THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given Anna Mathilda Streed final oral examination for the degree of

Master of Science.

We recommend that the degree of

Master of Science.

be conferred upon the candidate.

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Date

10-20 5M

THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Anna Mathilda Streed for the degree of Master of Science. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

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Date ____________________

10-20 5M

A STUDY OF THE RELATION BETWEEN CERTAIN VARIABLE FACTORS AND TENSILE STRENGTH IN A GROUP OF COTTON FABRICS

by

Anna Mathilda Streed

A thesis submitted to

the Faculty of the Graduate School

of the University of Minnesota

in partial fulfillment of

the requirements for the

degree of Master of Science

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A STUDY OF THE RELATION BETWEEN CERTAIN VARIABLE FACTORS AND TENSILE STRENGTH IN A GROUP OF COTTON FABRICS

INTRODUCTION

Statement of Problem

The purpose of this investigation has been the determination of the relationship between tensile strength and certain variable factors in a group of cotton underwear materials. The variable factors reported herein are weight and cost per square yard, ends and picks per inch, twist, yarn elongation, yarn number, moisture regain, and load stretch.

Historical

That textile materials of today are "markedly unstandardized" (Phelps 1922) is admitted by textile manufacturers (Jury 1921; Crossley 1921; Anon. 1920; Anon. 1921b) and is very apparent to the consuming public. The condition as it exists is accurately described by a writer in the "Textile World" (Anon. 1920) in these words: "It (Textile Industry) has no methods of identifying and classifying raw materials, yarns and fabrics, that bear any logical relation to each other, while its nomenclature is incomplete and often decidedly vague...... Rule of thumb methods and inaccurate classifications that have been endured by textile manufacturers and merchants for more than a century, are not acceptable to the highly organized electrical, automotive and allied industries. The latter are accustomed to buy, manufacture and sell according to recognized scientific standards and their demand for standardized specifications and testing methods has brought a satisfactory response from some manufacturers of mechanical fabrics". McGowan (1921) states that standardization is needed in all textile lines, not only for users of mechanical fabrics such as fabrics used for tires and belting, but also for users of other fabrics. He suggests four standardization headings: namely, (1) standardization of quality; (2) of measurements; (3) of performance; (4) of a variety of constants. According to this writer, the manufacturer would be more interested in the standardization of measurements and quality and the consumer in standardization of quality and performance. A. E. Jury (1921) points out the "remarkable improvements" which have been made in the manufacture of automobile tire fabrics in the last ten years. These improvements resulted from a demand for them, and were made possible thru "a definite knowledge of the conditions the fabric must meet and the application of exact technical information obtained by scientific tests of the fibres, yarns and finished fabrics". Walen (1918a) in developing a cotton air plane fabric divided his investigation into three parts: (1) "the determination of what properties should be studied; (2) the development of methods for determining the desired properties; and (3) the determination of the factors of manufacture which influence the properties together with the magnitude of the influence" . There is no doubt but that the scientific application of similar methods to some of the more commonly used cotton underwear fabrics would result in products of greater uniformity and quality. In the automobile industry the application of scientific methods to those manufacturing processes which result in the production of a high class fabric, the behavior of which, under certain conditions, may be accurately determined before use (Jury 1921), has resulted in increased business for the producer and has benefitted the consumer in that he knows the probable yield in satisfaction and wearing quality for his expenditure of money. It is reasonable to assume that similar benefits would result both to the manufacturer and the consumer thru the application of similar methods to the production of some of the more widely used textiles fabrics.

In order to obtain maximum values, reasonable standards must be set up. There are two possible methods by means of which these standards may be determined, namely, usage and scientific research. The difficulties which hinder the successful application of the first method are the many variables which have to be considered in that different persons do not wear nor care for their garments in the same way, giving wearing results which are not comparable. Moreover, a very long period of time for experimentation would be necessary before conclusions could be reached with safety. The second method is the better one therefore, in that work under controlled conditions and comparable results are possible. The American Home Economics Association has proposed to combine these methods (Birdseye 1921) in evaluating minimum wearing standards of the staple fabrics.

Indications are not lacking that there is a desire on the part of the consuming public for assurance that a dollar's purchase of at least certain fabrics will yield reasonably similar satisfaction in wearing quality. The first of these indications found expression in 1919 when the Textile Section of the American Home Economics Association (Birdseye 1921) "appointed its Committee on the Standardization of Textile Fabrics, whose purpose was to secure the cooperation of associations of manufacturers, retailers, and jobbers in studying minimum standards of wear for certain of the staple fabrics that enter largely into the wardrobe of the family of average means, and later, in placing on the market fabrics that meet or surpassed these standards, identified in such fashion that the consumer desiring to get the best value for her money could recognize them at sight or call for them by name". This plan has received the support of the Textile Division of the Bureau of Standards and of the National Research Council. A more recent manifestation of this same demand has come from a quite different group of consumers, namely, large hotel owners and the Pullman Company, who have requested the Textile Division of the Bureau of Standards to conduct tests for the determination of wearing qualities of bed linens. The work is to be done by the Bureau of Standards in conjunction with the Textile Division of the Department of Commerce (Anon. 1921b). The tests to be applied are: (1) resistance to abrasion; (2) resistance to bursting; (3) breaking strength; (4) tearing strength; (5) wear in folding; (6) effect of laundering, with the different tests conducted after the fabrics have been submitted to various cleansing fluids. It is hoped this piece of work may lead to the production of a sheeting which represents maximum quality for a given expenditure.

That investigational work should be the basis for standardization was stated by A. E. Jury (1921) with reference to mechanical fabrics and by E. Dean Walen (1918 and 1918a) with reference to cotton air plane fabrics. The same principle was recognized by the American Home Economics Association (Birdseye 1921) with reference to the more staple fabrics in common use, and by the previously mentioned large consumers of bed linen in their recent request of the Bureau of Standards (Anon. 1921b). "Fabric testing" may not come, necessarily, within the scope of "research", but it may produce data which will be of value in research work. There are in this country a number of organizations primarily intended for textile testing. Several of these are found in merchants' establishments and are organized primarily for the benefit of the merchant, their benefit to the public being of secondary importance. Sears, Roebuck and Company maintain such a textile testing laboratory. T. Eaton and Company

(1919) in their Winnipeg store maintain a laboratory whose "mission in life is to maintain the Eaton standard", and includes on the laboratory staff a textiles expert. The labroatory acts as assistant "to the department buyer" and "as a critic to the newspaper and catalogue advertising of Eaton merchandise". Filene's, in Boston, also maintain a textile testing laboratory which is described in a personal communication from E. B. Millard, consulting chemist for Filene's, as having been "equipped solely for the store's use". There is also one commercial testing company, The United States Conditioning and Testing Company of New York City. This firm works with raw silk, determining the moisture content and the percent natural gum in any given lot of fiber. It maintains conditioning and testing rooms not only in this country, but also in the chief silk producing countries of the world and will do work for any buyer of raw silk by whom they are employed.

Organizations primarily intended for, or associated with, investigational work in textiles are also in operation. One of the earliest of these was the Bureau of Standards, (Walen 1918), which was established in 1901 "to serve the government and the people, and it was deemed advisable to establish, among other lines of an investigational nature, a section devoted to the determination of the properties of textile materials and the factors influencing those properties". Upon request, this department has furnished the government with information concerning "the structure and design of fabrics which would be most efficient for the particular use for which they were intended". These activities have usually been concerned with the development of efficient military fabrics, the information having been given in the form of specifications for purchasing and for adequate inspection of these materials. The inspection and testing work of the Bureau has been confined to the settling of disputes which have arisen between the government and the manufacturer. "The relation of the section to the people has been much the same as to the government. Upon payment of a nominal fee, tests are made upon submitted material, according to the generally accepted practice or according to a specific method which might be desired" (Walen 1918). For several years the Bureau has conducted an annual textile conference "with the view of stimulating interest in obtaining exact information regarding the properties of textile materials". The reports of these conferences have been published as (Anon. 1917) "Proceedings of the First, Second, etc. Annual Textile Conference".

During the war the Bureau rendered very valuable service to the government by developing a cotton air plane fabric as good as, or superior to, the linen fabrics hitherto considered indispensable for this purpose (Walen 1918a). The flax fields of Ireland were not able to supply the increasing demand for linen. In January 1916 the Bureau began experimenting with cotton airplane fabric manufacture; in March 1917, specifications and instructions were given to manufacturers; in April 1917, the first fabrics were received by the Bureau; and by May 1917, these fabrics had passed the laboratory tests and were being placed on airplanes where they were found to be entirely satisfactory. The results of their investigation on sheeting should be of interest not only to hotel owners and the Pullman Company, but to all users of sheetings.

The Bureau of Plant Industry is another government institution which was organized for the purpose of carrying on investigational work part of which is associated with textiles. The work of this Bureau deals primarily with the plant fibre (Cobb 1920). Cobb points out that textile research must begin with the single fibre in order to determine those changes, "physical and chemical", which are produced in it by varying conditions. He claims that research along this line would solve many problems associated with the bleaching, dyeing and finishing processes. As a part of this work, one contribution of the Bureau of

Plant Industry has been the development of a method for measuring accurately the length of the cotton fibre (Cobb 1916).

Committee D-13 of the American Society for Testing Materials is a commercial organization the main purpose of which is textile standardization (Jury 1921). This society was organized in 1898 as the American Section of the International Association for Testing Materials, but was incorporated as the American Society for Testing Materials in 1902. Due to the experience gained by this society during the past twenty years in the standardization of many different kinds of materials for many large industries, the Society for Testing Materials hopes to accomplish some textile standardization. The committee is composed of "over forty members, principally representatives of manufacturers and consumers of mechanical fabrics and representatives of textiles schools and other institutes". The report of the Committee (Anon 1921b) shows the following sub-committees to have been appointed - (1) humidity, (2) fabric test methods, (3) testing machines, (4) classification and identification of fibres and fabrics, (5) nomenclature and definitions, (6) imperfections and tolerances, (7) yarn, thread and twine, (8) publicity. Altho the committee has not long been in existence (Jury 1921) it "has succeeded in the establishment of standard test methods which are in general use (Am. Soc. Tes. Mat. 1920) by producers and users of these materials". These methods are the result of work carried on over a period of years in the laboratories and manufacturing plants of the several members of the committee. At present the committee has extended its work (Jury 1921) to the development of "test methods for fibres, test methods and specifications for yarns, and specifications and tolerances for fabrics, particularly mechanical fabrics" (Anon 1921).

As a result of the numerous complaints received by laundrymen from dissatisfied customers, the Laundryowners' National Association Service Bureau has organized a Department of Chemical Engineering (Elledge and Wakefield,1921). This laboratory is associated with the Mellon Institute for Industrial Research in Pittsburgh. Russell T. Fisher (1922) points out that the work of this department of the Laundryowners' National Association will undeniably cause manufacturers to improve their products, inasmuch as inferior goods will find a diminishing sale as the public becomes increasingly capable of recognizing inferiority. Standards of quality both in color and cloth are needed.

The Textile Research Company (Walen 1920a) "is organized to make a research or investigational service available to manufacturers, and to supply that lack of systematic study within a mill in which time usually prohibits indulgence by mill men". "The Textile Research Company offers research or investigational service to anyone interested in such work in connection with the raw materials, methods, machinery and technical efficiency of manufacture and the development of the most satisfactory product for a given use, limiting its work strictly to the field of textiles."

The Cotton Research Company is another research organization financed by two cotton mill organizations for the joint benefit of both (Anon. 1920b). The work of the company includes the operation of an "experimental plant for making actual physical tests on manufacturing problems, and machinery operation in the mills. The work falling into this class refers to such problems as the relative percentage of waste in various cottons; the breaking strength of yarns with different twists and different grades of cotton; the best speeds, drafts and twists for various yarns from various grades of cotton; in fact, all of those problems which affect the manufacturer of cotton cloths."

The National Association of Cotton Manufacturers organized in 1917 an Industrial Research Committee. In 1921 (Fisher 1922) $6,000 was appropriated by this organization for research, and a research worker has been employed.

The aim of the committee is to establish standards of quality and to assist these manufacturers in maintaining this quality.

From the foregoing it is evident:

1. that some standardization of textile fabrics is feasible from the point of view of the manufacturer;

2. that the consuming public is beginning to express a desire for some standardization of staple fabrics used for clothing;

3. that several organizations are at work upon this problem of standardization;

4. that there is still a wide field open for investigation before the desired standardization can be attained.

EXPERIMENTAL

The Selection of Material

The materials chosen for this investigation are fabrics widely used for underwear. Only white fabrics have been included in order that problems arising from the effect of dye on the fibre might be eliminated. No weave structures other than the plain weave have been represented. In order that the materials studied might be as representative as possible, three grades, comprising a high, a medium, and a low quality, of each fabric were selected, except in the case of unbleached muslin of which two grades were considered adequate because of its more restricted use for underwear. The fabrics used for this investigation, therefore, consisted of three grades each, of batiste, nainsook, cambric, longcloth, and muslin, and two grades of unbleached muslin, seventeen fabrics in all, which were purchased at retail. These selections were made with the assistance of an experienced white goods buyer of a large department store.

The names of these fabrics together with their widths and cost per linear yard are listed in Table I. Altho cotton underwear fabrics are sold as being approximately 36, 40 or 44 inches wide, some deviation from these standards is shown in this list. Such variations in width may be due to manipulation in the finishing processes, but the extent to which this is true is not a part of this problem.

Table 1. Table showing width and cost per linear yard of fabrics studied.

Fabrics		Width in	
Name	Quality	inches	Cost
Batiste	A	42.750	$ 0.980
	B	39.000	0.750
	C	38.750	0.390
Nainsook	A	39.000	0.750
	B	44.500	0.590
	C	36.000	0.290
Cambric	A	36.625	0.390
	B	36.500	0.250
	C	35.625	0.190
Long Cloth	A	36.000	0.390
	B	36.125	0.250
	C	35.875	0.125
Muslin	A	36.000	0.250
	B	36.000	0.230
	C	36.000	0.150
Unbleached Muslin	A	36.250	0.190
	B	36.000	0.125

Variable Factors in Fabrics

The Bureau of Standards as a part of the proposed standardization of sheetings, have listed the following factors to be investigated:

1. Resistance to abrasion
2. Resistance to bursting
3. Breaking strength

4. Tearing strength

5. Wear in folding

6. Laundering with different tests conducted after submission to various cleansing fluids. (Anon.1921b) Other factors not listed above which function in determining wearing quality of a fabric are:

    1. Quality of staple used
    2. Weight per square yard
    3. Number of ends and picks per inch
    4. Twist per inch of the yarn
    5. Elongation of the yarn
    6. Size of the yarn
    7. Weave structure
    8. Amount and kind of sizing
    9. Ply of the yarn
    10. Crimp
    11. Load stretch
    12. Moisture regain

These factors may be physical, chemical, or physico-chemical and the variability of the same may be the product of individual or combined results of every step in the production of the fiber and the manufacture of the fabric. From this list of possible variables, the following were chosen for study in this investigation: (1) weight per square yard, (2) cost per square yard, (3) number of ends and picks per inch, (4) twist of yarn, (5) elongation of yarn due to removal of twist, (6) yarn number, (7) moisture regain, (8) load stretch, and (9) tensile strength.

Weight and Cost per Square Yard

1. Weight. Two nine inch square samples of each fabric cut at $\frac{a}{A}$ and $\frac{a}{B}$ as indicated in figure 1 were dried in a vacuum oven to constant weight at a temperature of from 100 to 105° C. (Dannerth 1908). Constant weight was considered to have been reached when the samples did not vary in weight more than .0003 gram, the standard employed by agricultural chemists. The average weight of the two was taken to be the dry weight of a nine inch sample of the fabric and from this the weight per square yard was calculated in the following manner. One nine inch square or 81 sq. in. is one sixteenth of the area of a square yard. Hence, the weight of a square yard would be sixteen times as great as the weight of a nine inch square. The weight of a square yard in grams was changed to ounces by multiplying by .0388.

Table 2. Showing weight persquare yard of fabrics studied.

Fabric		Constant wt. per sq. yd. in	
Name	Quality	Grams	Ounces
Batiste	A	37.584	1.458
	B	45.457	1.763
	C	39.021	1.514
Average		40.687	1.578
Nainsook	A	46.654	1.810
	B	48.017	1.863
	C	75.108	2.914
Average		56.593	2.196
Cambric	A	57.434	2.228
	B	71.910	2.790
	C	70.429	2.733
Average		66.591	2.584

Table 2. Showing weight per square yard of fabrics studied. (cont.)

Fabric		Constant wt. per sq. yd. in	
Name	Quality	Grams	Ounces
Long Cloth	A	71.696	2.782
	B	85.719	3.327
	C	76.564	2.971
Average		77.993	3.027
Muslin	A	107.775	4.182
	B	94.639	3.672
	C	82.292	3.193
Average		94.902	3.682
Unbleached Muslin	A	103.885	4.031
	B	92.500	3.594
Average		98.162	3.812

A study of table 2 shows that with the exception of muslin and nainsook, wherever three grades of a fabric were studied, the medium grade weighs more per square yard than either of the other grades. The reason for this would, upon investigation, undoubtedly be found to result from the number of ends and picks per inch, their yarn number, and the amount of sizing.

2. Cost per Square Yard. The cost per square yard of a fabric was determined in the following manner. The actual area of a yard as purchased was calculated; then, by proportion, the cost of a square yard was determined, as follows, -

the area of a square yard : the area of a yard as purchased = x : the cost of a yard as purchased.

The values derived from this calculation are listed in table 3.

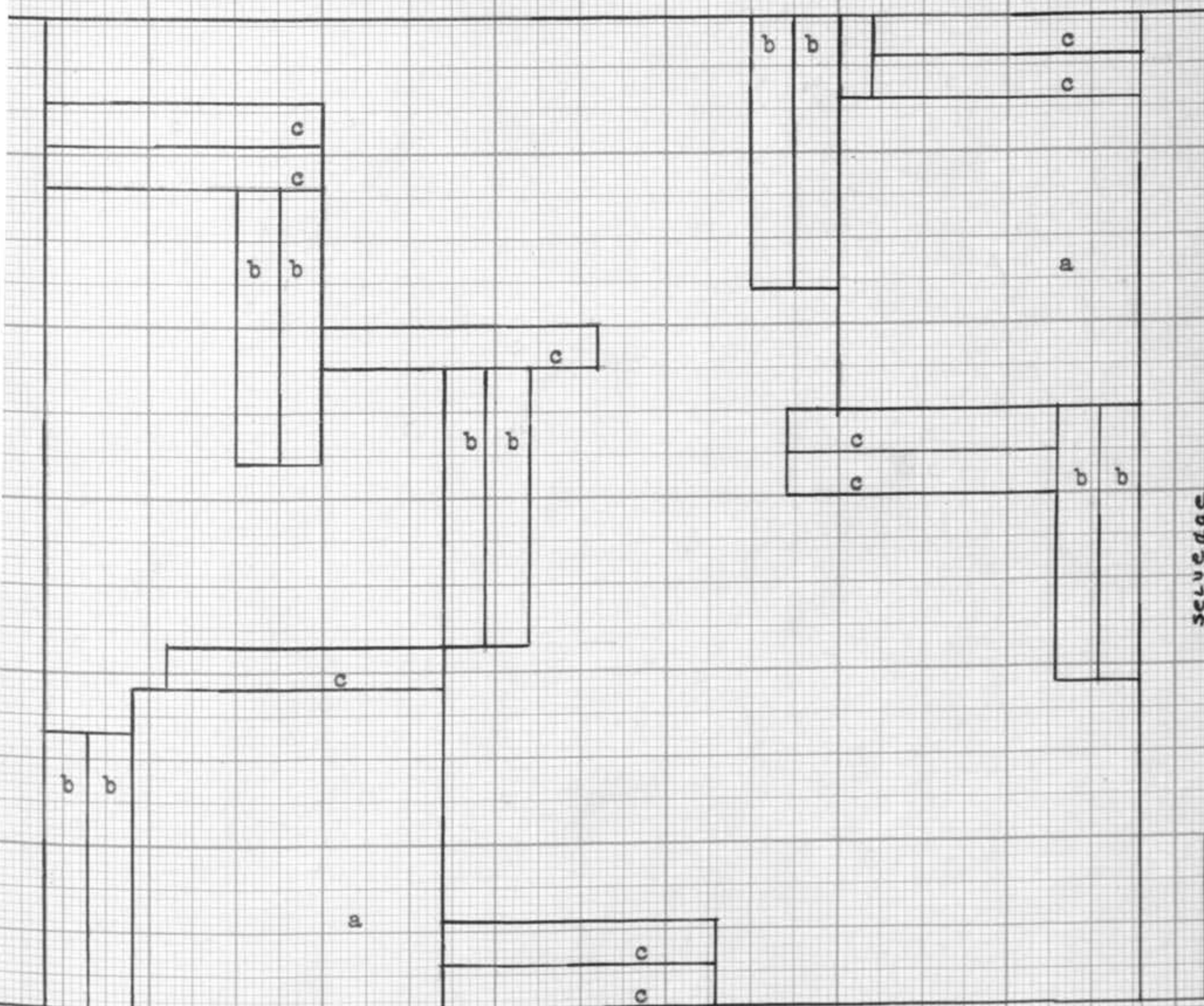

Figure 1. Diagram showing method of cutting strips for tensile strength tests and samples for weight per square yard calculations.

a = weight per square yard samples
b - warp strips
c - filling strips

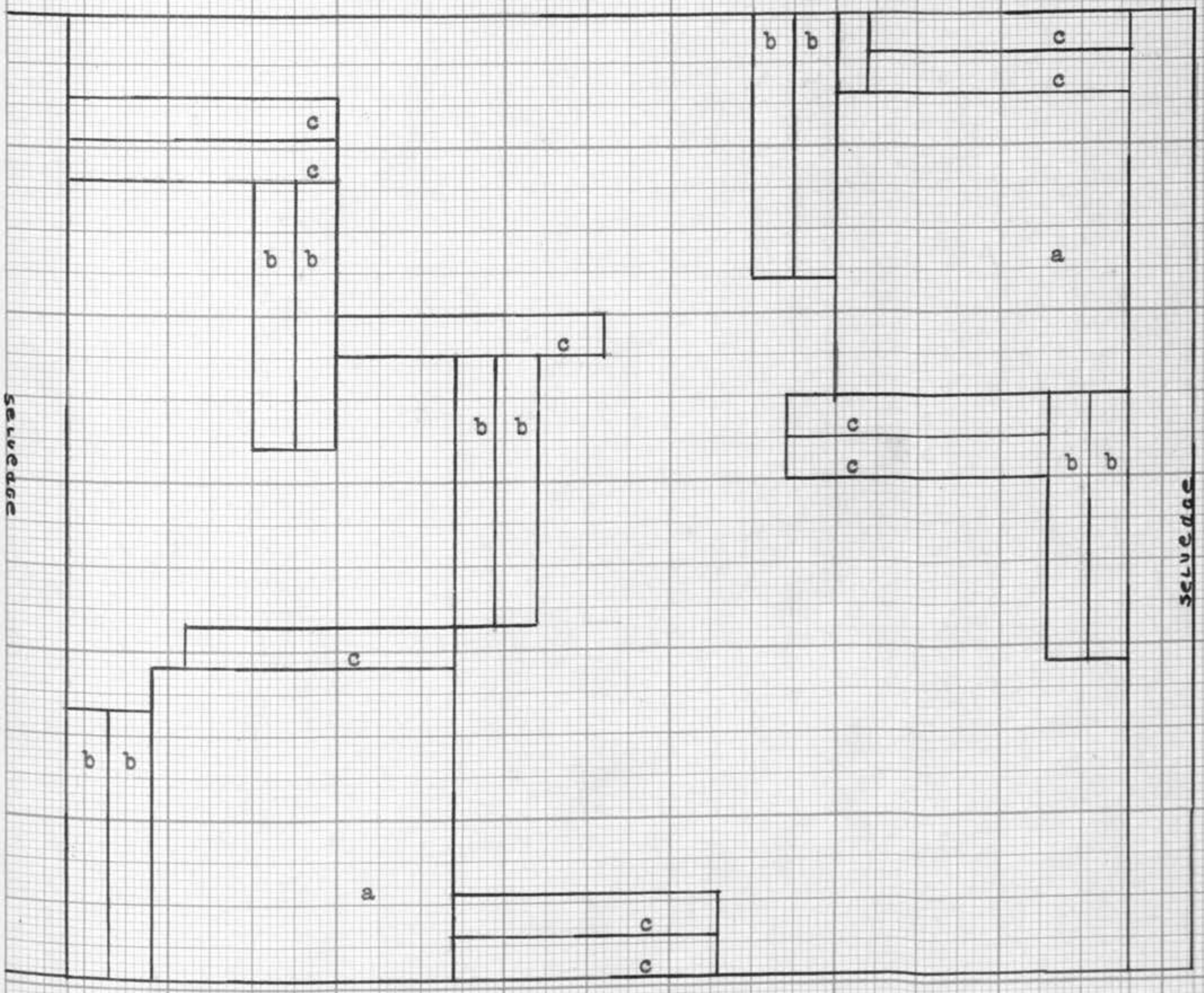

Figure 1. Diagram showing method of cutting strips for tensile strength tests and samples for weight per square yard calculations.

a = weight per square yard samples
b - warp strips
c - filling strips

Table 3. Table showing cost per square yard of fabrics studied.

Fabric Name	Quality	Cost per sq. yd.
Batiste	A	$ 0.825
	B	0.692
	C	0.362
Nainsook	A	0.692
	B	0.477
	C	0.290
Cambric	A	0.383
	B	0.246
	C	0.192
Long Cloth	A	0.390
	B	0.249
	C	0.125
Muslin	A	0.250
	B	0.230
	C	0.150
Unbleached Muslin	A	0.188
	B	0.125

Ends and Picks per Inch

Five counts were made over both warp or end yarns and filling or pick yarns of the fabric with a counter manufactured for that purpose. The fabric was laid smoothly over a piece of black velvet, the dark background serving to facilitate the counting. The count was made in front of a window so that the light rays were parallel to the threads being counted. This eliminated any shadows which could interfere with the counting (Chittick 1921). When there were large spaces between the threads, as in unbleached muslin (Chittick 1921), the space was considered as being part of a thread. If the needle of the counter failed to end immediately along the edge of a thread, as at the beginning, the amount actually covered was estimated as a fractional part of a thread. Chittick (1921) points out that warps vary in a fabric due to shrinkage during the finishing processes, forcing the warps more closely together. Such shrinkage is more likely to occur near the selvedge than in the center of the fabric, and for this reason no counts were made within two inches of the selvedges. One count was made two inches from each selvedge, one half way between each selvedge and the center, and one at the center. The average of the five counts was then found. Each count was made over one inch of the fabric. Chittick (1921) states that fillings are more likely to be irregular than warps, first as a result of the "irregular working of the take-up or let-off of the looms", and second because some looms are made with a "conditional take up, where more picks will go in when the filling threads are thin, and fewer threads when they are thick". Cloth should be held up to the light to ascertain the occurrence of thick or thin places. When such were present, after marking them, the count was made so that some thick, some thin, and some medium regions were included, and an average of these taken. In counting the filling threads, five counts were made, each over a full inch of the material.

A study of table 4 shows that in the two unbleached muslins, cambric A, and muslin A, there are more picks than ends per inch. In all of the other fabrics there are more ends than picks. In every case with one exception, Nainsook A, the highest priced fabric has the greatest number of ends and picks per inch, and, in all cases the lowest quality has the least.

<u>Twist of Yarn and Elongation</u>

1. <u>Twist.</u> Different authorities employ different methods for determining

Table 4. Table showing average number of yarns per inch in fabrics studied.

Fabric		Average number of yarns per inch in	
Name	Quality	Warp	Filling
Batiste	A	115.4	102.4
	B	98.2	87.2
	C	77.4	67.4
Average		96.7	85.7
Nainsook	A	97.8	88.4
	B	98.2	93.8
	C	73.0	69.2
Average		89.3	83.8
Cambric	A	101.0	102.4
	B	85.0	78.6
	C	68.6	57.2
Average		84.9	79.4
Long Cloth	A	104.8	95.4
	B	84.2	74.4
	C	68.4	59.8
Average		85.8	76.5
Muslin	A	89.8	90.2
	B	80.0	78.0
	C	68.2	53.6
Average		79.3	73.9
Unbleached Muslin	A	68.0	73.2
	B	48.2	51.6
Average		58.1	62.4

the twist in yarns. Herzfeld (1920) multiplies the square root of the yarn number by 3.8 when the yarn is made of long staple cotton and by 4 when short staple cotton is used. Another method used by him consists of fastening 3.93 inches in a hand vice, turning the screw in the opposite direction and counting the number of turns to the screw. By dividing the result by 3.93 the number of twists per inch can be found. Bowman (1908), using a twist counter, compared the amount of twist in five inch and one inch lengths. His experiment showed that when the number of turns per inch were taken for five inches the greatest average variation was 18½% ranging from 11% to 26%; when one inch lengths were used the average variation was 37% ranging from 23% to 50%. He suggests as one reason for the variation the fact that yarns are uneven and that twists tend to bunch at the narrower places. The Bureau of Standards (1918) use ten inch lengths on ply yarns and on other yarns such lengths as seem best. They use a yarn twister which also records the elongation due to the release of the twist and the straightening out of the crimp which results from weaving.

Table 5. Table showing average number of twists per inch and per cent variation in twist

Fabric		Av. No. of twists per in.		Av. % Variation in twist	
Name	Quality	Warp	Filling	Warp	Filling
Batiste	A	30.0	40.8	0.00	2.35
	B	32.4	28.2	13.32	6.81
	C	30.8	17.0	8.56	4.70
Average		31.1	28.7	7.29	4.62
Nainsook	A	33.2	35.8	4.34	9.39
	B	28.2	25.0	10.85	6.40
	C	24.2	24.0	4.30	6.67
Average		28.5	28.9	6.50	7.49

Table 5. Table showing average number of twists per inch and per cent variation in twist (cont.)

Fabric		Av. No. of twists per in.		Av. % Variation in twist	
Name	Quality	Warp	Filling	Warp	Filling
Cambric	A	31.8	20.8	5.78	15.19
	B	23.8	19.0	5.38	8.42
	C	21.6	21.8	7.03	10.07
Average		25.7	20.5	6.06	11.23
Long Cloth	A	27.0	26.4	0.22	5.15
	B	23.8	25.0	4.36	4.80
	C	28.6	23.8	5.32	7.02
Average		26.5	25.1	3.30	5.66
Muslin	A	24.0	24.4	10.01	8.36
	B	23.4	20.6	4.99	5.44
	C	24.2	25.6	1.32	3.44
Average		23.9	23.5	5.44	5.75
Unbleached Muslin	A	30.7	14.4	1.56	11.39
	B	22.8	16.2	4.56	11.36
Average		26.7	15.3	3.06	11.38

In order that irregularities due to uneven distribution of twist might be obviated as far as possible, ten inches of yarn were used for a sample and five separate determinations were made of both the warp and the filling yarns from each fabric, a twist counter designed to measure the elongation as well as twist being used. These five determinations were then averaged for both warp and filling. All of these fabrics were made of single ply yarns with right hand twist. The per cent variation in twist was determined as follows (Bowman 1908). The variation of each observation from the average was determined and reduced to per cent variation from the average. The "average per cent variation in twist" was then found by taking the average of the per cent variations from the average. Ex. Let the twist in five samples of warp = 42.0, 40.0, 40.0, 42.0, and 40.0. The sum of these figures = 204.0; the average = 40.8; therefore the average number of twists per inch = 40.8. 42.0 varies 1.2 from 40.8 or 2.94%. 40.0 varies 0.8 from 40.8 or 1.96%. There are two variations of 2.94% and three of 1.96%. The sum of these five variations = 11.76% or an average per cent variation of 2.35%.

A study of table 5 shows that the warps in these fabrics do not always have more twists per inch than the fillings. There is more variation in the number of twists per inch in the fillings than there are in the warps. The variations between the separate yarns of a group were greater in the fillings than in the warps. Some of the more expensive fabrics had the greatest amount of variation in the amount of twist per inch. Taking each group as a unit, the least amount of variation is found in the batistes with the long cloths second and the muslins third. The cambrics have the greatest amount of variation.

2. Elongation. The elongation was measured at the same time that the twist of yarn was measured. The elongation recorded was often incorrect for it frequently happened that a yarn was not strong enough to withstand the amount of pull necessary to straighten out all the crimp. This was more likely to be true of filling yarns than of warps. The elongation of yarns containing a large per cent of sizing was also difficult to measure because the sizing held the fibres so firmly together that they could not be straightened out entirely without causing a complete break in the yarn.

A study of table 6 shows that, on the whole, there was more elongation in the warp than in the filling yarns.

Table 6. Table showing elongation of yarnsof fabrics studied.

Fabric		Average elongation per inch of yarns in	
Name	Quality	Warp	Filling
Batiste	A	0.0170	0.0076
	B	0.0113	0.1144
	C	0.0296	0.0058
Nainsook	A	0.0378	0.0138
	B	0.0271	0.0485
	C	0.0315	0.0256
Cambric	A	0.0237	0.0119
	B	0.0372	0.0176
	C	0.0273	0.0210
Long Cloth	A	0.0178	0.0228
	B	0.0300	0.0250
	C	0.0295	0.0326
Muslin	A	0.0258	0.0216
	B	0.0526	0.0300
	C	0.0534	0.0480
Muslin Unbleached	A	0.0524	0.0081
	B	0.0588	0.0131

Yarn Number

In determining the yarn number the "fixed weight" system (Griffin 1921) was employed. In this system 840 yards of cotton to the pound is an international standard, and the yarn number is "inversely proportional to the size of the yarn" (Griffin 1921). Barker and Midgley (1914) suggest ravelling three inch lengths of yarn until a three yard lot is obtained. Twelve inch lengths were used instead of the three-inch lengths because fewer errors due to discrepancies in measuring would occur. The Bureau of Standards (1918) suggest four possible methods for determining the counts of yarn in the "fixed weight system". These are: (1) determination of weight of sample as received; (2) determination of weight of sample after exposing it to a controlled standard atmosphere for a given length of time; (3) determination of weight of sample dried to constant weight; and (4) determination of weight of sample at moisture regain weight. The third method was used since in that way more comparable results could be obtained. By this method the resulting yarn count will be somewhat greater than that obtained without the removal of moisture. (Bureau of Standards, 1918). Two three yard lots of twelve inch threads were dried and weighed to constant weight as in determining the weight per square yard of fabric. The two results were averaged. A cotton gauge point (Barker and Midgley 1914) was found by dividing 453.59 gram, the number of grams in a pound, by 840 yards, resulting in the factor 0.54. Then wt. of sample in gms. : .54 = 3 yd. : x. The number obtained for "x" is the size of the yarn or yarn number.

A study of table 7 shows that with the exception of one fabric, the counts of the filling yarns are higher and therefore the yarns are finer, than the counts of the warp yarns. This fabric is Cambric B.

Table 7. Table showing the yarn number of the warp and filling threads of fabrics studied.

Fabric		Yarn number of	
Name	Quality	Warp	Filling
Batiste	A	90.0	115.7
	B	65.0	90.0

Table 7. Table showing the yarn number of the warp and filling threads of fabrics studied. (cont.)

Fabric		Yarn number of	
Name	Quality	Warp	Filling
Batiste, cont.	C	65.0	70.5
Average		73.3	92.1
Nainsook	A	65.0	90.0
	B	65.0	90.0
	C	34.5	43.8
Average		54.8	74.6
Cambric	A	67.5	70.5
	B	43.8	37.7
	C	32.4	34.5
Average		47.9	47.6
Long Cloth	A	52.3	54.0
	B	30.6	36.0
	C	30.0	34.5
Average		37.6	41.5
Muslin	A	30.0	34.5
	B	30.6	35.2
	C	27.0	32.0
Average		29.2	33.9
Unbleached Muslin	A	24.2	27.9
	B	20.2	21.0
Average		22.2	24.4

Tensile Strength, Load Stretch and Moisture Regain

1. Moisture Regain. The moisture regain of a fabric was calculated from the tensile strength samples. Ten strips were cut both warp and filling ways of each fabric so as to insure representative sampling (See figure 1). Immediately after breaking the twenty specimens on the tensile strength machine, each group of ten was divided into two lots designated as Lot I and Lot II and quickly weighed under existing atmospheric conditions, the weight being recorded as "weight of sample in air". Each lot was then placed in a tared aluminum weighing can and weighed to constant weight. (See p. 13). The difference between the "weight of sample in air" and the constant weight of sample, was the weight of the moisture lost. This weight of the moisture lost was "computed as the percentage of the dry weight" (Am. Soc. for Testing Materials 1920a) and is the moisture regain of the material. Nelson and Hulett (1920) point out that this method of determining moisture content may do for commercial test methods, but does not give the true moisture content. The authors constructed an apparatus which measured the amount of water driven off and also the volume of gas due to decomposition during drying. In this experimental work, wheat flour, corn meal, cornstarch, cellulose, (Swedish filter paper), absorbent cotton and protein were heated. It was found that with the exception of wheat flour and protein, substances could be heated to 218° C in a vacuum for three hours, and yet very little moisture due to decomposition would be given off. In order to drive off all the moisture from a sample it should be heated at a temperature of from 110 degrees to 184 degrees C for five hours. Knecht (1920) points out that the minimum temperature of decomposition of common objects of every day life is not known and studied the cumulative effect of heat on cellulose and other materials. In 1906, C.O. Weber, whose experiments were never published, reported to him that the minimum temperature

at which cotton could be affected was 80° C. Knecht employed a temperature of 93° C in a large water-jacketed air bath for 336 hours. Some of the samples were exposed to the air of the oven on watch glasses; other samples were sealed in air tight test tubes. Bleached cotton yarn and calico on watch glasses remained unchanged for the first few days and then began slowly to change to a light greyish brown in color. Cotton yarn in the closed tubes changed more rapidly than that which had been left open. One tube was opened under mercury and back pressure showed that gas had been liberated. Moisture had condensed in all the tubes. This was readsorbed by the fabric on standing two days. The condensed water in one tube was tested with litmus which showed that it contained a volatile acid. When any tubes were opened, the yarns gave off the empyreumatic smell associated with burned fat. The strength of the yarn was found to have been decreased 50%, when tested after having been exposed to room atmosphere for two days. The yarns in the tubes also acquired a 'shrivelled or "perished" appearance'. The calico heated in tubes behaved in a manner very similar to that of the yarns. Further work on this subject is being planned by the author. These two studies are not comparable in that Nelson and Hulett used a vacuum while Knecht did not. Lavett and Van Marle (1921) point out that vacuum drying reduces the boiling point of a liquid because of the reduced air pressure, and thus accelerates the rate of evaporation. When a vacuum of 28 - 29 in. is maintained, water will boil at a temperature of 75° to 100° F. Evaporation at this temperature depends upon two factors, the rate at which heat is transmitted to the material and the rate at which the water is removed. As soon as the moisture content of a material is lessened, the rate of evaporation is lessened because the surface of the material exerts a restraining action. This restraining action will gradually increase until it becomes the governing factor. The vacuum prevents surface oxidation while the interior of a sample is being dried out. In vacuum drying heat is transmitted to the sample by contact with the vessel containing the sample which in turn is heated by contact with the shelves of the oven which are in contact with the directly heated surface of the oven. Lewis (1921) points out that in drying solids, the drying depends to a certain extent, upon the rate at whichmoisture can be diffused from the interior to the exterior of a sample. The determination of moisture regain therefore would seem to be a problem of removing adsorbed moisture from the fabric and presents several difficulties when comparable results are desired.

Table 8. Table showing the moisture regain of the fabrics studied.

Fabric		Per cent moisture regain of		Relative
Name	Quality	Warp	Filling	Humidity
Batiste	A	8.092	8.210	67.8
	B	8.756	8.570	77.1
	C	6.920	6.820	63.2
Nainsook	A	6.320	6.395	48.4
	B	4.819	4.854	52.5
	C	6.066	6.052	69.2
Cambric	A	6.642	6.875	70.4
	B	6.343	6.467	64.8
	C	6.379	6.371	65.5
Long Cloth	A	3.055	3.156	21.3
	B	3.568	3.679	30.3
	C	6.472	6.468	79.0
Muslin	A	6.420	6.565	65.0
	B	3.905	3.934	36.0
	C	5.409	5.287	54.9

Table 8. Table showing the moisture regain of the fabrics studied. (cont.)

Fabric		Per cent moisture regain of		Relative
Name	Quality	Warp	Filling	Humidity
Unbleached Muslin	A	5.952	5.912	52.9
	B	2.986	3.037	27.6

Table 9. Table showing load stretch of fabrics studied.

Fabric		Load stretch in inches of	
Name	Quality	Warp	Filling
Batiste	A	0.104	0.167
	B	0.104	0.167
	C	0.104	0.167
Nainsook	A	0.104	0.177
	B	0.177	0.188
	C	0.125	0.500
Cambric	A	0.167	0.792
	B	0.167	0.375
	C	0.156	0.333
Long Cloth	A	0.167	0.417
	B	0.142	0.333
	C	0.177	0.375
Muslin	A	0.198	0.625
	B	0.188	0.417
	C	0.208	0.459
Unbleached Muslin	A	0.375	0.375
	B	0.338	0.354

2. Load Stretch. The samples were tested for tensile strength on a combination automatic power yarn and cloth tester with autographic recorder for recording the stress strain curve. This curve is produced on a specially ruled chart at the same time that a dial records the tensile strength of the sample. In this way a complete picture of the stresses to which the sample is subjected during the test, is obtained. Five curves were recorded on each chart; each set of warps and fillings having been divided into two lots (See p. 25).

3. Tensile Strength. The strips used for tensile strength tests werecut on a thread in such a way as to obtain a different sampling of yarns in each strip, (See figure 1.), thus obtaining as representative a sampling of the material as possible. Ten strips were cut both warp and filling ways. Each strip was eight inches long, one and one fourth inches wide, and ravelled to exactly one inch, (Bureau of Standards 1918) so as to eliminate the possibility of any cut threads in the samples tested.

The sample was clamped into the jaws of the machine, taking care to place it in the center of the jaws with the edges of the jaws parallel to the crosswise yarns of the fabric so that any diagonal pull which might interfere with the test might be avoided. (Walen 1918a). The first five warp samples to be tested were designated as warp, lot I; the second five as warp, lot II; the filling samples were designated in the same manner. The corrected tensile strength (Haven 1921) was calculated according to the formula published by the American Society for Testing Materials (1920b),

$$\text{Tensile strength corrected to Standard Moisture Regain} = \frac{(\text{Tensile strength from Machine rending}) \times 139}{100 + (6 \times \text{Actual percentage regain})},$$

in which $139 = 100 + (6 \times 6.5)$, 6 being the number of pounds increase due to 1% increase of moisture and 6.5 being standard moisture regain. Hartshorne (1918), in discussing the effect of moisture on fabrics, points out that cotton tire fabrics increase approximately 7% for each 1% increase in moisture content from absolute dryness up to approximately 8½% and that "other cotton fabrics follow a similar though not identical law".

Immediately after the four lots from one fabric had been broken, they were weighed separately on an analytical balance and the weight for each group recorded as "weight of sample in air". Each group was placed in a numbered and tared aluminum weighing can and dried to constant weight (See p. 13). The American Society for Testing Materials (1920a) uses a ventilated drying oven and a temperature of 105° to 110° C. They consider constant weight to have been reached when the sample does not show a further loss of more than 0.1% of the previous weighing, the samples being weighed in the oven and the weighings being ten minutes apart.

Altho applying tensile strength tests to fabrics is a comparatively simple procedure, there are several factors which will affect the accuracy of the results (Turner 1920 & Am. Soc. for Testing Materials 1919) and care must be exercised in order to maintain comparable conditions thruout. Strips must be inserted evenly into the jaws so that pressure will be distributed evenly thruout the sample. Walen (1918a) states that a very slight deviation from true alignment will cause the strip to break at a lower tensile strength. For this reason one inch strips are best as they can be inserted more easily. The jaws must be tightly clamped so that there will be no possibility of slipping. The rate at which the load is applied also affect results. The faster the load is applied, the higher will be the results obtained. Twelve inches per minute is the usual speed employed in all work of this kind. (Am. Soc. for Testing Materials, 1919). Walen (1918a) also points out that "within the limitations of mechanical features of the testing machine, the slow application of load is the most severe one". Dimensions of the sample also affect results. A width of

Table 10. Table showing tensile strength and corrected tensile strength of fabrics studied.

Fabric		Tensile Strength in pounds		Corrected Tensile Strength in pounds	
Name	Quality	Warp	Filling	Warp	Filling
Batiste	A	35.44	21.81	33.163	20.310
	B	29.85	15.71	27.852	14.422
	C	28.24	16.88	27.737	16.650
Average				29.584	17.127
Nainsook	A	31.02	18.51	31.264	18.590
	B	33.56	20.51	36.106	22.082
	C	41.37	29.05	42.150	29.624
Average				36.507	23.432
Cambric	A	38.25	31.93	38.010	31.410
	B	40.85	36.44	41.134	36.488
	C	39.14	22.60	39.348	22.807
Average				39.497	30.235
Long Cloth	A	37.80	31.23	44.404	36.497
	B	43.79	27.13	50.135	32.489
	C	42.65	24.33	42.723	24.363
Average				45.754	31.116
Muslin	A	52.54	43.43	52.722	43.299
	B	44.81	38.92	50.450	43.776
	C	39.75	21.03	41.710	22.230
Average				48.294	36.435
Unbleached Muslin	A	48.62	48.86	49.800	50.107
	B	38.48	33.84	45.351	39.781
Average				47.575	44.944

one inch and three inches between the jaws in the generally accepted standard. (Am. Soc. for Testing Materials 1919). If the fabric were absolutely uniform, dimensional effects (Turner 1920) would, within certain limits, be absent. But fabrics are not uniform and weak places occur. When larger samples are used, an increase in the size of the sample increases the likelihood of a weak place being present and up to this point the tendency is for the breaking strength to decrease with the size of the specimen. Walen (1918a) says that "a straight line ratio exists between the width of the strip and the tensile strength" and that the unit strength is constant and "independent of the specimen dimensions". This straight line ratio between width and tensile strength does not hold for all fabrics. The relative humidity is also important for with high humidity a fabric may be twice as strong as at a low humidity (Turner 1920). The capacity of a machine also affects results (Am. Soc. for Testing Materials 1919). When textiles of low strength are tested in machines of high capacity, their apparent strength is greater than when the reverse is the case.

A study of table 10 shows that there is a very great difference in strength between samples ofwarps and samples of fillings with the exception of Cambric B and the unbleached muslin group.

DISCUSSION OF RESULTS

Weight per Square Yard and Its Relation to Tensile Strength

A study of tables 2 and 10 shows that the weight and tensile strength of the fabrics studied are closely related. When these fabrics are arranged in groups, i.e., batistes, nainsooks, etc., in descending order from the finest to the coarsest, the average tensile strength of each group will be found to increase as the average weight per square yard increases. Table 2 shows that there is a marked variation among the individual members of the different groups. Batiste C, nainsook B, cambric C, long cloth C and muslin B show the least variation in weight from the average in their respective groups; batiste B, nainsook C, cambric A, long cloth B, and muslin A show the greatest variation in their respective groups. These fabrics when arranged in the order of descending tensile strength for both warps and fillings separately, show a direct relationship between tensile strength and weight per square yard of cloth. (See figures 2, 3, 4 and 5). It is evident, therefore, that weight per square yard of a fabric is one of the determining factors of its tensile strength. The work of Taylor and Searle (1920) corroborates this view.

Cost per Square Yard and Its Relation to Tensile Strength

A study of tables 3 and 10 and figure 6 shows that in these fabrics, a relatively high cost per square yard does not insure great tensile strength for an inverse ratio exists in the relation of cost to tensile strength. The average cost per yard of these seventeen fabrics is $.345 and the fabrics that have

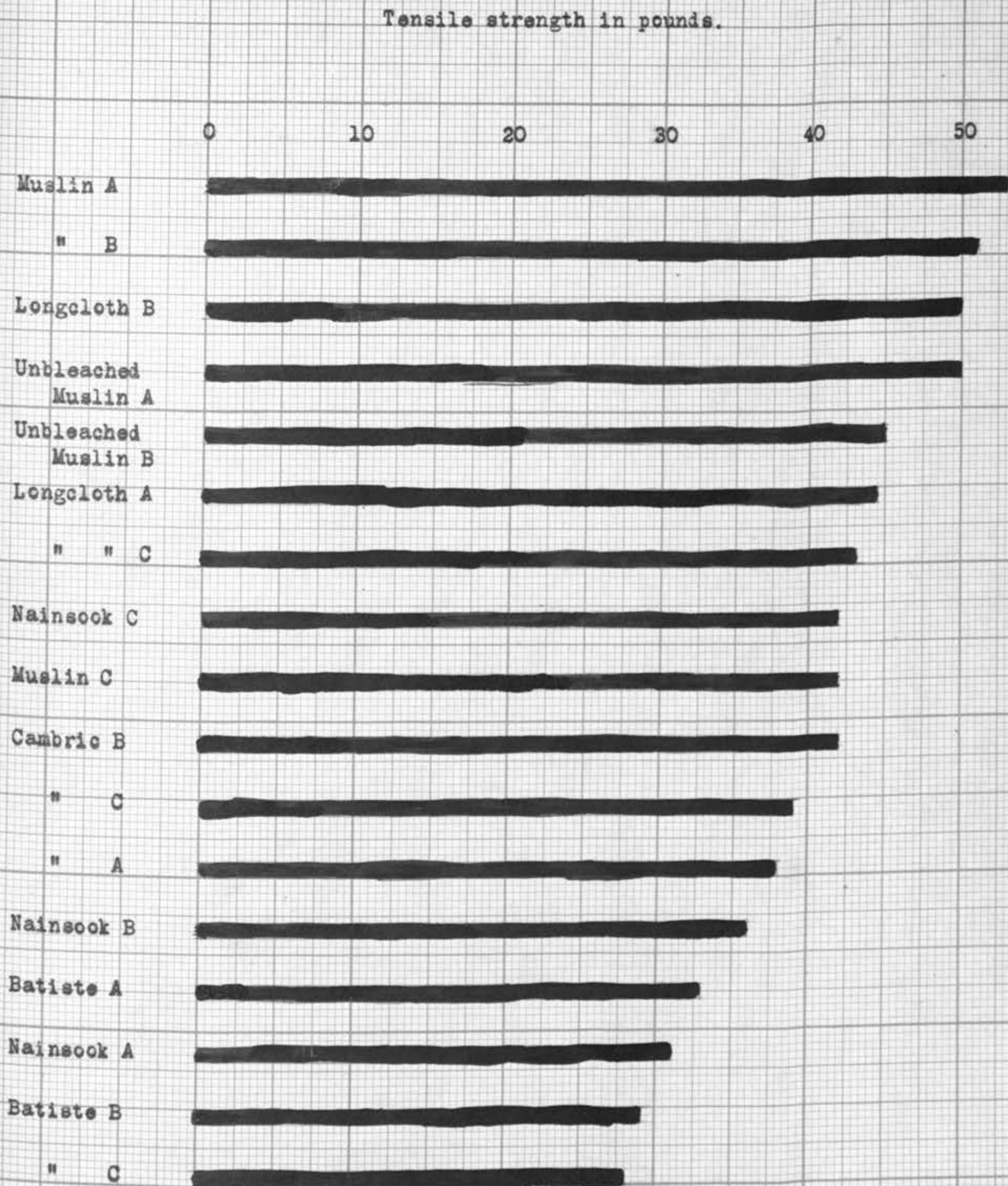

Figure 2. Tensile strength of warps.

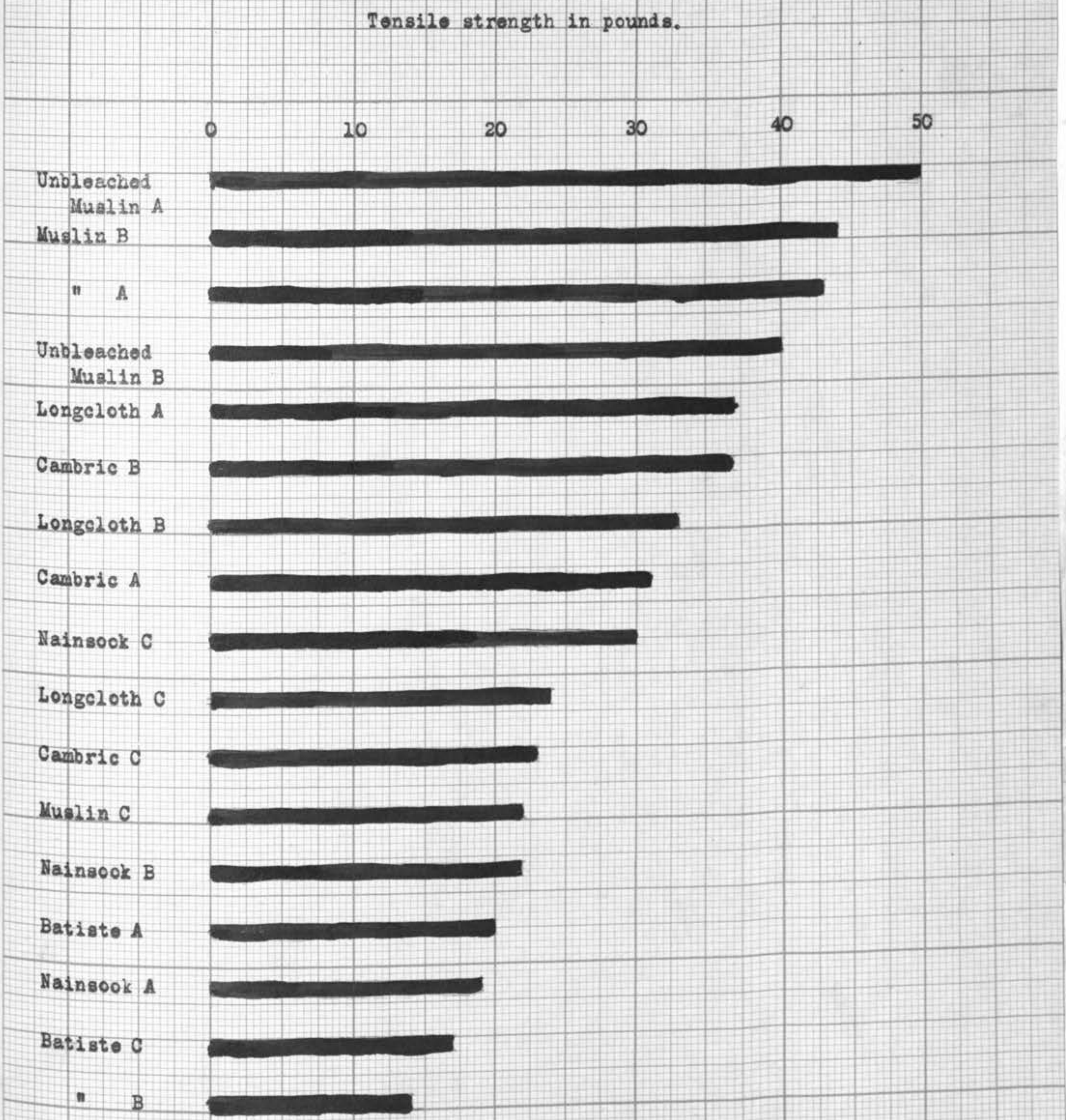

Figure 3. Tensile strength of fillings.

Weight per square yard in ounces.

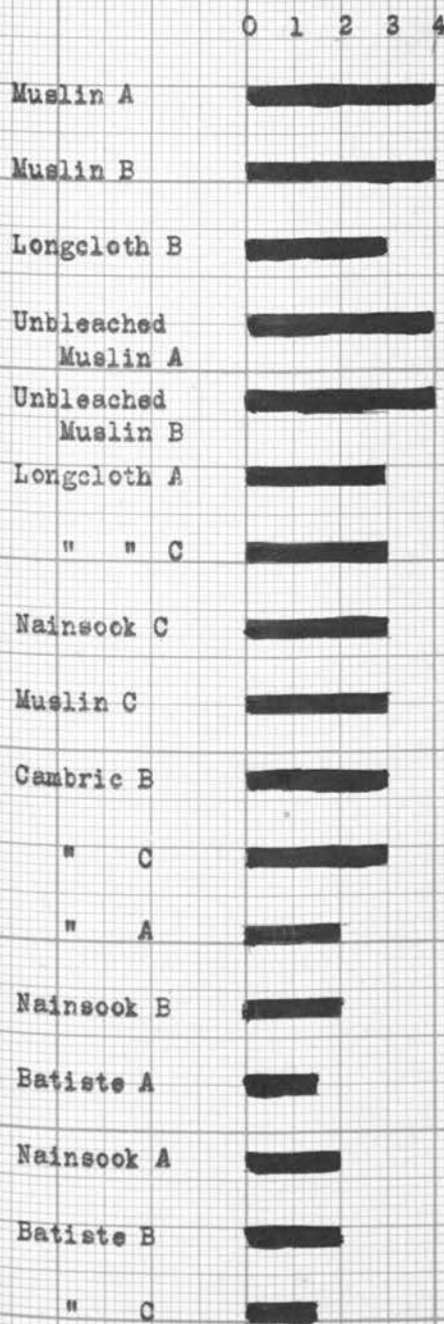

Figure 4. Weight per square yard arranged in order of tensile strength of warps.

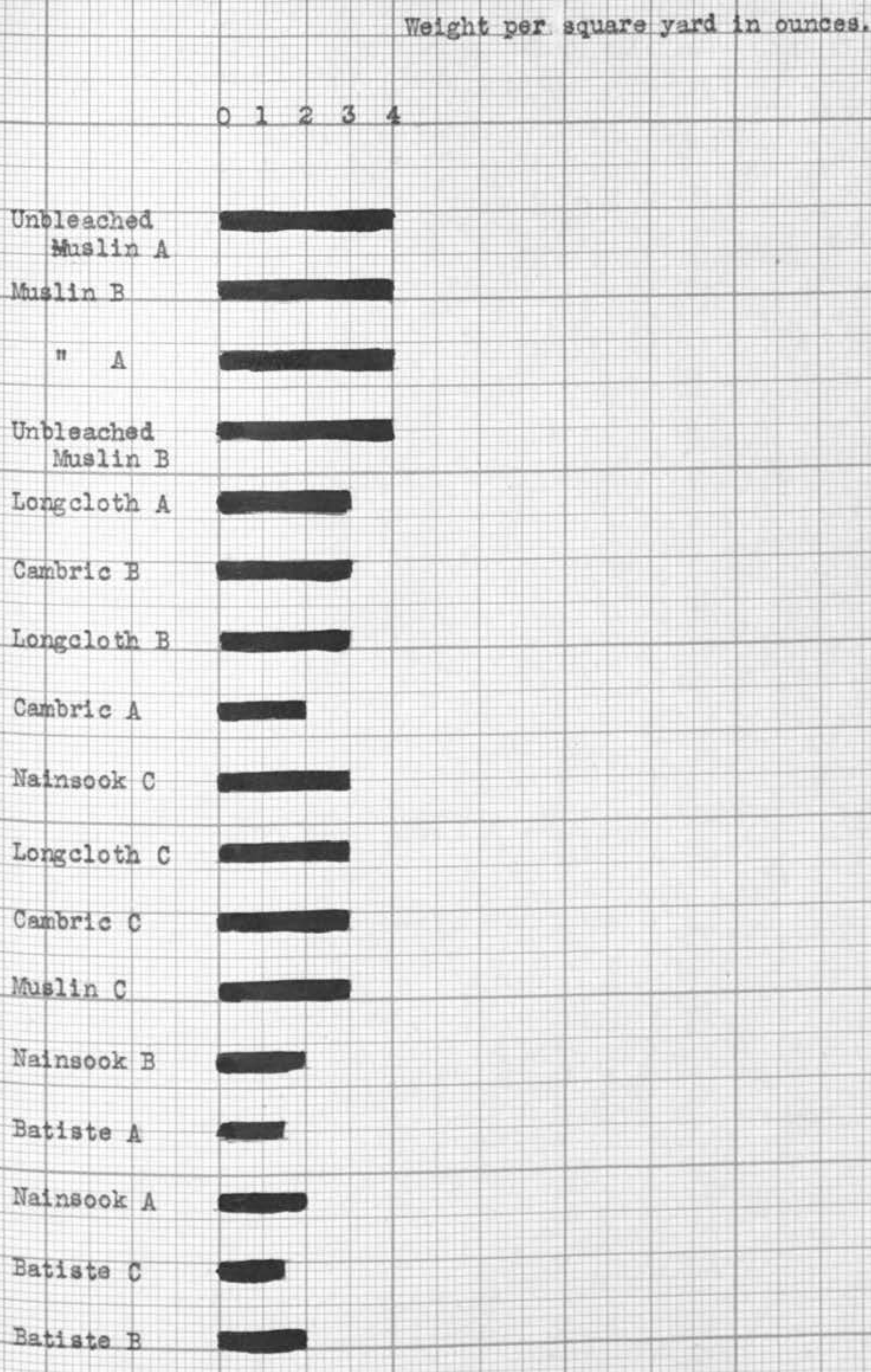

Figure 5. Weight per square yard in ounces arranged according to tensile strength of fillings.

the greatest tensile strength are grades A and B of the muslins, unbleached muslins and long cloths, all of which, with the exception of the unbleached muslin group, were bought at about the average price or a little below it. Nainsook A and B and batiste A, B and C rank the lowest with regard to tensile strength, and these are, with the exception of batiste C, the fabrics for which the highest price per square yard was paid. However, these fabrics have qualities of fineness and softness which offset for certain consumers their lack of tensile strength.

End and Picks per Inch and Their Relation to Tensile Strength

A study of tables 4 and 10 shows that those groups which have the greatest average number of yarns per inch are also the groups having the least average tensile strength per inch. A study of figures 2 and 7, and 3 and 8 shows that there is no apparent regularity in the distribution of ends and picks per inch in relation to tensile strength. This lack of uniformity is due to variations in the size of the yarn, number of twists per inch and quality of cotton fiber used. It is quite evident from a study of these tables that altho the number of yarns per inch does influence the tensile strength of the fabric, the importance of this factor apart from other factors is not as great as that of the weight per square yard.

Twist and Its Relation to Tensile Strength

A study of table 5 shows that the warps in these fabrics do not always have a greater number of twists per inch than the fillings, for the filling yarns of batiste A, long cloth B, muslin C, and nainsook B have more twists per inch than the corresponding warps. In cambric C, long cloth A, muslih A and nainsook C, the number of twists per inch in warps and fillings are almost identical. In the remaining ten fabrics the twist in the filling threads is

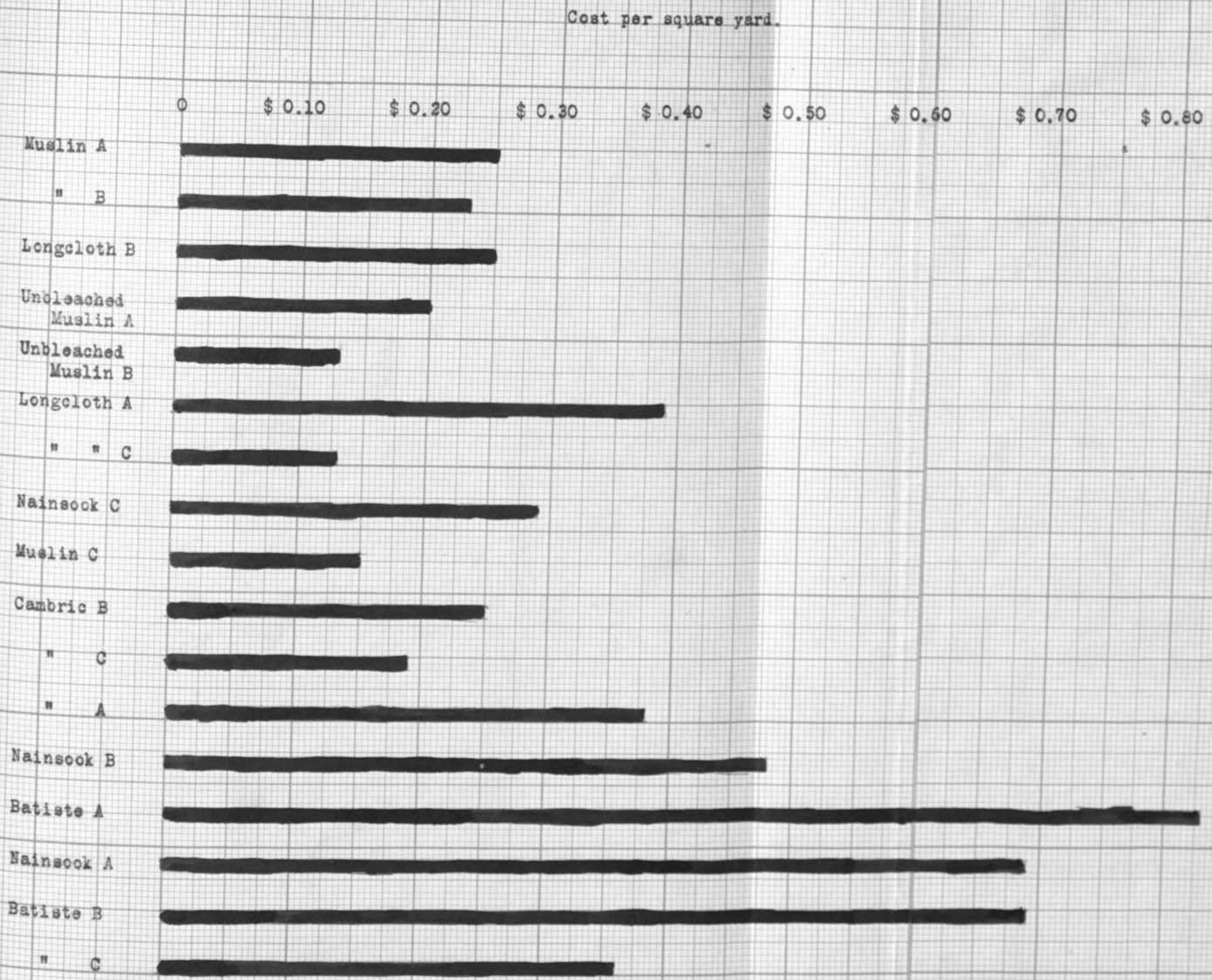

Figure 6. Cost per square yard in ounces arranged in order of tensile strength of warps.

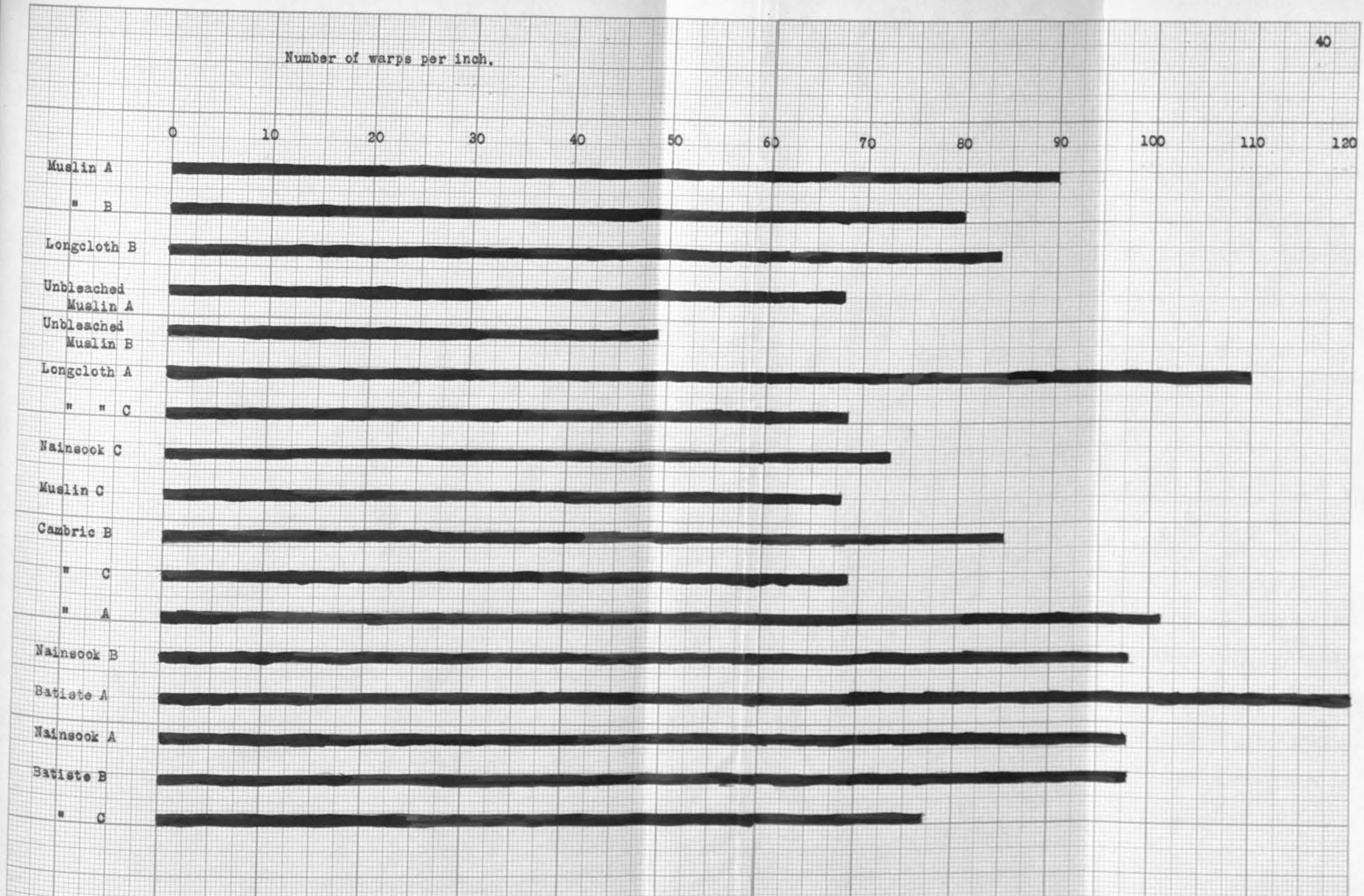

Figure 7. Number of warps per inch arranged in order of tensile strength of warps.

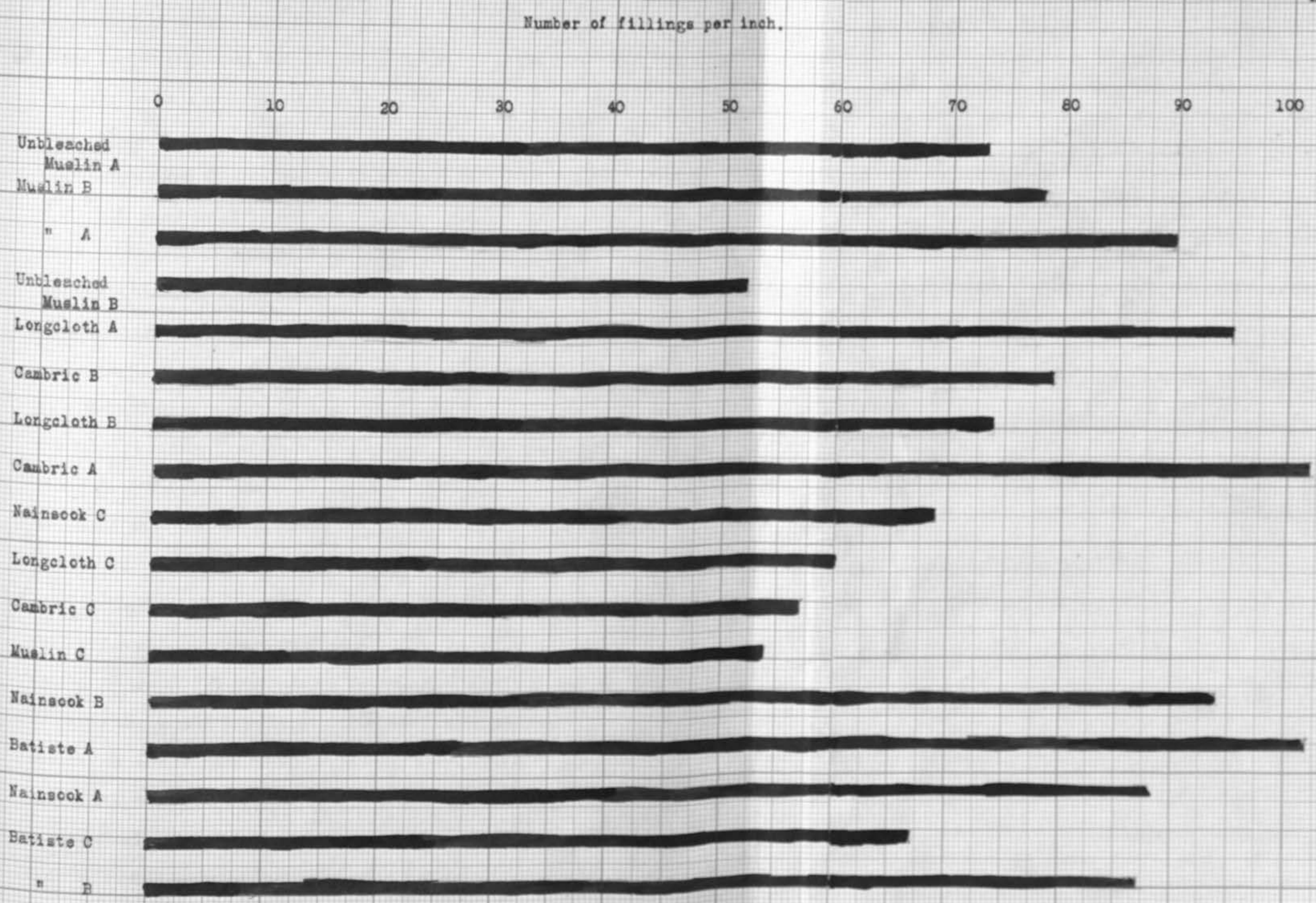

Figure 8. Number of fillings per inch arranged in order of tensile strength of fillings.

noticeably less than that in the warps. As a group, the muslins show the least variation between the number of twists in warps and fillings. The filling threads as a group show greater variation in the number of twists per inch than do the warps. The filling yarns of a group also show greater variations among themselves than do the warps of the same fagric. Irregularity in the distribution of twist is not confined to the lowest priced fabrics. On the whole, the greatest amount of variation in distribution of twist occurs in cambric A, batiste B and muslin A, while batiste A, muslin C and long cloth A have the least variation. Taking each group as a unit, the least amount of variation is found in the batistes , long cloths and muslins; while the cambrics have the greatest amount of variation. A study of figures 9 and 10 shows that the fabrics having from 20 to 25 twists per inch have the greatest tensile strength. This coincides fairly well with results obtained by Forsaith (1920) who found that the strength of single yarns increased with the amount of twist per inch up to 17 turns per inch after which it fell off rapidly; and the tensile strength of 60 yd. skeins increased up to 20 turns per inch after which it fell off rapidly. These tests were made upon yarns spun from strict middling upland cotton of 7/8 inch staple. When testing a fabric (Turner 1920) a number of yarns are tested together. When results of lea tests are compared with the results of single yarn tests of the same count, the strength per yarn in the lea is found to be less than the strength of single yarns tested separately. A 40's single thread and a lea of 40's showed a reduction of 22% while a 2/40's (2-ply) Egyptian when compared with lea tests showed a reduction of 50% in tensile strength. In cloth the reverse is true. The warps of a fabric show an increase as high as 50% over the tensile strength of the yarns tested separately, in spite of the fact that the yarns lose 6% of their strength in wearing. This phenomenon is explained by the interaction of non-uniform yarns and weave structure of cloth, these two elements acting either in unison or

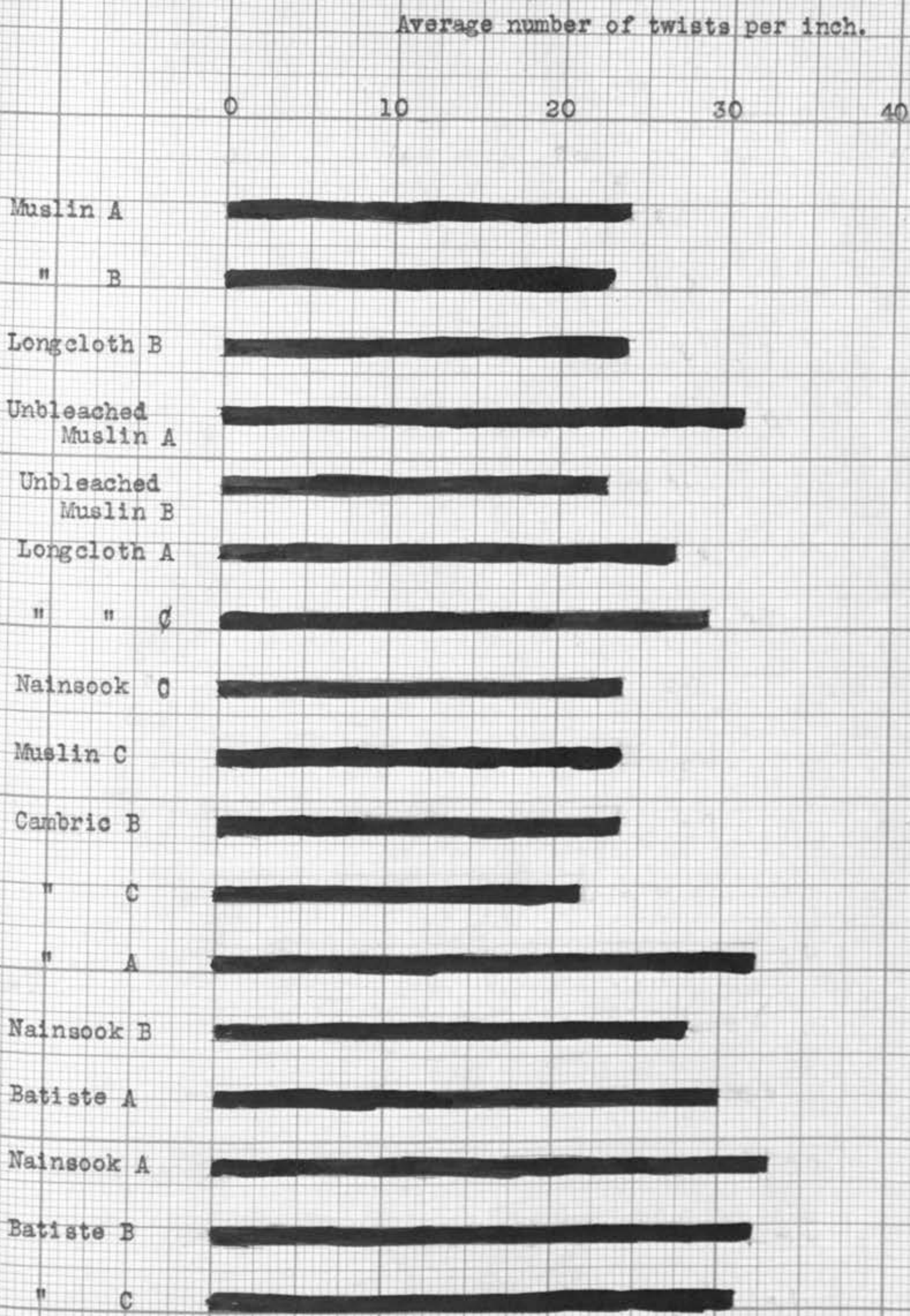

Figure 9. Average number of twists per inch of warp yarns arranged in order of tensile strength of warps.

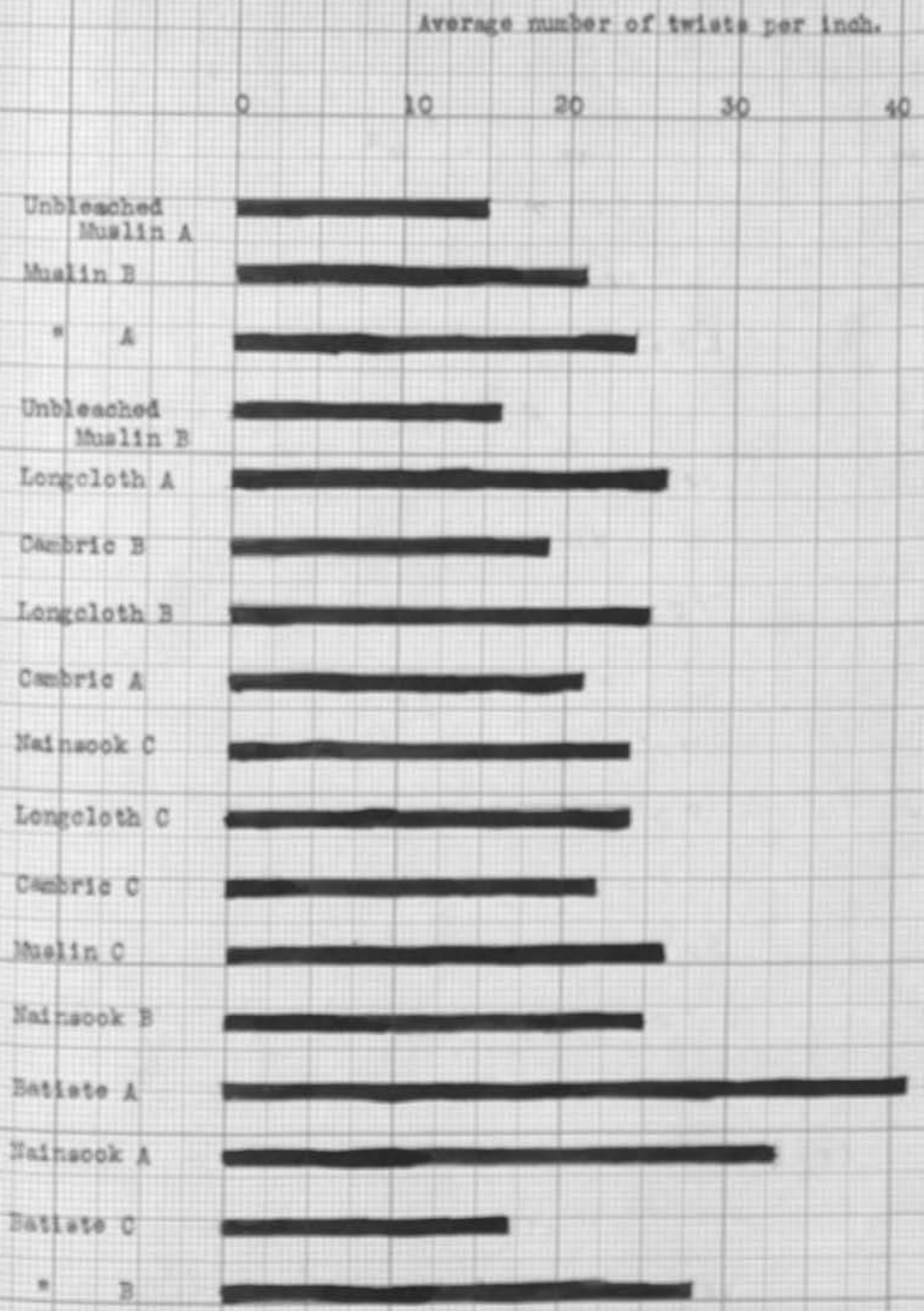

Figure 10. Average number of twists per inch of filling arranged in order of tensile strength of fillings.

independently. When lea tests and fabric tests are compared, the presence of filling yarns in the fabric must be taken into account. When tension is applied to warp threads these come under the influence of the binding forces of the filling threads which are in operation at each intersection of the two yarns. The intensity of these binding forces depends upon the weave structure. The stress applied to warp threads in testing is distributed, in part, to the filling threads at the intersections and the strength of the warp threads correspondingly increased. When there is a great deal of open space between each intersection of the filling threads with the warp, the increase in strength of the warps is correspondingly less than when the cloth is compactly made and the distances between intersections are short. Forsaith's work also showed that increasing the twist of yarn increased its weight and that the elasticity of a yarn varied directly with the twist. Priestman (1920) in England during the war had occasion to investigate the effect of twist of yarn upon cloth strength. A cotton shell fabric capable of withstanding a strain of 145 pounds finished was required, Short staple cotton was made up into yarn and it was found that additional twist did no compensate in strength for the lack of fiber length. Twists of 9, 10½ and 12 turns per inch were used. The yarn of this last group snapped off when tested, giving less tensile strength than that having 10½ turns per inch. When this yarn was made into cloth, it tested 149 lbs. in the grey and 169 lbs.finished. The fabrics made of yarns of less twist consistently lost 7 or 8% of their strength in the finishing process, An experimentation of the cloth showed that 1/20s fillings were woven with 2/36's warps which had exactly 11.2 twists per inch. The twists of the two threads were so nearly the same that the angles of their twists fitted into each other, a result which was not apparent until the cloth had been put through the finishing process. It was shown that the twist of any filling must bear a very definite relation to the "twist of the warp into which it is woven, if the greatest possible strength is to be obtained in the finished cloth". Table 5 shows that muslin A, longcloth A, nainsook C and cambric C have warps and fillings of equal twist.

Elongation of Yarns and Its Relation to Tensile Strength

Due to the impossibility of obtaining a correct measure of the elongation of these yarns (See p. 21) their relation to tensile strength can not be correctly evaluated. A study of table 6 shows that on the whole, those fabrics having the greatest average tensile strength have also the greatest amount of yarn elongation.

Yarn Number and Its Relation to Tensile Strength

A study of tables 7 and 10 shows that those groups of fabrics made of the finest yarns are also those groups having the least tensile strength. Figures 11 and 12 verify these findings. The size of the yarn has therefore a very direct influence on the tensile strength of a fabric.

Moisture Regain and Its Relation to Tensile Strength

A study of table 8 shows that the relative humidity of the testing room varied between wide limits, the lowest being 21.3 and the greatest 79.0. Hartshorne (1918) shows that the number of grams of water adsorbed by a fabric depends not only upon the relative humidity of the atmosphere, but also upon the temperature of the atmosphere, cotton adsorbing more moisture at a temperature of 30° C. than at 20 °C, the relative humidity in each instance being the same. This is shown to have been true for these fabrics. An examination of table 8 shows that unbleached muslin A and nainsook B were broken at a relative humidity of 52.9 and 52.5 respectively; while the temperatures were 25° C and

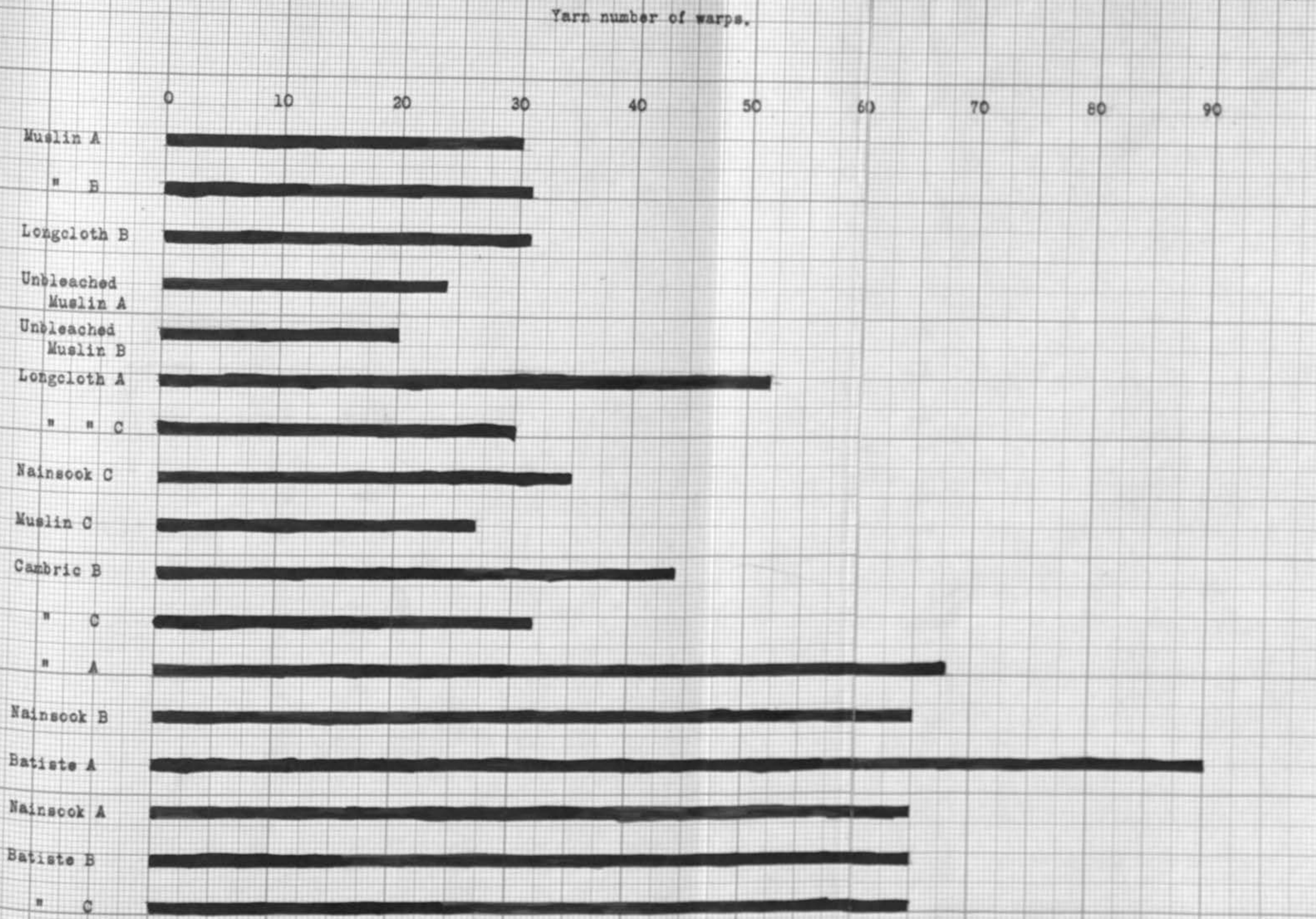

Figure 11. Yarn number of warps arranged in order of the tensile strength of warps.

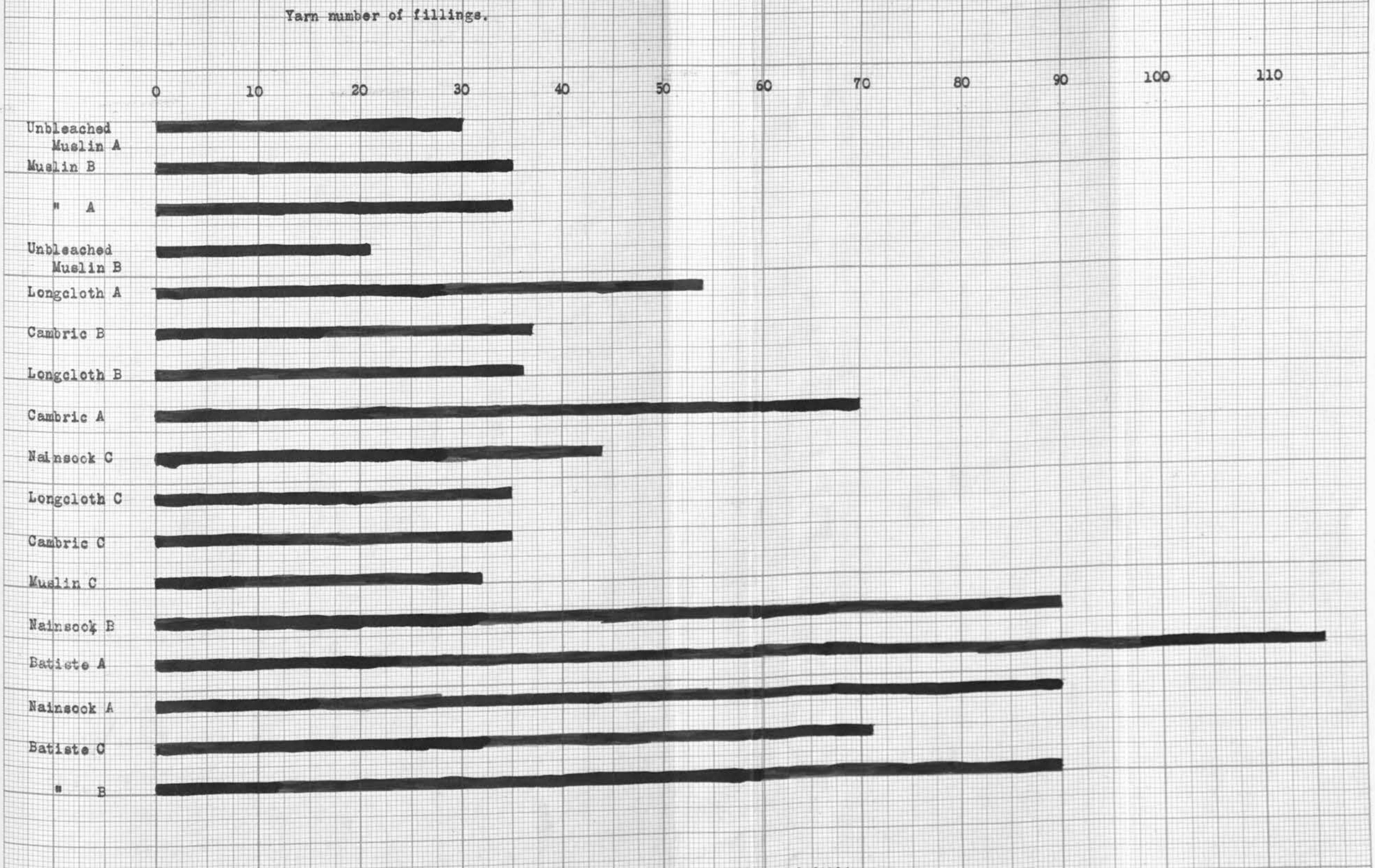

Figure 12. Yarn number of fillings arranged in order of tensile strength of fillings.

23° C respectively. The muslin had a moisture regain of 5.9%, and the nainsook of 4.9%.

The American Society for Testing Materials (1919) have also worked on the moisture regain of fabrics. Fabrics with loose open weave like cheese cloth adsorb moisture quickly and regain their strength quickly while the reverse is true of closely woven fabrics, so that a standard rate of increase can not be assumed for all fabrics. The per cent regain has a direct relation to the weight per square yard of the fabric and the rate of increase is nearly 37% per ounce of fabric weight. Consequently there is for every weight of fabric "a correction rate" equal to 0.37 multiplied by its ordinary weight in ounces per square yard.

Load Stretch and Its Relation to Tensile Strength

A study of tables 9 and 10 shows that as the average tensile strength of a group increases, in general its load stretch also increases (See figures 13 and 14). Walen (1918a) states that the load stretch diagram of fabrics is influenced by the character of the fibre, the structure of the yarn and the weave structure. He divides the load stretch curve into three parts; in the first part the load stretch is due almost entirely to the crimp of the yarn; in the second part it is due to the crimp of the yarns dominated by their stretch; and in the third part, up to the breaking load, it is due to the stretch of the yarn in its constrained condition, this last part being influenced very largely by yarn characteristics. That part of the curve due to removable crimp is dependent upon weave structure, thread diameter, and to some extent, upon the compressibility of yarns. When the diameter of yarns is increased while the weight of the fabric remains the same, the load stretch curve is not changed. Turner(1920) states that the tensibility of a fabric is

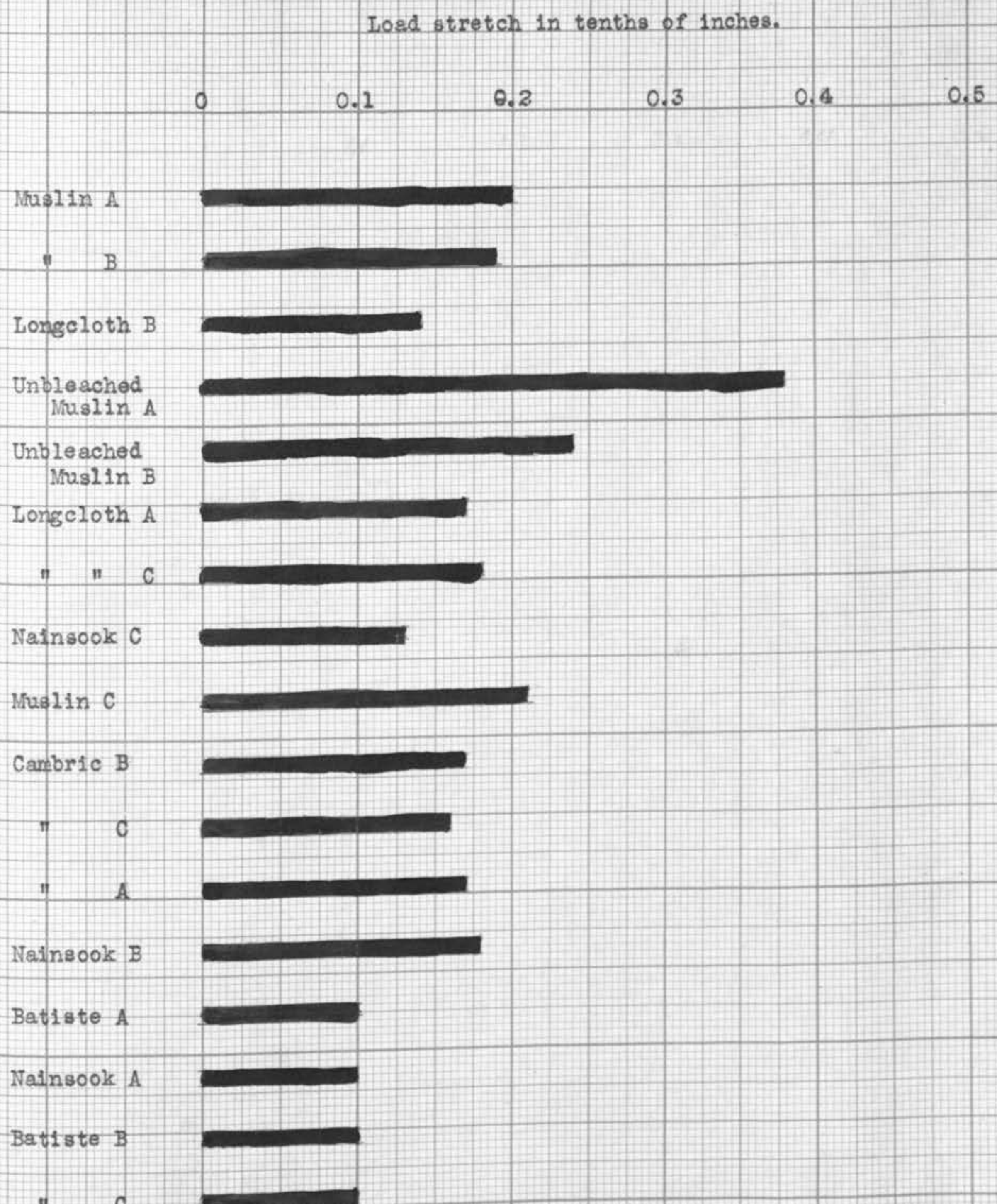

Figure 13. Load stretch of warps arranged in order of tensile strength of warps.

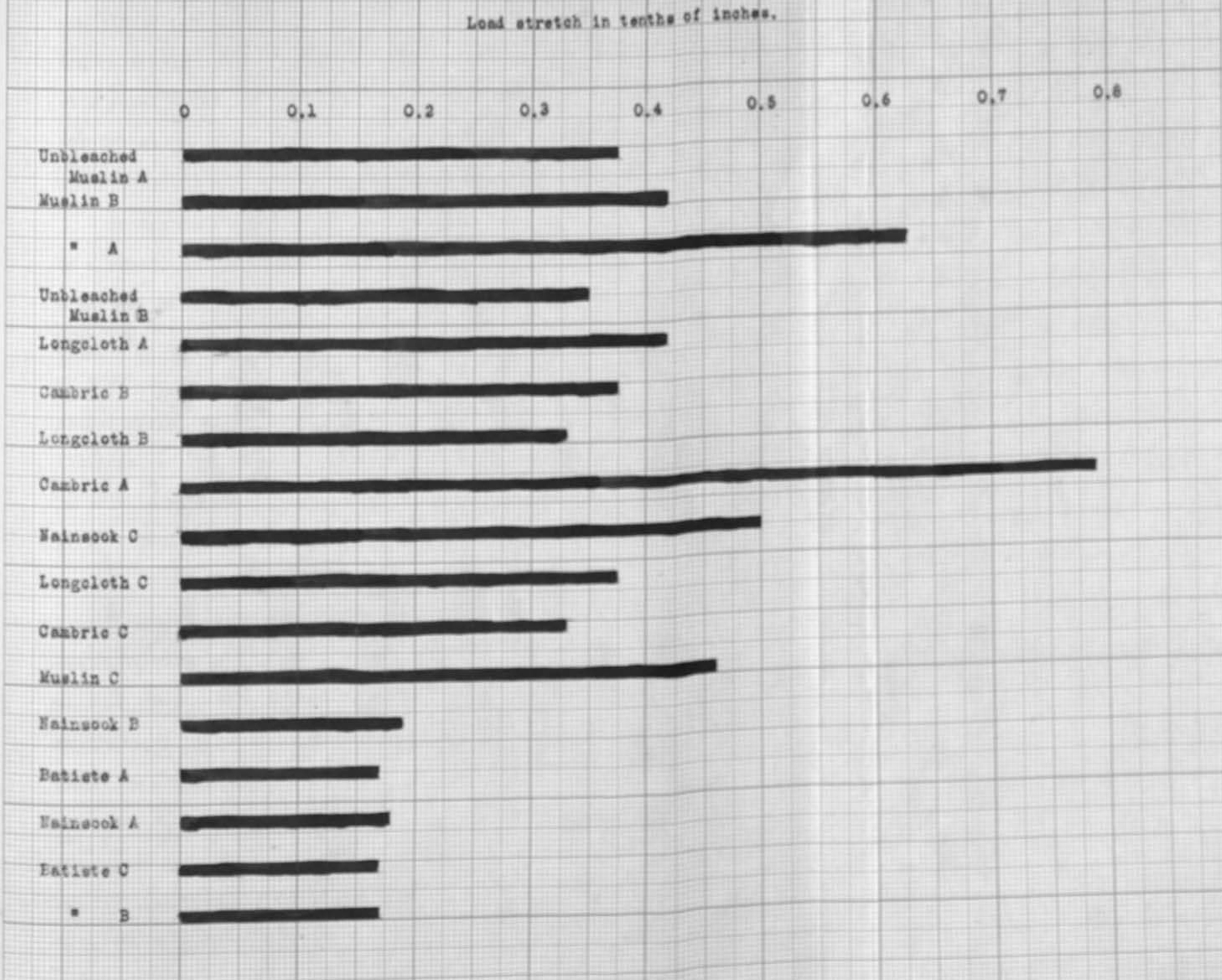

Figure 14. Load stretch of fillings arranged in order of tensile strength of fillings.

due almost entirely to its weave structure. Taylor and Earle (1920) in working on airplane fabrics found in a comparison of plain, twill and basket weaves with equal number of ends and picks per inch that the plain weave had a greater stretch at the different loads than either of the other two.

Tensile Strength

An examination of table 10 shows that, of the entire list, the batistes as a group, and as individual fabrics, rank lowest in tensile strength, batiste B having the lowest tensile strength of fillings and batiste C of warps. The nainsooks as a group rank second in average tensile strength. Nainsook A has an inferior tensile strength, both in warps and fillings, to the other members of the group, and to Batiste A. Nainsook C ranks highest, both in warps and fillings, of the fabrics of this group. The cambrics as a group, rank third in tensile strength. In the warps their average strain resistance is 3 pounds greater than the average for the warps in the nainsook group, but in the fillings it is 10 pounds greater, showing that the fillings of this group are superior in quality to those of the nainsook group on the basis of tensile strength. The difference between the average tensile strength of the warps and fillings of this group is 9.2 pounds, showing also a closer relation in quality of the two yarns in this group than is found between the warps and fillings of the other two groups. Cambric B is superior in tensile strength to either of the other two. The long cloths as a group rank fourth in tensile strength. In the warps their average is 6.2 pounds greater than for the warps in the cambrics, but for the fillings it is less, showing a greater percentage of difference between the warps and fillings of long cloths than of the cambrics. The muslins are, as a group, the best fabrics in so far as tensile strength is concerned, as determined by measurements of warps and fillings. In muslins A and B, the fillings very nearly approximate the warps in tensile strength, but the fillings in muslin C are very inferior to the warps in that fabric and because of their inferiority, lowered the average tensile strength of the fillings of this group. Unbleached muslin A has the strongest set of fillings in the entire list and is the only fabric that has stronger filling yarns than warps. The warps of this group have an average tensile strength which is only .7 lb lower than that of the muslin, while the fillings are higher by 8.5 pounds.

Wakefield (1922) makes the statement that "the demands made upon textiles by the consumer are that they be soft, pliable, strong, beautiful and capable of being renovated; and in special cases, that they be able to absorb moisture readily and insulate the body from heat and cold. This desire for maximum satisfaction in terms of wearing qualities may be satisfied in part by wider standardization of fabrics. The wearing quality of a fabric is difficult to determine. As yet we have no better measure of it than tensile strength, in spite of objections to this usage. (Turner 1920). Tensile strength tests have the advantage of being easily carried out and interpreted, and of being applicable for purposes of comparison. That tensile strength may not be a true criterion of the actual wearing quality of a clothing fabric is admitted, but to the present time, efforts to produce an abrasion machine which might more nearly approximate a measure of the kind of wear clothing undergoes, have not been successful. Efforts are being continued to produce such a machine. A personal communication from E. B. Millard, chemist for Filene's in Boston, referring to an abrasion machine used by them, states that "this machine is one of our own design which was built by a machinist; and which, at the present time, is still in an evolutionary stage." The chief difficulties with abrasion machines have been (1) the heat evolved during the test which mayscorch the fabric; and (2) the filling or glazing of the abrading surface with starch and dressing from the fabric being tested, which render calculations from such tests worthless. The Bureau of Standards has under construction an abrasion machine which they hope may prove successful. For a textile test, it has been found that the best method so far devised has been actual service conditions, a test which it difficult to apply with any degree of accuracy.

SUMMARY

The important findings of this study of a selected group of white cotton fabrics may be set forth as follows:

1. Weight per square yard, load stretch and moisture regain are more or less directly proportional to tensile strength;

2. Cost per square yard, average number of twists per inch, yarn number are more or less inversely proportional to tensile strength;

3. No constant relationship was observed between number of warps and fillings per inch, yarn elongation and tensile strength;

4. This investigation has shown that there is little or no standardization in the group of cotton fabrics studied.

5. Further studies are needed for the purpose of determining the relation between the factors reported herein, and other factors, such as abrasion and sizing which may possibly measure the wearing qualities of such materials.

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