of the cloths and the breaking strength of the yarns which had been subjected to the actions of the loom.

Tear resistance.—The tear resistance was determined from specimens 3 inches wide and 6 inches long, according to the preferred method of the American Society for Testing Materials.[8] The average result of 5 tests in the warp direction and of 5 tests in the filling direction is reported for each cloth.

## IV. RESULTS

### 1. EFFECT OF NUMBER OF WARP AND FILLING YARNS PER INCH

The effect of varying the number of warp and filling yarns per inch of cloth on the weight, thickness, air permeability, elongation at rupture, breaking strength, fabric assistance, and tear resistance of the basket- and plain-weave cloths is shown by the data given in table 1.

With only a few exceptions, the weight of the cloth is directly proportional to the sum of the number of warp and filling yarns per inch. There is no marked difference in the weight between similar cloths of the 2 weaves.

[4] Herbert F. Schiefer, *The compressometer, an instrument for evaluating the thickness, compressibility, and compressional resilience of textiles and similar materials*, BS J. Research **10**, 705 (1933) RP561.
[5] *A portable instrument for measuring air permeability of fabrics*, BS J. Research **6**, 51 (1931) RP261.
[6] Federal Specification for Textiles; Test Methods, CCC–T–191.
[7] C. W. Schoffstall and H. A. Hamm, *A multiple-strand test for yarns*, BS J. Research **2**, 871 (1929) RP61
[8] ASTM Standards on Textile Materials, ASTM designation D39–34, p. 8 (October 1935).

TABLE 1.—*Effect of number of warp and filling yarns per inch of cloth on the properties of cloth woven from 80s cotton yarn*

| Warp yarns per inch | 3/3 BASKET WEAVE | | | | | PLAIN WEAVE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Filling yarns per inch | | | | | | | | | |
| | 80 | 90 | 100 | 110 | 120 | 80 | 90 | 100 | 110 | 120 |
| **Weight Per Square Yard, Ounces** | | | | | | | | | | |
| 80 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 1.5 | 1.7 | 1.8 | 1.9 | 2.0 |
| 100 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 | 1.7 | 1.9 | 2.0 | 2.1 | 2.2 |
| 120 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 |
| **Thickness, Inch** | | | | | | | | | | |
| 80 | 0.010 | 0.011 | 0.0115 | 0.0115 | 0.012 | 0.0075 | 0.008 | 0.008 | 0.008 | 0.008 |
| 100 | .0095 | .010 | .0105 | .011 | .0115 | .009 | .0085 | .0085 | .0085 | .0085 |
| 120 | .010 | .010 | .0105 | .0105 | .011 | .009 | .009 | .009 | .009 | .009 |
| **Air Permeability** [1] | | | | | | | | | | |
| 80 | 663 | 579 | 515 | 439 | 402 | 416 | 317 | 254 | 195 | 175 |
| 100 | 441 | 390 | 318 | 307 | 264 | 295 | 243 | 195 | 167 | 124 |
| 120 | 394 | 354 | 297 | 259 | 221 | 290 | 211 | 162 | 125 | 99 |
| **Filling Elongation, Percent** | | | | | | | | | | |
| 80 | 9 | 11 | 13 | 13 | 13 | 11 | 13 | 14 | 16 | 19 |
| 100 | 11 | 11 | 12 | 13 | 14 | 14 | 15 | 16 | 17 | 18 |
| 120 | 10 | 12 | 13 | 14 | 16 | 14 | 14 | 16 | 16 | 18 |
| **Warp Elongation, Percent** | | | | | | | | | | |
| 80 | 10 | 10 | 10 | 10 | 10 | 12 | 12 | 11 | 12 | 13 |
| 100 | 12 | 11 | 12 | 12 | 12 | 16 | 17 | 18 | 18 | 20 |
| 120 | 14 | 14 | 14 | 15 | 14 | 21 | 19 | 21 | 20 | 23 |
| **Filling Breaking Strength, Pounds** | | | | | | | | | | |
| 80 | 17 | 20 | 23 | 27 | 29 | 21 | 25 | 29 | 34 | 38 |
| 100 | 21 | 22 | 25 | 29 | 31 | 24 | 28 | 31 | 33 | 39 |
| 120 | 20 | 24 | 25 | 28 | 33 | 26 | 29 | 33 | 34 | 36 |
| **Warp Breaking Strength, Pounds** | | | | | | | | | | |
| 80 | 23 | 23 | 23 | 23 | 23 | 25 | 24 | 24 | 25 | 25 |
| 100 | 29 | 29 | 29 | 29 | 28 | 31 | 32 | 30 | 29 | 27 |
| 120 | 36 | 35 | 35 | 36 | 35 | 35 | 34 | 31 | 33 | 29 |
| **Filling Fabric Assistance, Percent** | | | | | | | | | | |
| 80 | −6 | −1 | 5 | 9 | 9 | 17 | 23 | 32 | 39 | 41 |
| 100 | 12 | 8 | 10 | 17 | 15 | 34 | 40 | 40 | 34 | 45 |
| 120 | 11 | 19 | 14 | 15 | 23 | 45 | 40 | 50 | 39 | 34 |
| **Warp Fabric Assistance, Percent** | | | | | | | | | | |
| 80 | 23 | 21 | 21 | 21 | 20 | 32 | 26 | 26 | 32 | 32 |
| 100 | 22 | 22 | 22 | 22 | 18 | 28 | 32 | 24 | 20 | 12 |
| 120 | 26 | 23 | 23 | 26 | 23 | 25 | 21 | 12 | 17 | 3 |

[1] Cubic feet per minute per square foot of cloth at a pressure drop of 0.5 inch of water across the cloth.

TABLE 1.—*Effect of number of warp and filling yarns per inch of cloth on the properties of cloth woven from 80s cotton yarn*—Continued

| Warp yarns per inch | 3/3 BASKET WEAVE | | | | | PLAIN WEAVE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Filling yarns per inch | | | | | | | | | |
| | 80 | 90 | 100 | 110 | 120 | 80 | 90 | 100 | 110 | 120 |
| | Filling Tear Resistance, Pounds | | | | | | | | | |
| 80 | 4 | 5 | 4 | 5 | 5 | 3 | 3 | 3 | 3 | 3 |
| 100 | 4 | 4 | 5 | 5 | 6 | 2 | 3 | 3 | 3 | 3 |
| 120 | 4 | 4 | 4 | 5 | 4 | 2 | 2 | 3 | 2 | 2 |
| | Warp Tear Resistance, Pounds | | | | | | | | | |
| 80 | 5 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 3 | 3 |
| 100 | 5 | 6 | 6 | 5 | 5 | 5 | 3 | 3 | 3 | 3 |
| 120 | 6 | 7 | 7 | 6 | 6 | 3 | 4 | 3 | 4 | 3 |

The number and warp of filling yarns per inch does not affect the thickness of the cloths appreciably, although there is a slight tendency for the cloths to increase in thickness with the increase in the number of filling yarns. The difference in thickness between corresponding cloths of the basket and plain weaves is marked. The cloths of the basket weave, which have a fewer number of yarn interlacings, are thicker than corresponding cloths of the plain weave. The yarns of these cloths are of fairly low twist, that is, yarns of relatively large diameter which may be easily compressed. The difference in thickness between corresponding cloths of the two weaves may be attributed to the greater compression of the yarns in the plain weave resulting from the greater number of yarn interlacings.

The air permeability decreases greatly with an increase in the number of yarns per inch in either the warp or filling direction of the cloth. As expected, the air permeability of cloths of the basket weave is considerably greater than that of corresponding cloths of the plain weave. An increase of 50 percent in the sum of the number of warp and filling yarns per inch increases the weight by about 50 percent and decreases the air permeability to about one-fourth in the plain weave and to about one-third in the basket weave.

The elongation at rupture increases with the number of warp and filling yarns per inch. This increase is attributable to the increase in take-up resulting from the increase in the number of yarn interlacings. The elongation of cloths of the plain weave is greater than that of corresponding cloths of the basket weave for the same reason, which is in agreement with the results reported in Research Papers RP600 and RP861 and by Essam.

The filling and warp breaking strengths increase with the number of filling and warp yarns per inch, respectively. The breaking strengths are also affected by such factors as yarn twist, number of yarn interlacings, and loom abrasion. The effect of these factors is brought out clearly by the values for fabric assistance, in which the breaking strength of the yarn and the number of yarns per inch are taken into consideration.

The filling fabric assistance increases slightly with the increase in the number of warp yarns per inch and also with the increase in the number of filling yarns per inch. This increase is quite appreciable in the basket-weave cloths and in the plain-weave cloths which have a low number of filling or warp yarns per inch. It is attributable to the increase in the breaking strength of the cloths resulting from the increase in the number of yarn interlacings. It should be noted, however, that the filling fabric assistance of the plain weave decreases for cloths having a high number of filling or warp yarns per inch. For these cloths the yarns are packed very tightly resulting in great strains on the filling yarns. The number of yarn interlacings in these cloths exceeds the number usually considered satisfactory for good weaving.

The warp fabric assistance increases slightly with the increase in the number of warp yarns per inch for the basket weave. This increase is attributable to the increase in the number of yarn interlacings. The warp fabric assistance decreases slightly with the increase in the number of filling yarns per inch in both weaves. An increase should result because of the increase in the number of yarn interlacings. The decrease is attributable to abrasion of the warp yarns by the loom, which increases directly with the number of filling yarns per inch.

The warp fabric assistance decreases markedly in the plain weave with the increase in the number of warp or filling yarns per inch. The loom abrasion is more severe in the plain weave than in the 3/3 basket weave. This increase in loom abrasion and the great packing of the warp and filling yarns in the plain weave account for its low fabric assistance in the warp direction.

The fabric assistance is in general greater in the plain weave than in corresponding cloths of the basket weave, which is in agreement with the results reported in Research Papers RP600 and RP861 and by Essam. An exception should be noted, however, in the warp fabric assistance for the cloths having a high number of warp and filling yarns per inch for which the warp fabric assistance of the basket weave exceeds that of the plain weave. This effect is attributable to the larger number of yarn interlacings and to the greater packing of warp and filling yarns in the plain weave, resulting in greater loom abrasion and poor weaving.

The tear resistance depends upon the freedom of movement of the warp and filling yarns and upon the elongation and breaking strength of the yarns. The number of warp and filling yarns appear to have little effect on the tear resistance. The tear resistance is greater for the basket weave, which is more open and contains fewer yarn interlacings than the plain weave, which is in agreement with the results noted in Research Paper RP600. The tear resistance of the warp is greater than that of the filling. This difference is attributable to the fact that the elongation and breaking strength are greater for the warp yarns than for the filling yarns.

### 2. EFFECT OF FILLING TWIST

The effect of changing the twist multiplier of the filling yarn on the properties of 3/3 basket-weave and plain-weave cloths is shown by the data given in table 2.

TABLE 2.—*Effect of filling twist on the properties of cloth woven from 80s cotton yarn in which the twist multiplier of the warp yarn is 3.33, with 100 yarns per inch in the warp and with 96 yarns per inch in the filling*

| Designation | | 3/3 Basket weave | | | | | Plain weave | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Filling twist multiplier | | 2.48 | 2.93 | 3.33 | 4.07 | 5.64 | 2.48 | 2.93 | 3.33 | 4.07 | 5.64 |
| Weight, oz/yd² | | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Thickness, in | | 0.010 | 0.010 | 0.011 | 0.011 | 0.0115 | 0.0085 | 0.008 | 0.008 | 0.008 | 0.0085 |
| Air permeability [1] | | 357 | 383 | 430 | 497 | 547 | 169 | 203 | 222 | 252 | 290 |
| Elongation, % | W | 11 | 12 | 12 | 12 | 12 | 17 | 16 | 17 | 17 | 19 |
| | F | 11 | 12 | 13 | 13 | 15 | 15 | 16 | 15 | 15 | 19 |
| Breaking strength, lb | W | 29 | 31 | 30 | 29 | 30 | 31 | 31 | 32 | 31 | 31 |
| | F | 20 | 24 | 27 | 25 | 21 | 31 | 31 | 32 | 30 | 31 |
| Fabric assistance, % | W | 20 | 25 | 20 | 16 | 20 | 26 | 26 | 30 | 26 | 26 |
| | F | −1 | 11 | 18 | 14 | 19 | 56 | 44 | 40 | 35 | 73 |
| Tear resistance, lb | W | 5 | 6 | 5 | 5 | 5 | 3 | 3 | 3 | 3 | 2 |
| | F | 4 | 4 | 5 | 5 | 6 | 2 | 3 | 3 | 3 | 3 |

[1] Cubic feet per minute per square foot of cloth at a pressure drop of 0.5 inch of water across the cloth.

The weight of the cloths is not affected by a change in the filling twist, which is in agreement with the results noted in Research Paper RP861 for cloths woven from 10s cotton yarns.

The thickness of the basket-weave cloths increases slightly with the increase in the twist of the filling yarns. The thickness of the plain-weave cloth is not affected by the filling twist. The thickness of the plain-weave cloths is considerably less than that of the basket-weave cloths, a fact already noted earlier in this paper.

The air permeability increases greatly with the increase in the filling twist. It is considerably lower for the plain-weave cloths than for corresponding cloths of the basket weave.

The warp elongation at rupture varies little with the increase in twist of the filling yarns. The increase in the filling elongation of the cloths is attributable to the increase in elongation of the yarns resulting from higher twist. The difference in elongation between corresponding cloths of the plain and basket weaves is attributable to the difference in take-up resulting from the number of yarn interlacings.

The warp breaking strength and fabric assistance are affected very little by the twist of the filling yarns. The filling breaking strength, however, increases to a maximum at the filling twist multiplier 3.33, the twist multiplier at which the breaking strength of the yarn is a maximum,[9] and then decreases for higher twists. The variation is greater in the basket weave. The breaking strength and fabric assistance are greater in the plain weave. The variations in the results for elongation, breaking strength, and fabric assistance of this series of cloths with the increase in the filling twist are in substantial agreement with those noted in Research Paper RP861 for cloths woven from 10s cotton yarns.

The filling tear resistance appears to increase slightly with the twist of the filling yarns. This increase is attributable to the increase in elongation and to the increase in the freedom of movement of the filling yarns of higher twist because of their smaller diameter and smoother surface. The tear resistance of the basket-weave cloths is greater than that of the plain weave, because of the greater freedom of movement of the yarns in the direction of the tear.

[9] Herbert F. Schiefer and Daniel H. Taft, *Mechanical properties of cotton yarns*, J. Research NBS **15**, 237 (1935), RP826.

### 3. EFFECT OF LOOM ABRASION AND YARN INTERLACING

The effect of loom abrasion and of yarn interlacing on the breaking strength and fabric assistance of cloths, in which the number of warp yarns per inch was kept constant at 114 and the number of filling yarns per inch was varied, is shown by the curves in figure 3. The lower group of curves gives the warp and filling breaking strength of the cloths, the breaking strength of the warp and filling yarns which had been subjected to the actions of the loom, and the breaking strength of the warp and filling yarns tested by the multiple-strand method. The upper group of curves gives the warp and filling fabric assistance of the cloths based upon the breaking strength of the yarns which

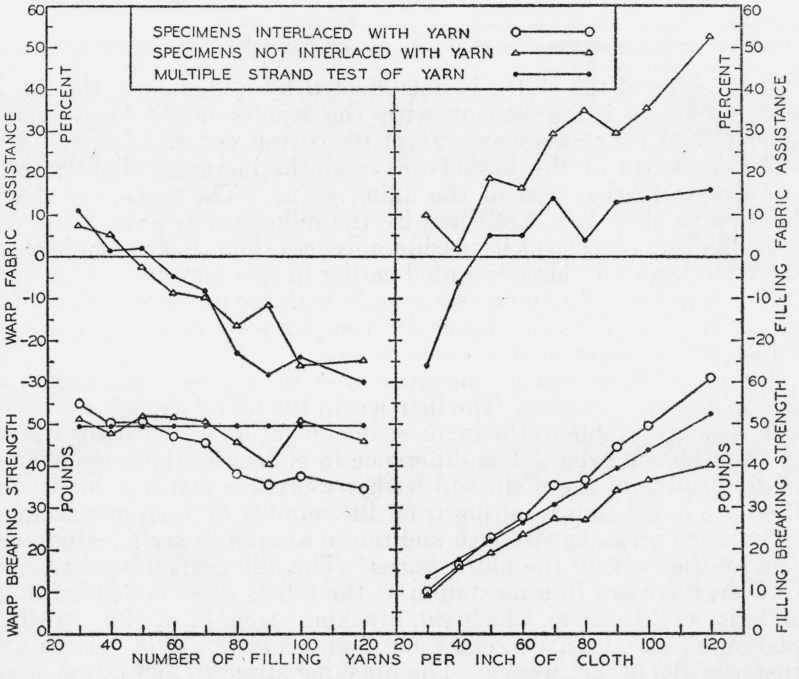


FIGURE 3.—*Breaking strength of cloth specimens woven from 2/140 mercerized cotton yarn, yarn specimens which had been subjected to the actions of the loom without interlacing with a second set of yarns, and original yarns tested by the multiple-strand method.*

The fabric assistance of the cloths is based upon the breaking strength of the yarns which had been subjected to the actions of the loom and upon the breaking strength of the yarns tested by the multiple strand method.

had been subjected to the actions of the loom and upon the breaking strength of the yarns tested by the multiple-strand method.

Loom abrasion decreases the breaking strength of the yarns in the cloth. The decrease is proportional to the amount of loom abrasion, that is, to the number of filling yarns per inch since the movements of the loom are directly proportional to the number of filling yarns per inch. This effect is clearly shown by the progressive decrease in the warp breaking strength of the cloths and in the breaking strength of the warp yarns which had been subjected to the actions of the loom with the increase in the number of filling yarns per inch. It is

also clearly shown by the progressive decrease in the breaking strength of the filling yarns which had been subjected to the actions of the loom relative to the breaking strength of the filling yarns tested by the multiple-strand method.

Fabric assistance increases with the number of yarn interlacings. This effect is clearly shown by the progressive increase in the filling breaking strength of the cloth relative to either the breaking strength of an equal number of filling yarns tested by the multiple-strand method, or to the breaking strength of the filling yarns woven across an area of the warp from which the warp yarns have cut out. The results for the warp indicate that loom abrasion decreases the warp breaking strength at a greater rate as the number of filling yarns per inch is increased than the increase resulting from the increase in the number of yarn interlacings. It should be noted, however, that the effects of these two opposing factors are equal at 50 filling yarns per inch. Below 50 filling yarns per inch the effect of the number of yarn interlacings is greater than loom abrasion as indicated by a positive fabric assistance. Above 50 filling yarns per inch the effect of loom abrasion is greater as indicated by a negative fabric assistance.

WASHINGTON, December 30, 1935.