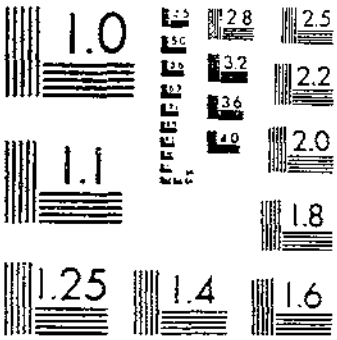
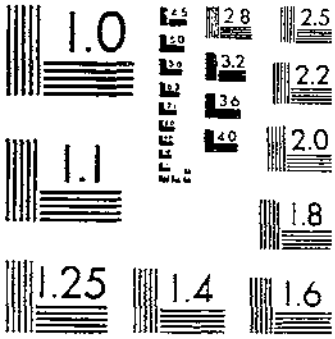
STIFFNESS IN FABRICS PRODUCED BY DIFFERENT STARCHES AND STARCH MIXTURES.

PETERSON, E. C., DANTZIG, T.

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

TECHNICAL BULLETIN No. 108 APRIL, 1929

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

STIFFNESS IN FABRICS PRODUCED BY DIFFERENT STARCHES AND STARCH MIXTURES, AND A QUANTITATIVE METHOD FOR EVALUATING STIFFNESS

By ESTHER C. PETERSON, *Assistant Chemist, Division of Textiles and Clothing, Bureau of Home Economics, and* TOBIAS DANTZIG, *Professor of Mathematics, University of Maryland, Consulting Mathematician for the Bureau of Home Economics*

CONTENTS

INTRODUCTION

Very few scientific studies have been reported which assist in the selection of sizing ingredients for the finishing of fabrics in either the manufacturing or the laundering process. The value of these sizing formulas is usually judged by the so-called "feel" or "handle" of the sized fabric. A few attempts have been made to determine experimentally the suitability of different starches and other sizing materials in terms of their ability to influence the penetrating and adhesive power of the paste and the stiffness and pliability of the sized fabric. However, the great number of contradictory results reported makes it obvious that these more specific properties of the fabric have not been adequately defined and studied upon this basis of definition.

In a series of studies in this laboratory an attempt is being made to differentiate and define the individual properties of a sized fabric that collectively constitute its "feel" and to develop methods for the physical measurement of these properties. It will then be possible to determine the relative values of various starches and other agricultural products suitable for sizing mixtures. Stiffness is one of the most important of these properties and is the subject of the work reported in this bulletin.

29753—29——1

STIFFNESS PRODUCED IN FABRICS BY DIFFERENT STARCHES AND STARCH MIXTURES [1]

By Esther C. Peterson

Starch was selected for study because it is one of the most common sizing materials. A better knowledge of the different properties of a fundamental sizing ingredient will not only guide the manufacturer in his original sizing applications but will also aid in the formulation of simple, effective means of more nearly restoring to the laundered cloth the new, unwashed appearance. A study of the comparative stiffness imparted by the different starches will help in the choice of a sizing agent for fabrics.

EXPERIMENTAL PROCEDURE

PREPARATION OF STARCHES

The study of a substance as complex and indefinitely known as starch involves a number of difficult factors. Rask and Alsberg (*21*)[2] have reviewed reports which show that starches of different species and even starches from different varieties of the same species may differ in their properties. A part of this apparent difference may be due to differences in the maturity of the plant at the time of harvest. However, it is probable that differences in the manufacture of the starch and the use of alkali or acid during this process may account for many of the variations which are recorded in the literature. Rask and Alsberg have partially reviewed reports concerning the effects of slight acid or alkali upon starch and in their own work have pointed out that the hydrogen-ion concentration of wheat-starch pastes is decidedly on the acid side of neutrality. To complicate matters still more Sharp (*23*) states that there is a change in hydrogen-ion concentration of wheat and other mill products with age.

Taking these various factors into account, it was thought advisable to prepare the starch used for a part of the experimental work and to compare it with different commercial products. Fortuna rice was obtained from the Louisiana Experiment Station; Kharkof hard winter wheat flour from the Kansas State Agricultural College; and Boone County White corn from the United States Department of Agriculture experiment farm at Rosslyn, Va. The Russet Rural potatoes used were selected by William Stuart, Bureau of Plant Industry, Department of Agriculture. The detailed methods employed for preparing the starches from these various grains and tubers are given below.

POTATO STARCH

Potato starch was prepared in general according to the methods outlined by Wiley (*30*) and by the Office of Extension Work, North and West (*27*), of the Department of Agriculture. The potatoes were scrubbed and finely ground. The pulp was placed in sieves and washed thoroughly several times in distilled water until the last rinse showed very little turbidity. Rinse waters containing the freed starch were combined and left to settle overnight. In the morning the water was siphoned off from the starch, which formed a

[1] Acknowledgment is made of the laboratory assistance given by Helen Woodward.
[2] Reference is made by italic numbers in parentheses to "Literature cited," p. 27.

compact layer on the bottom. The thin layer of darkened impurities on the top was scraped off and the starch again suspended in distilled water and allowed to settle. This process was continued until there was no sign of a grayish layer on top of the cake of starch. The product was then washed with alcohol and ether, air-dried, and put through a 70-mesh sieve.

WHEAT STARCH

Rask and Alsberg (*21*) have outlined a method for the laboratory preparation of wheat starch. They made a dough of the flour, ripened it for 45 minutes and kneaded it under a gentle stream of tap water to remove the starch from the gluten. The starch suspension was treated with a 1 per cent sodium chloride solution to dissolve out the globulins, and the filtered product was washed with 95 per cent alcohol. Because of the larger quantities of starch required for the work in this laboratory their method was modified slightly. It was found possible to free the resulting starch from protein by mechanical means alone, though the yield by this method was very poor. Consequently, the use of the salt solution was abandoned.

A thick dough was made with the flour and distilled water and allowed to stand for one hour. It was then placed in muslin bags and worked by hand in tubs of distilled water. The water was changed frequently, and the washing continued until the final water remained almost clear. The wash waters were combined, and the suspended starch was allowed to settle overnight. In the morning the water was siphoned off from the starch layer, which was packed solidly at the bottom. Above this was a layer of glutinous material less solidly packed and exceedingly sticky. The starch layer was resuspended in water, and the washing and settling continued until the sticky, glutinous layer ceased to form on the top.

The impure starch gluten from the settling basin was then centrifuged. Since a solid drum type of centrifuge was not available the perforated drum was lined with oiled silk. The starch packed in a pure white solid layer on the drum wall while the impurities formed a less solid deep cream layer on the inside. The water was siphoned out, the impure layer scraped off, and the starch layer left in the drum until several runs had been made. In this way a thick cake of starch was built up. The starch was removed and further purified by washing and settling by the same method used to free the original starch layer from traces of gluten. It was then washed with alcohol and tested for protein with Millon's reagent; ether-washed until tests showed it to be fat free; dried at room temperature; and put through a 70-mesh sieve.

CORN STARCH

No laboratory method for the preparation of corn starch has been reported, and the general method ordinarily followed in the mills was not advisable for a product which was to be used for experimental purposes. The corn was ground to a coarse meal and soaked in distilled water overnight. It was then washed for one hour with twice its bulk of distilled water in an oscillating-type washing machine. The water was changed and the washing repeated for another hour. Four such washings were made in order to loosen the starch. The milky starch water from the machine was strained through a milk strainer

and placed in large settling basins overnight. In the morning the water was siphoned off. The corn starch did not pack at this stage as did the wheat and potato starches, but was dipped out as a thick milk. This material was centrifuged, and an oiled-silk lining was used in the drum. The thin dark inner layer was scraped off and a cake of the still impure yellowish-gray starch built up. This was washed in alcohol, and later in ether until fat free.

This product gave a decided test for protein with Millon's reagent. The aim had been to avoid any hydrolysis of the starch by eliminating the use of either acid or alkali in its preparation. At this point, however, there appeared no other method of freeing the starch from protein. This protein material was therefore dissolved out with salt and alkali solutions according to the methods of Osborne (*18*) and Leach (*15*). Two and one-half liters of a 10 per cent sodium chloride solution were used for each kilogram of the impure starch, and five successive washings were made. The deep yellow color of the salt extract showed signs of soluble protein. After a final washing with distilled water the starch was treated with 2½ liters of a 0.3 per cent sodium hydroxide solution, and after standing for one-half hour was filtered by means of suction. After two such washings the starch was suspended in 3 liters of distilled water and allowed to settle overnight. The thick yellow solution at the top was then siphoned off and the starch cake again suspended in sodium hydroxide. At this point it was noticed that the suspension very quickly separated into two distinct layers, and the yellow layer appeared this time at the bottom. The milky starch suspension was siphoned off and more alkali added to the yellow layer. This process was repeated until the white suspension of starch ceased to form at the top. The starch suspension was filtered and washed with water until the hydrogen-ion values were found to be between 7 and 7.2 as shown by Clark's (*4*) colorimetric tubes. Both phenol red and cresol red were used as indicators. It was then washed with alcohol, dried in the air at room temperature, and put through a 70-mesh sieve. The commercial products showed a hydrogen-ion concentration of 6.8 to 7.2.

RICE STARCH

Several laboratory methods have been reported for the preparation of rice starch. Tadokoro and Sato (*26*) made a study of common and glutinous rice starch and have outlined the method used in the manufacture and purification of their experimental starches. They treated the rice flour with 0.3 per cent sodium hydroxide for 7-hour periods until a negative protein reaction was obtained. Wise (*31*) also lists two methods, one by Jones and a so-called American method, but each of these also employs alkali to free the material from protein. Schlüter (*22*), in an English patent, describes a method for the preparation of rice starch by mechanical means. The rice, with a predetermined quantity of water, is finely ground in a pebble mill and the starch separated from the other substances by centrifugal treatment. Upon trying to follow this method it was at once discovered that the success of the centrifuging depended upon the consistency of the ground mixture. The relation of the quantity of material to the size of the mill, the size and number of pebbles, and the variety of rice to be ground were all factors in determining the consistency of the mixture after one hour's grinding. A sufficient separation of the starch

was not obtained to justify using this method, though its possibilities were recognized had time been available for a more complete study of its control.

However, it was found that a water suspension of the ground mixture settled out overnight. Accordingly, 5 pounds of rice was ground at a time in a pebble mill with an equal weight of water until a smooth paste was obtained. An excess of water was added and the whole allowed to settle overnight. In the morning the water was siphoned off and the caked starch layer lifted out. More water was poured on the mealy residue and the suspension allowed to stand until a sharp division appeared between the top milky layer and the mealy layer at the bottom. The milky layer was siphoned off and more water added. This process was continued until all of the starch had been obtained. By centrifuging the starch in a drum lined with nainsook, a cake was formed which was thick at the base and tapered gradually to a very thin layer at the top. The impurities were found at the top and the starch at the bottom. There was no sharp line of demarcation; so a considerable quantity of starch was discarded with the impurities which were later resuspended in water and recentrifuged. The starch was then washed in alcohol and ether and air dried. However, upon testing with Millon's reagent, considerable quantities of protein were found to be present and chemical methods had to be used for further purification. A combination of the methods outlined by Kajiura (*13*) and Tadokoro and Sato (*26*) was adopted.

The impure rice starch was first washed with 10 per cent sodium chloride solution, and then treated with sodium hydroxide. Approximately 2½ liters of 10 per cent sodium chloride solution were used for each kilogram of starch. After washing with distilled water the starch was treated with 2½ liters of 0.3 per cent sodium hydroxide solution and allowed to stand for one hour. A distinct yellow layer appeared at the top and bottom of the container. The top layer was decanted into one Büchner funnel and the middle layer into a second. Most of the yellow bottom layer was discarded, but the best of it was combined with that in the first funnel. The middle layer now comprised about two-thirds of the original material. Each portion was again washed with 0.3 per cent sodium hydroxide. The upper dark yellow portion in each case was filtered and discarded. Tests with Millon's reagent at this point gave a negative protein reaction. The purified product was washed with distilled water until a hydrogen-ion concentration of 7 to 7.2 was shown by Clark's (*4*) colorimetric tubes when cresol red and phenol red were used as indicators. The commercial product showed a hydrogen-ion concentration of 7.2 to 7.4.

The advisability of using either the corn or the rice starch which was prepared in the laboratory has been questioned because of the alkali treatment in its preparation. Nevertheless, these starches were used in determinations testing the stiffness produced in fabrics by different starch pastes and the results were compared with those on commercial and other laboratory preparations.

DESICCATION OF STARCHES

It has been pointed out that heat has a marked effect upon the decomposition of starch. Knecht (*14*) has shown that starch in sealed tubes at 93° F. turned cream-colored in one week and brown in two weeks. The effect of varying the time and temperature of heating

was studied by Sherman and Baker (*24*). They have reported that 0.2 per cent of the starch became soluble after heating at 80° F. for 10 minutes to 1 hour, 0.3 per cent after 19 hours, and 0.35 per cent after 30 hours. These reports show very conclusively that the desiccation of the starch in the oven must be avoided. The method employed was therefore that outlined by Rask and Alsberg (*21*). The starch was placed in crystallizing dishes over calcium chloride in a vacuum desiccator in which a vacuum of 3 centimeters of mercury was maintained for five days. The moisture content at the end of this time was determined for nine samples and found to be approximately 5 per cent. The starch desiccated in this way was stored over calcium chloride until ready for use.

PREPARATION OF FABRIC FOR SIZING

Long cloth described in Table 1 offered a uniform, plain-weave cotton fabric of desirable weight, and was selected for use throughout these studies. The original fabric contained very little sizing material, and this was removed as effectively as possible according to a method developed in this laboratory by A. Elizabeth Hill and the writer. Ten to fourteen yards of fabric were desized at one time.

TABLE 1.—*Properties of the long cloth that was tested for stiffness after the various starch pastes had been applied*

Weight per square yard		Original fabric				Desized fabric	
		Threads per inch		Tensile strength [1]		Tensile strength [1]	
		Warp	Filling	Warp	Filling	Warp	Filling
Ounces	*Grams*			*Pounds*	*Pounds*	*Pounds*	*Pounds*
2.82	80	88	82	21.0	19.6	21.2	15.1

[1] Strip method.

The cloth was first treated with a 1 per cent sodium hydroxide solution at 100° C. for 30 minutes. Two liters of solution were used for each yard or 80 grams of fabric. The sodium hydroxide treatment was followed by one water rinse at 100° C. and two subsequent rinses at 60° C. Each rinse employed 3 liters of distilled water for every 80 grams of fabric and was carried out in an oscillating-type washing machine. The long cloth was then treated with a 5 per cent acetic acid solution for 30 minutes at 100° C., 2 liters of water being used for each 80 grams of cloth. There followed three rinses similar to those used after the sodium hydroxide treatment. Any remaining acid was neutralized by a a boiling castile-soap solution of .05 per cent concentration. Two liters of solution were used for each 80 grams of fabric. The cloth was agitated in the soap solution in the oscillating washing machine for 15 minutes. It was then rinsed as before. The 60° C. rinses were continued until a neutral test to phenophthalein was given in a concentrated sample obtained by boiling down 800 cubic centimeters of the wash water to approximately 10 cubic centimeters. An absolutely starch-free sample was never obtained by this method. However, the method was more effective

than many which were tried and less injurious to the fabric than some others which were slightly more effective.

SIZING OF FABRIC

To 15 grams of the desiccated starch, weighed in a 50 cubic centimeter beaker, were added 20 cubic centimeters of cold distilled water. Three hundred and seventy-five cubic centimeters of boiling distilled water were measured out into a 500 cubic centimeter three-necked balloon flask, and a mechanical stirrer was introduced through the middle neck. While the stirrer was in motion the cold-water starch suspension was introduced through one of the side arms, and 10 cubic centimeters more of cold water was used to rinse out the beaker, thus making in all 30 cubic centimeters of cold distilled water which was added.

Starch pastes are affected by agitation, as shown by Harrison (*10*), who reports that the viscosity of potato starch is reduced from 250 to 50 by one minute of shaking at 16° C., and to 20 by the same shaking at 90° C. Petit and Richard (*19*) subjected starch paste, contained in U tubes with internal projections, to a blast of air so as to cause violent agitation. The product was passed through filter paper and gave a molecular rotation of 210° C. Viswanath, Row, and Ayyanger (*28, p. 160–163*) had shown that shaking 1 gram of starch for one hour in 50 cubic centimeters of water at 70° C. produced 44.91 per cent liquefaction. Therefore, the time and speed of stirring were kept at a minimum and held as constant as possible throughout this series of experiments.

The balloon flask containing the starch paste was then placed in a boiling-water bath. The two side arms were closed and the middle one was attached to a reflux condenser to prevent loss of moisture during the heating process.

The optimum time of heating and the best temperature of applying sizing mixtures have been discussed in the literature, but there is much disagreement among the different investigators. Bean (*3*) states that thorough cooking is required to prevent the size from being rubbed off. Most writers agree that better adhesive qualities of a starch paste are obtained if the gelatinization temperature is exceeded. While one finds listed in a number of places gelatinization temperature constants for the various starches, there is much contradiction in them, and Alsberg (*1*) and Alsberg and Rask (*2*), who have reviewed the literature and made extensive studies along these lines, have definitely shown that there is a gelatinization range but no constant for a given starch. Hinckley (*11*), endeavoring to obtain an optimum condition for an application of the size, studied a range of temperature from 171° to 212° F. and showed advantages of the lower sizing temperature. MacNider (*16*) advocates 180° F. Farrow (*6*) refers to another work that gives figures to prove that better sizing results from a high temperature, which is in accord with Nivling's (*17*) ideas on this subject.

It has been shown that the length of time of heating the starch paste has an effect upon its viscosity, which in turn may affect its penetrating power. Farrow and Neale (*7*) made an interesting study of the wetting of yarn during sizing in order to determine the part played by surface forces, such as viscosity and surface tension. Harrison (*10*) has determined a series of viscosities for different

starches, keeping a constant temperature of 100° C., but increasing the time of heating the paste from 5 minutes to eight hours. Ginsberg (*8*) has also studied the effect of prolonged boiling upon the viscosity of starch pastes and filling mixtures.

For this work it did not seem practical, for the present at least, to vary both temperature and time of heating the paste. Therefore, a constant temperature of 100° C. was maintained throughout, while the heating was varied over a range of from 10 to 60 minutes. After the flask had been allowed to remain in the water bath for a desired length of time, it was removed and the paste poured into a liter beaker.

The dry desized sample of long cloth, 11 by 12 inches, was dipped into distilled water to wet it and then wrung through a wringer. The wringer was so adjusted that the same tension between the rolls could be obtained for the whole series of experiments. After wetting, the fabric was dipped into the starch paste and allowed to remain there for three minutes. It was then put through the wringer in order to remove the surplus paste. By stretching the fabric over a square wooden frame and holding it in place by a second tightly fitting frame, a smooth surface was obtained when the fabric was dry. This method was found to be more successful than earlier ones in which the samples were placed overnight in book presses or dried by being passed through an electric ironer immediately after being wrung. In the latter case the wet sample stuck to the padding of the ironer, and it was evident that some starch came off. Furthermore, it was necessary to pass the sample through the ironer at 300° F. five or six times in order to dry it thoroughly. If the samples were hung on the line before being put through the ironer, it was impossible to prevent uneven drying even when they were reversed frequently. Thus, since the moisture content at the time of pressing was unknown, this method was discontinued. For the same reason the first method of placing the partially dried samples in book presses was also discontinued.

The dried fabric was marked off into strips 2 inches wide and 8 inches long, with cross marks at every inch. The strips were cut on the paper cutter and hung overnight in a humidity room [3] which was maintained day and night at 50 per cent relative humidity and at a temperature of 70° C. On the next day the stiffness of the fabrics was determined in the humidity room according to a quantitative method developed by the authors (pp. 14 to 26).

EXPERIMENTAL DATA AND CONCLUSIONS

EFFECT OF TIME OF HEATING ON THE STIFFENING POWER OF STARCH PASTE

Before any comparisons could be made of the stiffness produced in a given fabric by different starches, it was first necessary to determine whether or not there existed for each paste an optimum period of heating for the production of a maximum stiffening power. In case the factor of time had any appreciable effect, a comparison of the stiffening property of the starches could then be ascertained on a basis of optimum conditions for each as well as on a basis of identical treatment. The following ranges of time were studied: For

[3] The constant temperature and relative humidity room in the division of tests and technical control of the Government Printing Office.

potato starch from 5 to 60 minutes, for wheat and corn starches from 10 to 60 minutes, and for rice starch from 10 to 80 minutes.

The data collected, however, showed by the methods of analysis employed, that over the range studied the time of heating the starch pastes had no appreciable effect upon the stiffness of the fabrics to which the pastes had been applied. Table 2 gives these data and results.

By calculating the standard error of difference between the means, it is evident that the degree of probability is sufficiently great to attribute any variation in the results obtained for the stiffness of samples to the nonuniformity of the test fabric rather than to any difference brought about by differences in the periods of time of heating the starch pastes. In view of these results, all of the stiffness readings for fabrics sized with the same starch were considered together, irrespective of the length of time for which the corresponding pastes had been heated.

TABLE 2.—*Effect of time of heating the starch paste upon the stiffness produced in a given fabric*

STARCH PREPARED IN LABORATORY

Time of heating starch paste in water bath at 100° C. (minutes)	Wheat starch		Rice starch		Corn starch		Potato starch	
	Number of samples (N)	Average stiffness [1]	Number of samples (N)	Average stiffness [1]	Number of samples (N)	Average stiffness [1]	Number of samples (N)	Average stiffness [1]
5							16	38.7
10	32	43.2	16	42.9	16	42.3	16	36.4
15							16	38.9
20	32	43.3	16	41.0	16	41.6	32	36.0
30	32	43.2	16	43.4	16	43.1	32	37.0
40	32	41.6	16	44.6	16	43.8	24	36.0
60	32	42.0	16	42.6	16	42.7	24	33.6
Mean		42.8		42.9		42.7		36.7
Standard devintion		2.7		2.1		2.0		4.5

STARCH FROM COMMERCIAL SOURCE A

5							16	41.1
10	16	51.0	16	42.2	16	40.4	16	39.9
15	16						16	40.3
20	16	51.7	16	43.2	16	43.0	32	40.4
30	16	52.0	16	41.7	16	41.3	32	40.7
40	16	53.1	12	41.4	16	41.0	24	41.2
60	16	50.7	12	42.0	16	45.2	24	38.4
80			4	42.7				
Mean		51.0		42.2		42.4		40.3
Standard deviation		3.1		2.2		3.1		4.2

CORN STARCH FROM COMMERCIAL SOURCES B AND C

Time of heating starch paste in water bath at 100° C. (minutes)	From B		From C	
	Number of samples (N)	Average stiffness [1]	Number of samples (N)	Average stiffness [1]
10	16	40.3	16	38.7
20	16	41.7	16	39.8
30	16	40.5	16	38.7
40	16	38.8	16	39.0
60	16	41.3	16	39.5
Mean		40.5		39.1
Standard devintion		2.7		2.5

[1] Mean stiffness of N samples expressed as 0.430 × millimeter length of projected fabric supporting own weight at 45° angle.

COMPARISON OF STIFFNESS IMPARTED BY DIFFERENT STARCHES

A study was made of the stiffening powers of four different species of starch, namely, corn, wheat, rice, and potato. Samples of each of these starches were prepared in the laboratory (p. 2) and also obtained from commercial source A. Corn starch was also secured from commercial sources B and C. Comparisons were drawn between the stiffness of fabrics sized (1) with different species of starch from commercial source A; (2) with different species of starch of laboratory preparation; (3) with the same species of starch from commercial and laboratory sources, and (4) with the same species of starch from commercial sources A, B, and C.

With the commercially prepared starches from source A, fabrics sized with the wheat starch were decidedly stiffer than any of the others; corn and rice starch produced practically the same stiffness; while the fabric to which the potato starch was applied was least stiff. A comparison of the starches prepared in the laboratory showed that rice, wheat, and corn produced practically the same stiffness, whereas the potato starch gave a less stiff fabric than the others. If the laboratory starches are compared with the commercial product, it is found that the fabrics sized with the commercial wheat and potato starches are correspondingly stiffer than those sized with the laboratory preparations of these same starches. The rice and corn starches produced no apparent differences. If the different corn starches are next considered, it is shown that the starch from commercial source A produced the same stiffness as the laboratory preparation; that from commercial source B a slightly less stiff fabric; while the one from commercial source C showed the least stiffening power.

Table 3 gives a comparison of the mean stiffness values for the different starches studied and shows the relative degree of probability that they possess true differences in stiffness. True differences have been considered to exist between the samples if the difference between the means was three or more times the standard error of difference, Yule (*32, p. 269*).

A list of all the starches studied, irrespective of the source from which they were obtained, is given in Table 4, in descending order of the ability of their pastes to produce stiffness in a fabric. The corresponding mean stiffness and standard deviation from the mean are also reported for each starch. This order of stiffening power of the different starch pastes does not agree with the statements of Wiesner reported by Polleyn (*20, p. 22*) and Standage (*25, p. 137*), whose comparisons are given in Table 5. Wiesner, whose method of obtaining stiffness values is described on page 14, has employed different concentrations of starch paste. Consequently, since his comparisons have not been made on the same basis of concentration, they can not be regarded as reliable without accompanying experimental data showing the effect of concentration upon the stiffening power of the paste. Standage has given no clue as to the source of his authority or the method used in ascertaining the starch comparisons which he has reported. He has given differences in the stiffening power displayed by different grades of the same species of starch, but has not reported observations made upon first-class grades of the same species from different commercial sources.

TABLE 3.—*Comparison of the stiffening powers of several starches determined by comparing the stiffness produced in a fabric by the different starch pastes* [1]

Starches compared		Number of samples of stiffened fabric N	Mean stiffness of N samples expressed as 0.430× millimeter length of projected fabric supporting own weight at 45° angle, M	Standard deviation σ	Standard error of difference between mean stiffness values, $\sigma_D=\sqrt{\frac{\sigma_1^2}{N_1}+\frac{\sigma_2^2}{N_2}}$	Difference between mean stiffness produced by two starches, M_1-M_2	Ratio of mean stiffness difference to standard error of difference, $\frac{M_1-M_2}{\sigma_D}$	Comparison of stiffening powers of one starch in terms of another assuming the one to possess 100 per cent stiffening action
Starch	Source							
Wheat	Commercial A	80	51.9	3.1	0.49	9.5	19.5	100
Corn	do	80	42.4	3.1				81
Do	do	80	42.4	3.1	.43	.2	.4	100
Rice	do	76	42.2	2.2				[2] 100
Do	do	76	42.2	2.2	.42	1.9	4.0	100
Potato	do	160	40.3	4.2				96
Wheat	do	80	51.9	3.1	.43	9.7	22.7	100
Rice	do	76	42.2	2.2				81
Wheat	do	80	51.9	3.1	.48	11.6	24.2	100
Potato	do	160	40.3	4.2				78
Corn	do	80	42.4	3.1	.48	2.1	4.4	100
Potato	do	160	40.3	4.2				95
Rice	Laboratory preparation.	80	42.9	2.1	.31	.1	.2	100
Wheat	do	160	42.8	2.7				[2] 100
Do	do	160	42.8	2.7	.31	.2	.5	100
Corn	do	76	42.7	2.0				[2] 100
Do	do	76	42.7	2.0	.42	6.0	14.2	100
Potato	do	160	36.7	4.5				86
Rice	do	80	42.9	2.1	.32	.2	.7	100
Corn	do	76	42.7	2.0				[2] 100
Rice	do	80	42.9	2.1	.42	6.2	14.7	100
Potato	do	160	36.7	4.5				86
Wheat	do	160	42.8	2.7	.41	6.1	14.8	100
Potato	do	160	36.7	4.5				86
Wheat	Commercial A	80	51.9	3.1	.41	9.0	22.4	100
Do	Laboratory preparation.	160	42.8	2.7				82
Corn	Commercial A	80	42.4	3.1	.41	.3	.8	[2] 100
Do	Laboratory preparation.	76	42.7	2.0				100
Rice	Commercial A	76	42.2	2.2	.34	.7	2.2	98
Do	Laboratory preparation.	80	42.9	2.1				100
Potato	Commercial A	160	40.3	4.2	.49	3.5	7.3	100
Do	Laboratory preparation.	160	36.7	4.5				91
Corn	Commercial A	80	42.4	3.1	.38	.3	.8	[2] 100
Do	Laboratory preparation.	76	42.7	2.0				100
Do	Commercial A	80	42.4	3.1	.46	1.9	4.0	100
Do	Commercial B	80	40.5	2.7				96
Do	Commercial A	80	42.4	3.1	.45	3.2	7.3	100
Do	Commercial C	80	39.1	2.5				92
Do	Commercial B	80	40.5	2.7	.41	1.4	3.4	100
Do	Commercial C	80	39.1	2.5				97
Do	Commercial B	80	40.5	2.7	.38	2.2	5.8	95
Do	Laboratory preparation.	76	42.7	2.0				100
Do	Commercial C	80	39.1	2.5	.36	3.6	9.9	92
Do	Laboratory preparation.	76	42.7	2.0				100

[1] It has not been considered worth while to give the corresponding numbers for the elastic modulus of the starched fabrics since, in the opinion of the author, they have only a comparative value. The elastic modulus for the samples under observation varied from 15,000 to 44,000 dynes per square centimeter as compared with 2,000,000,000,000 for mild steel.

[2] Since the difference between the means is less than three times the standard error of difference a true difference can not be considered to exist between the samples.

TABLE 4.—*Arrangement of starches in descending order of the ability of their pastes (3.7 per cent starch) to produce stiffness in a given fabric*

Starch	Source	Number of samples (N)	Mean stiffness [1] M	Standard deviation σ	Coefficient of variation $\frac{\sigma}{M}$
					Per cent
Wheat	Commercial A	80	51.9	3.1	5.9
Rice	Laboratory preparation	80	42.9	2.1	4.8
Wheat	do	160	42.8	2.7	6.3
Corn	do	76	42.7	2.0	4.6
Do	Commercial A	80	42.4	3.1	7.3
Rice	do	76	42.2	2.2	5.2
Corn	Commercial B	80	40.5	2.7	6.7
Potato	Commercial A	160	40.3	4.2	10.5
Corn	Commercial C	80	39.1	2.5	6.4
Potato	Laboratory preparation	160	36.7	4.5	12.1

[1] Mean stiffness of N samples expressed as 0.430 × millimeter length of projected fabric supporting own weight at 45° angle.

TABLE 5.—*Stiffening powers of the different starch pastes employed as sizing agents according to reports by Wiesner and Standage*

According to Standage		According to Wiesner		
Starch	Relative stiffness produced by starch paste referred to rice 100 as standard	Starch	Lengths of projected bends of yarn indicative of stiffness	Concentration of starch paste
			Mm.	*Per cent*
Standard rice	100	Maize	223.7	7.6
Grade A rice	95	Wheat	215.8	7.9
Grade B rice	91	Potato	213.6	15.6
Maize	85			
Wheat	80			
Potato pure	68			
Potato farina	65			

The standard deviations calculated for each group of stiffness values show that there is a considerable variation between the samples of the same starch. This variation may be due to one or more of several possible causes. The nonuniformity of a textile fabric itself and the great difficulty in obtaining a uniform distribution of the size over the surface of the fabric were the greatest uncontrollable factors. Especially was difficulty experienced in obtaining a uniform distribution of the potato-starch paste because of the much more viscous character of this paste. The inaccuracies resulting from this difficulty are plainly seen in the increased standard deviation of the stiffness produced by potato starch as compared with those produced by the other starches.

EFFECT OF STARCH PASTE CONCENTRATION ON THE STIFFNESS PRODUCED

Preliminary work was started in order to determine the effect of the concentration of the starch paste on the stiffness produced in a fabric. The standard paste mixture (p. 7) was made, and to that

were added from 10 to 100 cubic centimeters of water. In every case dealing with concentration the pastes remained in the water bath at 100° C. for 30 minutes. The resulting stiffnesses obtained tend to indicate that in the cases of wheat, rice, and corn starches any addition of water to a paste containing 3.7 per cent starch produces a falling off in the stiffness reading of the fabric over the range of concentrations studied. In the case of potato starch, however, as much as 90 to 100 cubic centimeters of additional water were necessary before a decrease in stiffness readings resulted. An explanation for this observation might be given in that the very viscous pastes do not penetrate the fabric but remain on the surface to be scraped off as the cloth passes between the rolls of the wringer. As the concentration is reduced, more starch actually remains in the fabric after it has passed the wringer and a stiffer fabric results. These observations suggest an interesting study in the correlation of the viscosity of the starch pastes with the stiffness of the sized fabrics. An attempt was made to estimate the amount of starch that had been deposited by weighing the starched and unstarched fabric. However, the weight of the starch that remained on the fabric impregnated with the pastes of the concentration used in these experiments was found to be less than the variation in the weight of the fabric itself.

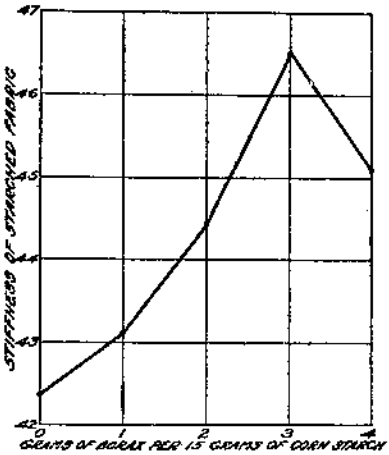


FIGURE 1.—The effect of borax upon the stiffness of a sized fabric

EFFECT OF FOREIGN SUBSTANCES ADDED TO THE STARCH PASTE

From 1 to 4 grams of borax were added successively to the standard paste made with commercial A corn starch. The fabric increased in stiffness from 42.2 to 46.5 with the addition of the borax up to 3 grams, beyond which the further addition of borax produced a less stiff fabric (Fig. 1.) A possible explanation might be given in that the alkaline action of the borax caused a partial hydrolysis of the starch. The resulting lowering of the viscosity produced a better penetrating paste and consequently a greater deposit of starch and a stiffer fabric. An excess of borax may cause too great an hydrolysis, which destroys the adhesive qualities of the paste, and the stiffness of the fabric decreases.

Preliminary experiments tended to show that salt, beeswax, paraffin, and hydrogenated vegetable oil up to 4 grams per 15 grams of starch had no appreciable effect on the stiffness produced by cornstarch paste as shown by the method that was used in measuring stiffness.

A QUANTITATIVE METHOD FOR MEASURING STIFFNESS

By Esther C. Peterson and Tobias Dantzig

In establishing any criterion of stiffness for flexible materials, certain requirements should be met. The method should be quantitative, thereby providing a numerical expression of stiffness. It should be sufficiently general to permit the scale and the unit selected to be applicable to a great variety of materials, yet sensitive enough to indicate variations in stiffness produced by the different materials in question. The application of the method should be practical and should require but simple apparatus and manipulation. Above all, the method should be scientific, based upon the fundamental laws which govern the phenomenon.

The only method for determining the stiffness of textile fabrics which is reported in the literature is the one suggested by Grimshaw (*9*). However, methods have been given for measuring the stiffness of other materials, the most analogous of which are those applied to yarns and paper.

Polleyn (*20, p. 22*) has cited Wiesner's procedure for testing the stiffness of yarns in which he used a projecting method slightly different from that employed by Grimshaw. Wiesner clamped the yarn in a vertical position with the free end extended upwards. By gradually raising the clamp, a position was reached where the thread bent forward until the tip was on the same horizontal plane as the clamp. The length of the bend when the thread was clamped in this position gave a relative measure of the stiffness of the yarn.

After the work in the Bureau of Home Economics was well under way, Ewald (*5*) reported the development of an instrument for measuring the stiffness of paper. He expresses stiffness in terms of the distance a given weight can be moved from the fixed to the free end of a horizontally projected strip of paper before the strip gives way under the weight.

Viscosity determinations have been cited (*29*) as indirectly indicating the stiffening effect produced in a fabric by a given starch paste. However, the viscosity determinations frequently made in the mills act merely as a check upon the uniformity of the sizing mixtures themselves and have never been correlated with the resultant stiffness of the fabrics to which they have been applied. Since Grimshaw's method is the only one reported that applies directly to the measurement of fabric stiffness, it will be considered in detail.

Grimshaw (*9*) considered the stiffness of a fabric to be the ability of that fabric to support its own weight. Accordingly he projected from a horizontal clamp a 2 by 8 inch strip of sized fabric. Inch lengths had been previously marked along the strips, and each strip was clamped so that 2, 3, 4, 5, and 6 inch lengths were successively projected. The clamp was so placed that the strips fell directly in front of an accurately adjusted graph paper. The inch positions on each of the projected lengths were indicated on the graph and these points used to plot rough curves for the projected fabrics. By placing several curves on the same sheet of paper Grimshaw was able to estimate relative differences in stiffness from a study of the graphs. While this method showed qualitative differences in the stiffness of variously sized fabrics, no report has been found to indicate that Grimshaw has ever attempted to interpret his results mathematically

or to develop a numerical measure of stiffness. In the section which follows, it will be shown that the principle utilized by him serves as a point of departure for establishing a quantitative method for measuring the stiffness of fabrics.

MATHEMATICAL DEVELOPMENT OF A QUANTITATIVE MEASURE OF STIFFNESS

Any consideration of the fundamental physical laws governing the stiffness of fabrics suggests an analogy with the stiffness of metals. There, stiffness finds an expression in the so-called Young's modulus, which is numerically the force that will produce unit deformation when applied to the stretching of a cylindrical bar of the material of unit length and unit cross-sectional area.

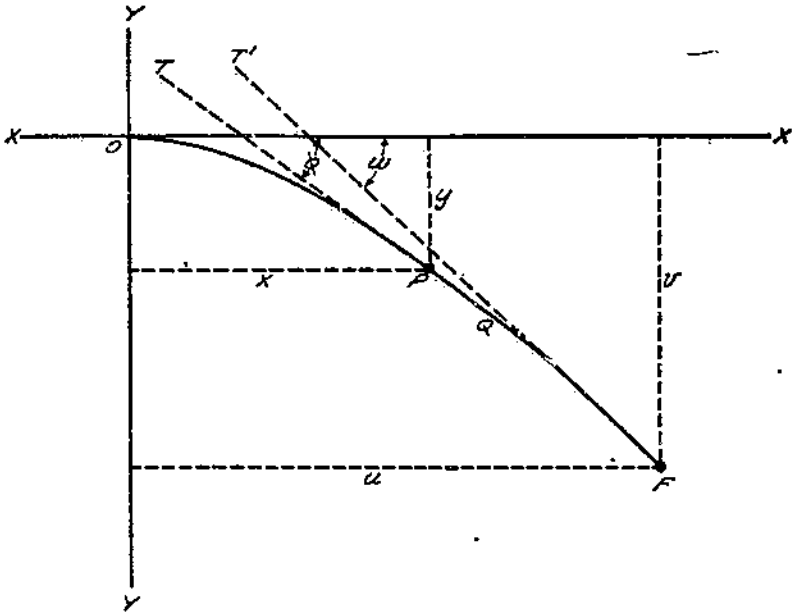


FIGURE 2.—Geometrical formulation governing the stiffness of a fabric in which OPF represents the elastic curve of a projected strip of fabric clamped at the point O; TP the tangent to the curve at any point P whose coordinates are x and y; $T'F$ the tangent at the free end F whose coordinates are u and v; and Q any point on the curve to the right of P. Tangent TP makes an angle ϕ and tangent $T'F$ an angle ω with the x axis

The method of measuring the elastic modulus of metals is direct and involves a comparatively elaborate procedure. No attempt to simplify this procedure has been made, probably because the modulus varies but little with differences in heat treatment and composition. But, even if such a simplified procedure were known, its direct application to textiles would present unsurmountable difficulties, chiefly due to the lack of uniformity in the fibrous texture and to the tendency of the material to warp and stretch under deformation.

Fortunately, there are a great number of problems in the elastic equilibrium of bodies that depend on the modulus, and these suggest several indirect methods for the measure of stiffness. Among such methods is flexure, and it presents but few obstacles in application. The principle involved depends on the deformation of a supported

strip bent under its own weight, which is the same as that underlying Grimshaw's method. A mathematical formulation of this principle is as follows:

Consider a rectangular strip of breadth b, thickness h, and length l, clamped in a horizontal plane XOX and actuated by its own weight. The strip will assume a position of equilibrium. This is shown in Figure 2 in OPF, with O as the point of clamping, F the free end, and P any point on the elastic line. The vertical plane containing a longitudinal section is taken for the coordinate plane, and the horizontal and vertical lines passing through the fixed point are taken for the axes. The coordinates of P are denoted by x and y, those of the free end F by u and v. In what follows the purpose is to investigate the shape of the elastic line, and particularly the position of the point F which obviously is a function of four variables; namely, the elastic modulus of the material E, its specific weight w, its thickness h, and the free length of the strip l.

Consider a cross section through P. The line perpendicular to the plane XOY and passing through the center of this cross section is called the neutral axis. I denotes the moment of inertia of this cross section with respect to its neutral axis and may be expressed

$$I=\frac{1}{12}bh^3 \tag{1}$$

The bending stresses acting to the right of this cross section exert couples on the portion to the left, and these couples have a resultant with respect to the neutral axis at P which is called the bending moment and is denoted by M. M is a function of the abscissa x of the point P given by the integral

$$M(x)=\int_s^l (X-x)wbhdS=wbh\int_s^l (X-x)\,dS \tag{2}$$

In this equation s is the length of the arc OP, while X and S are respectively the abscissa and the arc relative to an arbitrary point Q of the portion to the right of P.

The fundamental equation of flexure, the so-called Euler-Bernoulli equation, establishes a connection between the bending moment and the curvature K of the elastic line at P. The relation is

$$EIK=M \tag{3}$$

In the classical theory of flexure of beams this equation can be solved by elementary methods because there a relatively small flexibility of the beam is the only case of practical importance. Thus the elastic line is nearly straight, and it is justifiable to assume $S=X$ so that equation 2 is integrated without much difficulty. Furthermore, the curvature is given by

$$K=\frac{\frac{d^2y}{dx^2}}{\left[1+\left(\frac{dy}{dx}\right)^2\right]^{3/2}}$$

and since the slope $\frac{dy}{dx}$ at P is very small, the curvature K can with excellent approximation be taken equal to $\frac{d^2y}{dx^2}$.

The case of a flexible strip, in the present study can not be handled in this manner. It requires the introduction of an auxiliary unknown, the angle of contingency ϕ, which the tangent at P makes with the horizontal. Then by definition

$$K=\frac{d\phi}{ds} \tag{4}$$

and equation (3) becomes

$$\left(\frac{EI}{wbh}\right)\frac{d\phi}{ds}=\int_s^l (X-x)dS \tag{5}$$

The constant entering in the left side of this equation has the dimension of a cube of a length. Thus $\left(\frac{EI}{wbh}\right)$ may be set equal to c^3.

$$c^3=\frac{EI}{wbh}=\frac{1}{12}\frac{Ebh^3}{wbh}=\frac{1}{12}\frac{Eh^2}{w} \tag{6}$$

The solution of equation 5 will determine ϕ as a function of s, l, and c.

$$\phi=H(s, l, c). \tag{7}$$

The inclination, ω, of the tangent at the free end would then be obtained by setting $s=l$ in (7).

$$\omega=H(l, l, c) \tag{7'}$$

Furthermore, since

$$\cos\phi=\frac{dx}{ds} \text{ and } \sin\phi=-\frac{dy}{ds}$$

The following equations are obtained by integration

$$x=\int_0^s \cos\phi ds=f(s, l, c)$$

$$y=-\int_0^s \sin\phi\, ds=g(s, l, c) \tag{8}$$

from which, by substitution $s=l$, the coordinates of the free end can be determined.

$$u=f(l, l, c)$$

$$v=g(l, l, c) \tag{8'}$$

The determination of the functions H, f, and g, involve mathematical manipulations and approximations. Details of these are given in a paper by one of the coauthors[4] of this report. It is shown there that the problem can be reduced to the solution of the differential equation:

$$c^3\frac{d^2\phi}{ds^2}+(l-s)\cos\phi=0 \tag{9}$$

[4] DANTZIG, T., ON THE EQUILIBRIUM OF AN ELASTIC BLADE. [Paper read Dec. 3, 1927, before Washington, D. C., section, Mathematical Association of America.]

under the boundary conditions

$$\frac{d\phi}{ds}=0 \text{ for } s=l \tag{10}$$

$$\phi=0 \text{ for } s=0$$

Equation 9 can be integrated into a power series which contains only powers of $(l-s)$ having exponents which are multiples of 3. The first terms of this expansion are:

$$\phi=\omega-\left(\frac{1}{6}\cos\omega\right)\left(\frac{l-s}{c}\right)^3-\left(\frac{1}{180}\sin\omega\cos\omega\right)\left(\frac{l-s}{c}\right)^6 \tag{11}$$

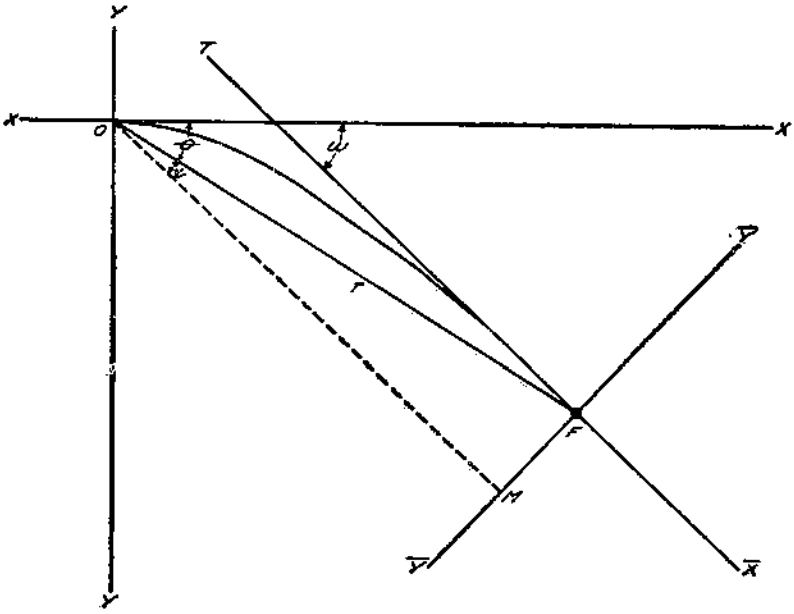


FIGURE 3.—The same geometrical formulation governing the stiffness of fabrics given in Figure 2 referred to axes $\overline{X}$, $\overline{Y}$ composed of the tangent to the curve at the free end F and the normal to the tangent at that point. The chord subtending the arc assumed by the elastic curve is represented by r and makes an angle θ with the original set of axes X, Y and an angle ψ with the new set of axes $\overline{X}$, $\overline{Y}$

This series converges very rapidly when $(l-s)$ is less than c, and even when $(l-s)$ is greater than c, provided the ratio $(l-s)/c$ is not very large. For the purpose of this paper a sufficiently good approximation is obtained by employing only the first two terms of the series

$$\omega-\phi=\frac{1}{6}\cos\omega\left(\frac{l-s}{c}\right)^3 \tag{11'}$$

If this approximation is adopted for all points of the elastic line, then from the boundary conditions $s=0$, $\phi=0$, the following equation is obtained:

$$\frac{6\omega}{\cos\omega}=\left(\frac{l}{c}\right)^3 \tag{12}$$

This establishes the relation between the free length l and the angle ω.

The equation of the elastic line assumes a particularly simple form when the tangent and the normal at the free end are taken for the new coordinate axes. (Fig. 3.)

Let $\bar{x}$, $\bar{y}$ denote the new coordinates. The transformation from the old to the new coordinates can be made by means of the following equations:

$$\bar{x} = (x-u)\cos\omega - (y-v)\sin\omega$$
$$\bar{y} = (x-u)\sin\omega + (y-v)\cos\omega \tag{13}$$

The same approximations are obtained by means of equations 8 and 13.

$$\bar{x} = s - l$$
$$\bar{y} = -\frac{1}{24}\cos\omega\frac{(s-l)^4}{c^3} \tag{14}$$

By eliminating $(s-l)$ in equations 14, the equation of the elastic line in cartesian form is obtained.

$$\bar{y} = -\left(\frac{\cos\omega}{24\,c^3}\right)\bar{x}^4 = -\left(\frac{\omega}{4\,l^3}\right)\bar{x}^4 \tag{15}$$

Thus, it can be stated with good approximation that the elastic line has the shape of a quartic parabola with vertex at the free end.[5] At this point the curvature and its first derivative vanish; the curve is very flat at the free end. Furthermore, it is deduced from equation 14 that the distance $\bar{y}$ from any point P on the elastic line to the extreme tangent is an infinitesimal of the fourth order with respect to the arc PF and therefore also with respect to abscissa $\bar{x}$. Therefore, by setting $PF = (l-s)$, it follows that

$$r = OF = el \tag{16}$$

Where e is a positive number slightly less than 1, and which rapidly tends to 1 when l approaches 0. Finally, if ψ denotes the angle OFT = angle FOM, then

$$\sin\psi = \frac{MF}{OF} = \frac{l}{24}\frac{\cos\omega}{el}\frac{l^4}{c^3} = \frac{l}{4e}\omega$$

The angle ψ is, therefore, approximately equal to one-fourth of the angle ω.

$$\psi = \frac{l}{4}\omega, \text{ and the polar angle } \theta = FOX \tag{17}$$

$$\theta = \omega - \psi = (3/4)\,\omega \tag{18}$$

Equations 12, 16, and 18 permit the following approximate polar equation of the locus of the free end:

$$r = 2ec\sqrt[3]{\frac{\theta}{\cos(4/3)\theta}} \tag{19}$$

In Table 5 are given the values of the functions $\frac{r}{c}$ and $\frac{c}{r}$ in terms of θ assuming $e=1$. The locus is shown in Figure 4.

[5] Hopwood (12) in studying the elastic properties of lead, tin, and cadmium wires determined the elastic curve assumed by the wires falling under their own weight to be a parabola of the type $x=ay^n$ with the origin at the point of clamping and the horizontal and vertical directions, the x and y axes, respectively.

TABLE 5.—*Values of the functions* $\frac{r}{c}$ *and* $\frac{c}{r}$ *in terms of* θ *assuming* $e=1$ *in the equation* $r=2ec\sqrt{\frac{\theta}{\cos(4/3)\theta}}$ *which represents the locus of the free end of a projected strip of fabric in polar coordinates*

[The symbol r represents the length of the chord subtending the elastic curve, c the stiffness, θ the angle in degrees which r makes with the x axis, and e the ratio of r to the length of the strip]

θ in degrees	0	5	10	20	30	40	45	50	60	67½
r/c	0	0.889	1.138	1.462	1.762	2.108	2.335	2.600	3.640	∞
c/r	∞	1.125	0.888	0.685	0.568	0.475	0.4301	0.385	0.275	0

Because of the approximating assumptions, Table 5 and Figure 4 should not be relied upon for θ greater than 60°.

EXPERIMENTAL VERIFICATION

In order to verify experimentally the above interpretation, approximately 50 photographs were taken of projected fabrics in an effort to get an exact representation of the curves assumed by strips falling

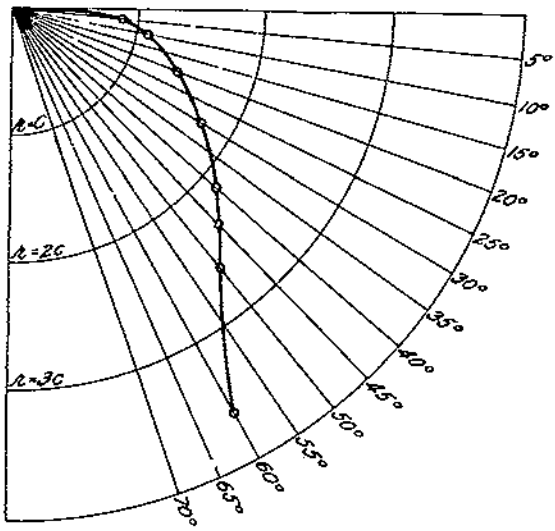


FIGURE 4.—The locus of the free end of a projected strip of fabric in polar coordinates in terms of r and c for different values of θ assuming $e=1$. The values of $\frac{c}{r}$ corresponding to the different angles are given in Table 5

under their own weight. A constant length of 4 inches was used throughout, and the degree of stiffness of the fabrics varied over a wide range. Table 6 gives the characteristic features of some of these curves. Shadow curves were also obtained and carefully plotted. These were more clear-cut and accurate than the photographs, since the method used in obtaining them eliminated any chance of foreshortening which may have entered in the case of the photographic work. Table 7 gives the various properties of the shadow curves for strips 3 inches long, and Table 8 gives the properties of the 4-inch strips.

TABLE 6.—*Characteristics of the elastic curves assumed by 4-inch lengths of projected fabrics as shown photographically*

Sample No.	Length of chord subtending elastic curve assumed by projected strip of fabric	Ratio of chord of elastic curve to length of strip of fabric	Angle the tangent to free end of projected strip makes with x axis	Angle chord (r) of elastic curve makes with x axis	[1] $\frac{\omega}{\theta}$
	r in inches	[2] *e=r/l*	*ω in degrees*	*θ in degrees*	
1	4.19	0.9815	17.0	11.5	1.478
2	4.03	.9449	19.0	13.7	1.387
3	4.06	.9522	37.0	28.0	1.322
4	4.06	.9522	51.5	39.5	1.304
5	4.06	.9522	52.5	40.3	1.303
6	4.03	.9449	52.5	39.5	1.320
7	4.03	.9449	56.5	44.0	1.284
8	4.03	.9449	60.0	47.3	1.269
9	4.00	.9375	64.0	47.0	1.362
10	4.06	.9522	61.0	48.5	1.258
11	4.09	.9595	63.0	51.5	1.223
12	4.06	.9522	62.0	52.0	1.192
13	4.00	.9375	63.0	53.0	1.189
14	4.03	.9449	66.0	54.0	1.222
15	4.00	.9375	68.5	54.5	1.257
16	4.03	.9449	70.5	56.5	1.248
17	4.03	.9449	73.0	59.0	1.237
18	4.00	.9375	74.0	58.7	1.261
19	3.90	.9224	71.5	58.0	1.233
20	3.93	.9302	72.0	59.5	1.210
21	4.00	.9375	73.5	60.0	1.225
22	3.93	.9302	73.5	60.5	1.215
23	3.93	.9302	77.0	62.0	1.242
24	3.93	.9302	75.5	63.0	1.198
25	4.00	.9375	75.0	63.0	1.191

[1] Theoretical value $\frac{\omega}{\theta}=1.333$.

[2] In photographing the fabrics an enlargement of sixteen-fifteenths was made as shown by graph paper behind the projected strips. Therefore, in calculating e, l was assumed to be 4 1/15.

TABLE 7.—*Characteristics of the elastic curves assumed by 3-inch lengths of projected fabric as shown by shadow curves*

Sample No.	Length of chord subtending elastic curve assumed by projected strip of fabric	Ratio of chord of elastic curve to length of strip of fabric	Angle the tangent to free end of projected strip makes with x axis	Angle chord (r) of elastic curve makes with x axis	[1] $\frac{\omega}{\theta}$
	r in inches	*e=r/l*	*ω in degrees*	*θ in degrees*	
1	2.87	0.9684	42.0	31.5	1.333
2	2.87	.9684	25.0	18.5	1.351
3	2.93	.9896	38.5	28.5	1.351
4	2.90	.9790	38.5	30.0	1.283
5	2.93	.9896	45.5	33.3	1.366
6	2.93	.9896	40.5	30.0	1.350
7	2.93	.9896	29.8	23.8	1.252
8	2.93	.9896	35.5	26.5	1.340
9	2.93	.9896	36.0	26.0	1.384
10	2.93	.9896	32.5	24.5	1.327
11	2.93	.9896	32.8	24.5	1.339
12	2.93	.9896	40.0	29.5	1.356
13	2.90	.9790	38.3	28.0	1.368
14	2.87	.9684	39.3	29.0	1.355
Mean					1.340
Standard deviation					0.0332
Corrective factor [1]					+0.007

[1] Theoretical value $\frac{\omega}{\theta}=1.333$.

[1] Difference between experimental mean and theoretical value.

TABLE 8.—*Characteristics of the elastic curves assumed by 4-inch lengths of projected fabric as shown by shadow curves*

Sample No.	Length of chord subtending elastic curve assumed by projected strip of fabric	Ratio of chord of elastic curve to length of strip of fabric	Angle the tangent to free end of projected strip makes with x axis	Angle chord (r) of elastic curve makes with x axis	[1] $\frac{\omega}{\theta}$
	r in inches	$e=r/l$	*ω in degrees*	*θ in degrees*	
1	3.75	0.945	66.0	52.0	1.269
2	3.87	.977	58.5	46.0	1.272
3	3.87	.961	64.0	50.5	1.267
4	4.00	1.000	64.5	53.0	1.217
5	3.78	.953	68.0	52.5	1.295
6	3.78	.953	63.0	51.5	1.223
7	3.87	.977	54.5	44.5	1.202
8	3.87	.977	62.0	49.0	1.265
9	3.84	.969	58.0	45.0	1.288
10	3.87	.977	59.0	47.5	1.242
11	3.84	.969	59.0	49.0	1.204
12	3.84	.969	63.5	50.0	1.270
13	3.87	.977	63.0	50.0	1.260
14	3.78	.953	63.5	50.5	1.257

[1] Theoretical value $\frac{\omega}{\theta}=1.333$.

It will be noted that, when the angle θ increases to the extent shown in Table 8 for the 4-inch strips, the value for $\frac{\omega}{\theta}$ decreases from the theoretical. Also the longer the strips, the greater becomes the error in e and the assumption that $r=l$ ceases to hold. In the case of the 3-inch strips, however, e varies from 0.968 to 0.989, which shows that here the approximation $r=l$ is close to the experimental. The observed ratio $\frac{\omega}{\theta}$ varies from 1.25 to 1.38 with an average value of 1.339, which is within 0.4 per cent of the theoretical value $\frac{\omega}{\theta}=4/3$.

To verify equation 15 the shadow curve No. 1 of wheat starch shown in Figure 5 was selected for study. The value for $\omega=42°$, and the coordinates of the clamped end after the transformation of the axes are found to be $\overline{X}=72.64$ mm. and $\overline{Y}=13.26$ mm., which gives a stiffness value

$$c=-\sqrt[3]{\frac{\overline{x}^4 \cos \omega}{24\,\overline{y}}}=40.21$$

In Figure 6 the theoretical quartic given by equation 15 is traced beside the shadow curve shown in Figure 5. Here, however, the shadow curve has been transformed so that it is referred to the same set of axes to which the theoretical curve applies. The ordinates of the two curves corresponding to given abscissa vary within 1 per cent.

APPLICATION TO SIZED FABRICS

A summary of the mathematical theory shows

(6) $$c^3=\frac{1}{12}\,\frac{Eh^2}{w} \text{ and}$$

(19) $$c^3=\frac{\cos\,(4/3)\,\theta}{8\,\theta}\,r^3$$

Therefore, in a given fabric, where h and w are constant and the stiffness varied, the quantity c is proportional to the cube root of

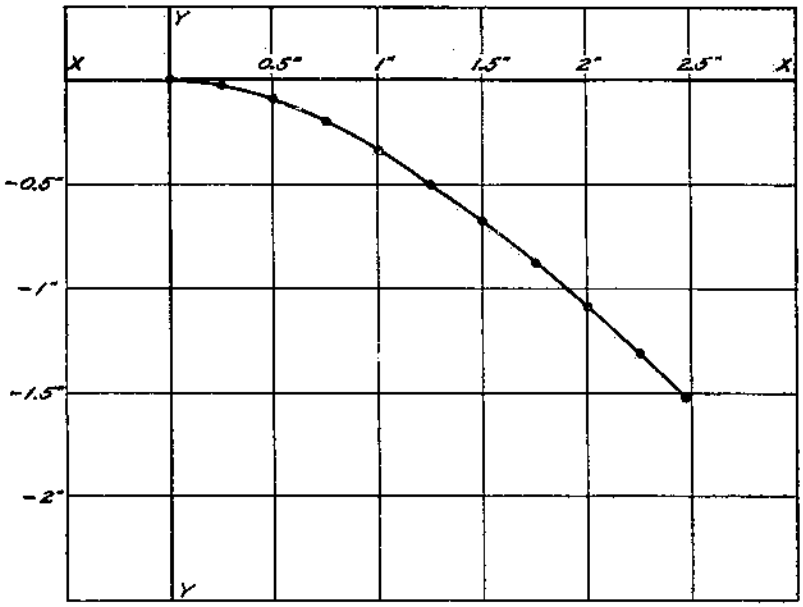


FIGURE 5.—Curve assumed by a projected strip of fabric sized with wheat starch. The origin of and the X Y axes indicates the point of clamping

the elastic modulus. Under these conditions, since c depends on E only, c can be taken as the measure of stiffness.

On the other hand, from equation 19 it is seen that for a constant angle θ, c is proportional to r. Thus the radius vector of a projected

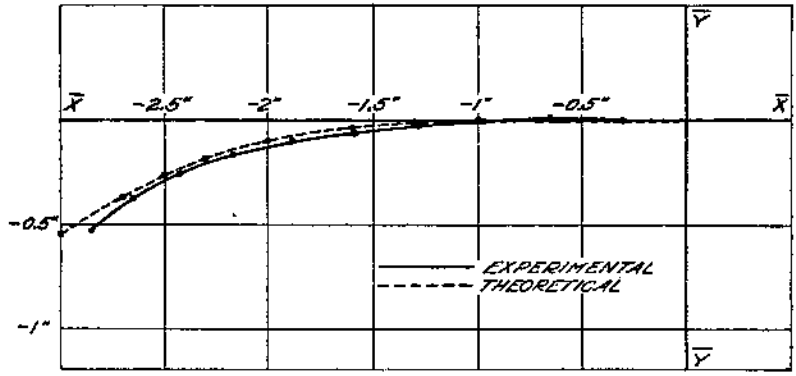


FIGURE 6.—Curve assumed by a projected strip of fabric sized with wheat starch (fig. 5) compared with the theoretical curve developed for projected fabrics. The curves are here referred to a set of axes composed of the tangent to the curve at the free end of the projected strip and the normal to the tangent at that point

strip, the free end of which rests on a fixed oblique line $\theta=\theta_0$, could be made to measure c, provided a proper scale were adopted.

This principle was utilized in devising an apparatus to measure the stiffness c as shown in Figure 7. A vertical board B is provided

with a groove passing through the upper corner and inclined 45° to the horizontal. Into this groove is fitted a metal bar protruding about 2½ inches and uniformly graduated, beginning with zero at the upper corner. Since $\theta=45°$, the corresponding value of r/c equals $\sqrt[3]{4\pi}=2.325$. Therefore, the distance between the graduations is taken as 2.325 mm. so that c can be read off directly from the scale.

To determine the stiffness of a sized specimen, a strip S of a convenient width and length is inserted between the rubber-covered rolls RR which serve as an adjustable clamp. The rolls are so adjusted that the clamping effect which they produce takes place in the same plane as the metal bar and is the zero reading on the scale. The fabric is gradually fed through the roller clamp in the direction shown by the arrow until that position has been reached where the free end

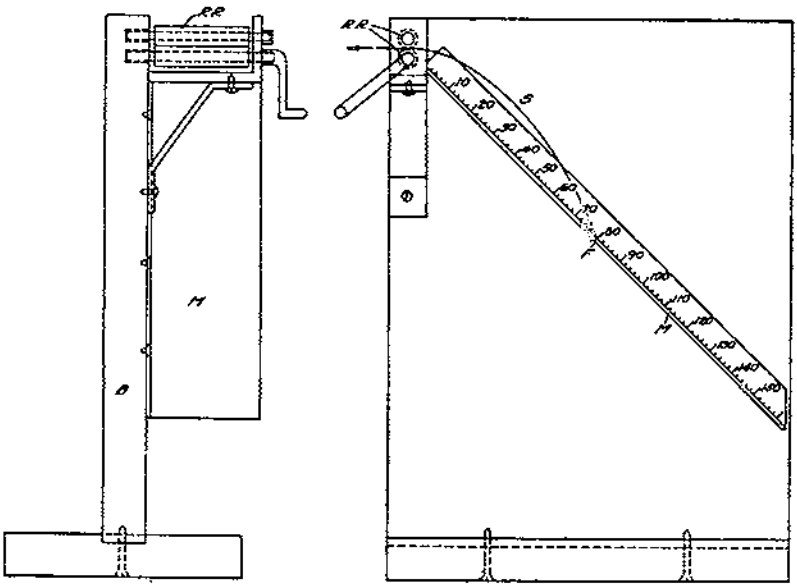


FIGURE 7.—Diagram of apparatus for measuring stiffness of fabrics. B is a vertical board upon which is mounted the clamp RR consisting of two rubber rolls, S a projected strip of fabric turned through the rolls in the direction indicated by the arrow, and M a metal shelf upon which the end of the strip F rests until it is sufficiently short to support its own weight. At this point the scale reading denoting the stiffness of the fabric is taken

of the strip F barely touches the metal bar M. The reading indicated on the scale at this point gives directly the stiffness of the material. Figure 8 shows the apparatus with a strip of test fabric inserted in the roller clamp.

Instead of the arbitrary millimeter scale a more natural scale may be calibrated by means of strips of uniform material of varying thickness. The material selected for this calibration should possess uniform elastic properties such as metal foil. The position assumed by each of the strips would then be indicated on the scale in terms of the corresponding thickness of the strip. Thus, when any tested material registers, for example, 0.016 by this scale, it is understood that the stiffness is 16, meaning that the material has the same stiffness as a certain metal foil 0.016 inch thick. While this method is somewhat more natural than the preceding, it has the slight disadvantage of a nonuniform scale.

A relationship between the stiffness of materials and their respective thicknesses may be established in the following manner: Let E be the elastic modulus of the standard material, W its specific weight, and h its thickness. Let E_0, W_0, and h_0 designate the corresponding

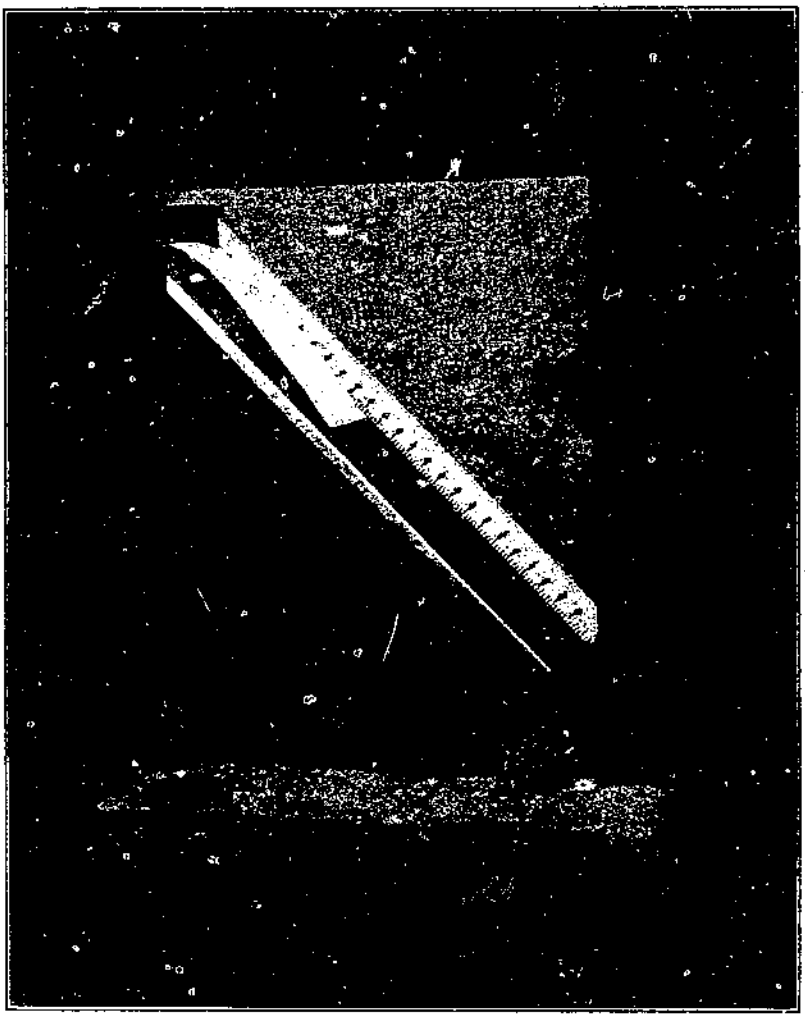


FIGURE 8.—Apparatus for measuring the stiffness of textile fabrics and related materials. The principle involved depends on the deformation of a supported strip bent under its own weight. The stiffness is proportional to the cube root of the elastic modulus and to the radius vector of the projected strip

properties of the material to be tested. If the stiffness c is assumed to be the same, then it follows that

$$c^3 = \frac{Eh^2}{12W} = \frac{E_0 h_0^2}{12W_0}$$

$$c = \sqrt[3]{\frac{E}{12W}}\, h^{2/3} = \sqrt[3]{\frac{E_0}{12W_0}}\, h_0^{2/3} \tag{2}$$

$$c = Kh^{2/3} = K_0 h_0^{2/3}$$

where K is a constant depending on the specific material under consideration. If different thicknesses of the same material are considered, their respective stiffnesses bear the following relationship:

$$\frac{c}{c_1}=\frac{Kh^{3/5}}{K_1h_1^{3/5}}$$

and since for the same material

$$K=K_1 \text{ then}$$

$$\frac{c}{c_1}=\frac{h^{3/5}}{h_1^{3/5}} \text{ or } \frac{c}{c_1}=\rho^{3/5}$$

where ρ is the ratio of the two thicknesses. Thus, if, for a given material, the two test specimens show a thickness ratio ρ equal to 8, then the corresponding stiffness relationship will be $c=4\ c_1$.

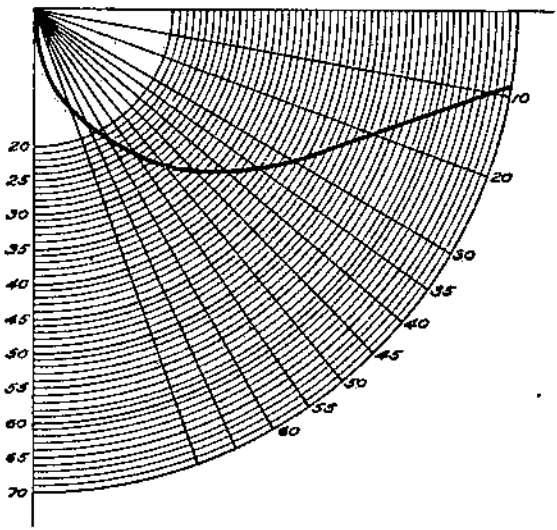


FIGURE 9.—Graph in polar coordinates showing the stiffness of fabrics for different values of θ when r is kept constant at 3 inches. The elastic curve of a projected strip of fabric is represented by the equation $c=1/2\ r\sqrt[3]{\frac{\cos(4/3)\theta}{\theta}}$ in which c designates the stiffness units, r the radius vector of the projected strip in mm., and θ the angle which r makes with the x axis

The original Grimshaw curves may be assigned stiffness units in the following manner. By assuming the formula $c=1/2\ r\sqrt[3]{\frac{\cos(4/3)\theta}{\theta}}$ and calculating the value of c for different assumed values of θ, keeping r constant at 3 inches, c can be plotted in terms of θ. If the resulting curve shown in Figure 9 is etched upon transparent celluloid and placed upon the Grimshaw curve, the stiffness units for the latter can be read off directly at the point where r, extended on the Grimshaw curve, crosses the plotted curve.

SUMMARY

An effort has been made to differentiate the various physical factors combined in the vague term "feel" so universally adopted in mill and laundry practice to describe the properties of a fabric. In this work stiffness has been considered an important property included in this term. A physical method for measuring the stiffness of materials and the abilities of wheat, rice, corn, and potato starches to produce stiffness in a cotton fabric have been determined. The

methods employed for desizing the fabric and preparing the starches and starch pastes are given.

Different varieties of starch may show different stiffening properties. In, general considering wheat, rice, corn, and potato, the wheat produced the stiffest fabric and the potato the least stiff, whereas the corn and rice gave practically the same effect.

The same species of starch from different sources may exhibit different stiffening properties. Three different stiffness values were obtained for the four samples of corn starch secured from different sources.

Varying the time of heating the starch paste from 5 to 60 minutes had no appreciable effect on the stiffness of the sized fabric when measured by the methods employed in this laboratory.

Preliminary studies were also made to determine what effect concentration and the addition of foreign substances had on the stiffening action of starch paste. The experiments tended to show:

A dilution of the standard paste produced a gradual decrease in the resulting stiffness of the fabrics sized with wheat, rice, and corn starches. In the case of potato starch, it was necessary to reduce the concentration approximately 17 per cent of the original (3.7 per cent to 3.06 per cent) before any decrease in the fabric stiffness became apparent. An explanation based on the extremely viscous character of the potato starch paste seems plausible.

The addition of borax increased the stiffening power of corn starch until a maximum of 20 per cent compared to the weight of the starch had been reached, when a decrease in the stiffening power resulted.

Salt, paraffin, beeswax, and hydrogenated vegetable oil up to 27 per cent of the weight of starch did not appreciably affect the stiffness of fabrics sized with corn starch.

Projected strips of starched fabrics falling under their own weight follow elastic laws and assume a curve given by the formula for the quartic parabola $\bar{y} = -\frac{\omega}{4l^3}\bar{x}^4$, where x and y are the coordinates when the vertex of the parabola is at the free end of the projected strip and the x and y axes are the tangent and normal, respectively, at the free end.

From the elastic curve it is deduced that the stiffness of the projected strip is proportional to the cube root of the elastic modulus expressed by the equation:

$$c^3 = \frac{Eh^2}{12w}$$

and to the length of the radius vector as given by the equation:

$$c^3 = \frac{\cos\,(4/3)\theta}{8\theta}\,r^3$$

LITERATURE CITED

(1) ALSBERG, C. L.
1926. STUDIES UPON STARCH. Indus. and Engin. Chem. 18: 190–193.

(2) ———, and RASK, O. S.
1924. ON THE GELATINIZATION BY HEAT OF WHEAT AND MAIZE STARCH. Cereal Chem. 1: [107]–116, illus.

(3) BEAN, P.
1915. VARIOUS METHODS OF MODIFYING STARCH FOR SIZING PURPOSES. Jour. Textile Inst. 6: 223–230.

(4) CLARK, W. M.
1922. THE DETERMINATION OF HYDROGEN IONS. Ed. 2, 480 p., illus. Baltimore.

(5) EWALD, W.
1927. EIN NEUER STEIFIGKEITSPRÜFER FÜR PAPIERE. Zellstoff und papier 7: 112–115, illus.

(6) FARROW, F. D.
1923. SIZING: A REVIEW OF THE LITERATURE. Jour. Textile Inst. 14: T254–T263.

(7) ———, and NEALE, S. M.
1925. THE WETTING OF COTTON. WETTING OF RAW COTTON BY HOT STARCH PASTES. Jour. Textile Inst. 16: T209–T222, illus.

(8) GINSBERG, I.
1926. THE SIZING OF TEXTILE FIBERS. Textile Colorist 48: 28–31, 52, illus.

(9) GRIMSHAW, A. H.
1922. MEASURING STIFFENESS OF SIZED CLOTH. Textile World 61: 2965, 2967 (35, 37), illus.

(10) HARRISON, W.
1911. ON SOME PROPERTIES OF STARCH RELATING TO ITS STIFFENING POWER. Jour. Soc. Dyers and Colourists 27: 84–87, illus.

(11) HINCKLEY, E. H.
1919. SLASHING OF COTTON WARPS. Textile World Jour. 55: 2543–2545 (129–131), illus.

(12) HOPWOOD, F. L.
1915. ON THE PLASTIC BENDING OF METALS. Phil. Mag. and Jour. Sci. (6) 29: 184–190, illus.

(13) KAJIURA, S.
1912. THE PROTEINS OF RICE. Biochem. Jour. 6: 171–181.

(14) KNECHT, E.
1924. ON THE PROLONGED ACTION OF A MODERATE HEAT ON BLEACHED COTTON AND SOME OTHER SUBSTANCES. Fuel Sci. and Pract. 3: 106–108.

(15) LEACH, A. E.
1920. FOOD INSPECTION AND ANALYSIS. Ed. 4, rev. and enl. by A. L. Winton. 1090 p., illus. New York and London.

(16) MACNIDER, G. M.
1917. TEMPERATURE CONTROL IN WARP SIZING. Textile Manfr. [Manchester, England] 43: 180.

(17) NIVLING, W. A.
1924. STARCHES. THEIR FLUIDITY AND VISCOSITY IN RELATION TO SIZING VALUE FOR TEXTILES. 82 p., illus. New York City.

(18) OSBORNE, T. B.
1897. THE AMOUNT AND PROPERTIES OF THE PROTEIDS OF THE MAIZE KERNEL. Conn. State Agr. Expt. Sta. Ann. Rpt. (1896) 20: 391–397.

(19) PETIT, P., and RICHARD.
1926. SUR LA LIQUÉFACTION MÉCANIQUE DE L'EMPOIS D'AMIDON. Compt. Rend. Acad. Sci. [Paris] 182: 657–659.

(20) POLLEYN, F.
1911. DRESSINGS AND FINISHINGS FOR TEXTILE FABRICS AND THEIR APPLICATION. Translated from German by C. Salter. Ed. 3, 263 p., illus. London.

(21) RASK, O. S., and ALSBERG, C. L.
1924. A VISCOSIMETRIC STUDY OF WHEAT STARCHES. Cereal Chem. 1: 7–26, illus.

(22) SCHLÜTER, E.
1924. AN IMPROVED PROCESS FOR THE PRODUCTION OF RICE-STARCH. British Patent No. 225,101. [Abstract in Chem. Abstr. 19: 1961. 1925].

(23) SHARP, P. F.
1924. WHEAT AND FLOUR STUDIES. II. AGING I. THE CHANGE IN HYDROGEN ON CONCENTRATION OF WHEAT AND MILL PRODUCTS WITH AGE. Cereal Chem. 1: 117–132.

(24) SHERMAN, H. C., and BAKER, J. C.
1916. EXPERIMENTS UPON STARCH AS SUBSTRATE FOR ENZYME ACTION. Jour. Amer. Chem. Soc. 38: 1885–1904.

(25) STANDAGE, H. C.
1907. AGGLUTINANTS OF ALL KINDS FOR ALL PURPOSES. 267 p. London.
(26) TADOKORO, T., and SATO, S.
1923. ON THE DIFFERENCES BETWEEN SOME COLLOIDAL PROPERTIES OF COMMON AND GLUTINOUS RICE STARCH. Jour. Col. Agr., Hokkaido Imp. Univ. 13: [1]–65, illus.
(27) UNITED STATES DEPARTMENT OF AGRICULTURE, OFFICE OF EXTENSION WORK, NORTH AND WEST.
1916. POTATO STARCH AND ITS USE IN THE HOME. Jour. Home Econ. 8:38–39.
(28) VISWANATH, B., ROW, T. L., and AYYANGAR, P. A. R.
1916. SOME FACTORS AFFECTING THE COOKING OF DHOLL (CAJANUS INDICUS). India Dept. Agr. Mem. Chem. Ser. 4: [149]–163, illus.
(29) W. S.
1922. THE "NIVLING" SYSTEM OF STANDARDISED SIZING. Textile Mercury 66: 223, illus.
(30) WILEY, H. W.
1900. THE MANUFACTURE OF STARCH FROM POTATOES AND CASSAVA. U. S. Dept. Agr., Div. Chem. Bul. 58, 48 p., illus.
(31) WISE, F. B.
1921. THE MANUFACTURE OF STARCH FROM RICE. Bull's-Eye 1 (11): 18–20.
(32) YULE, G. U.
1924. AN INTRODUCTION TO THE THEORY OF STATISTICS. Ed. 7, rev., 415 p., illus. London.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

April 9, 1929

Secretary of Agriculture	ARTHUR M. HYDE.
Assistant Secretary	R. W. DUNLAP.
Director of Scientific Work	A. F. WOODS.
Director of Regulatory Work	WALTER G. CAMPBELL.
Director of Extension Work	C. W. WARBURTON.
Director of Personnel and Business Administration.	W. W. STOCKBERGER.
Director of Information	M. S. EISENHOWER.
Solicitor	R. W. WILLIAMS.
Weather Bureau	CHARLES F. MARVIN, *Chief.*
Bureau of Animal Industry	JOHN R. MOHLER, *Chief.*
Bureau of Dairy Industry	O. E. REED, *Chief.*
Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Forest Service	R. Y. STUART, *Chief.*
Bureau of Chemistry and Soils	H. G. KNIGHT, *Chief.*
Bureau of Entomology	C. L. MARLATT, *Chief.*
Bureau of Biological Survey	PAUL G. REDINGTON, *Chief.*
Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Bureau of Agricultural Economics	NILS A. OLSEN, *Chief.*
Bureau of Home Economics	LOUISE STANLEY, *Chief.*
Plant Quarantine and Control Administration	C. L. MARLATT, *Chief.*
Grain Futures Administration	J. W. T. DUVEL, *Chief.*
Food, Drug, and Insecticide Administration	WALTER G. CAMPBELL, *Director of Regulatory Work, in Charge.*
Office of Experiment Stations	E. W. ALLEN, *Chief.*
Office of Cooperative Extension Work	C. B. SMITH, *Chief.*
Library	CLARIBEL R. BARNETT, *Librarian.*

This bulletin is a contribution from

Bureau of Home Economics	LOUISE STANLEY, *Chief.*
Textiles and Clothing Division	RUTH O'BRIEN, *Senior Textile Chemist, in Charge.*

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
10 CENTS PER COPY
▽

END