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PHYSICAL TESTING OF COTTON YARNS

BY

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1. PURPOSE OF THE INVESTIGATION

The numerous branches of cotton growing and manufacturing constitute one of the largest industries of the United States. Large quantities of raw cotton are spun into yarns, which are either sold in this condition or are made into threads, twine, rope, fabric, etc., and these products find their way to all parts of the world.

Their value to the ultimate consumer depends upon the quality of the raw material and the care of manufacture. The test by service is the ideal test of quality, but such tests are generally not practicable. It therefore becomes necessary to have methods of testing which may be applied easily and which will furnish reliable data for use in agreements between producer, distributer, and consumer.

In the cotton industry little or no standardization as to methods of testing has been undertaken, and although tests are performed,

the industry is dependent very largely upon the units and methods as carried out by certain manufacturers and individuals. In a more or less desultory fashion, the study of the physical and chemical properties of textile material by means of laboratory tests has been carried on in this country for a number of years.

The recent development of more systematic and greatly improved methods of testing, with a consequent augmented accumulation of data, has given the results obtained a much more practical significance than in former years.

The demands for information from the Government departments and those engaged in the manufacture, distribution, and use of textiles in regard to better methods and standardization of tests has resulted in the establishment recently of testing apparatus in textile institutions, public testing laboratories, stores, and mills. During the past five years the National Bureau of Standards has had under investigation the problem of testing textile material in all its forms. Since the dealers and manufacturers of cotton yarn were in great need of more definite knowledge and generously supplied the necessary material, an investigation upon the physical and chemical properties of cotton yarn was undertaken.

Only a limited number of yarns has thus far been investigated, but it is believed that the results already attained and presented in this paper will furnish information of value to manufacturers and consumers. The object of the work was to show the desirability of improving the technical regulations of the trade and the necessity of employing better specifications.

It is believed that if a thorough study of this subject is published more definite specifications can be employed by the trade and some of the misunderstandings now existing may be avoided, at the same time uniformity may be promoted in yarn deliveries and methods of testing.

2. MATERIALS USED

The samples of yarns employed in this investigation were secured from members of the National Association of Cotton Manufacturers, through the courtesy of Mr. Arthur T. Bradlee, chairman of the subcommittee appointed by the association to draw up

specifications for cotton yarns. The yarn sizes used were of singles 25 to 100, inclusive, and of two-ply the range was from 14 to 100, inclusive.

3. MEASUREMENTS MADE

(*a*) *Weighings.*—All weighings were made upon carefully adjusted analytical balances and the weight ascertained in grams to the fourth place of decimals.

(*b*) *Tensile Strength.*—The instrument employed in the tensile-strength determination is so constructed that it registers to within 1 gram stresses from 1 to 1000 grams. This apparatus is of the dead-weight type, the recording arm rests upon knife edges, and a uniform stress is applied by means of water pressure. The rate of speed remained constant; that is, the lower clamp or drum holding one end of the yarn under test descends at a uniform rate of 9 inches per minute, and as the instrument was carefully calibrated, all corrections were made at the time of test.

(*c*) *Twist Counting.*—Two common types of apparatus were employed and check tests made upon all yarns. As this test is familiar to all in the textile trade it is only necessary to state that a yarn is clamped in two places and then one end is slowly untwisted. When singles are tested the distance between the clamps is 1 inch, and for ply yarns a 10-inch length is employed; the number of turns or twists, however, is usually recorded per inch of length.

(*d*) *Yarn Reeling.*—All measurements were made with great care upon carefully calibrated yarn reels each having a circumference of 1.5 yards.

4. CONDITIONING ROOM

The necessity of keeping the atmosphere in a constant and known condition for the several determinations, as outlined later, required a careful adjustment of both temperature and humidity in a special conditioning room constructed for the purpose.

5. EFFECTS OF MOISTURE AND TEMPERATURE IN GENERAL UPON YARNS

The marked variation in the count, yardage, strength, and elongation of cotton yarns is directly influenced by the amount of moisture present in them. In view of this fact, it is not only

advisable but necessary that some standard conditions of humidity and temperature should be adopted and recognized in the testing of yarns, fabrics, and textiles.

Many instances have occurred during the past year in which large consignments of yarns and fabric were rejected, for the reason that the deliveries did not meet the requirements of tests as outlined in the contract specifications. In several cases the manufactures discovered they had made their tests under abnormal conditions of the atmosphere, so that fictitious results were thus recorded.

It has been suggested that the proper method of testing should be in an absolutely dry condition. This, however, would be impracticable, as the results obtained would not indicate the actual strength, elongation, and wear of yarns and fabric under normal atmospheric conditions. The actual testing could not be accomplished when in the dry state, and furthermore when coming into contact with the surrounding atmosphere the material would immediately absorb moisture and by the time the specimen was tested the amount of moisture present could not be calculated.

Without knowledge of the temperature and humidity of the atmosphere at the time of test, unreliable results may be obtained. If the atmosphere in the room or closet in which the tests are performed can not be regulated, then the temperature and humidity should be ascertained and a correction made to give results that would be obtained if made under standard atmospheric conditions.

The results given in the following tables, except where otherwise stated, were obtained in an atmosphere containing 65 per cent relative humidity at 70° F.

The term "relative humidity" means the percentage of moisture present in the air at a certain temperature, as compared with the amount of moisture that the air would contain at saturation if at the same temperature. The 65 per cent relative humidity above mentioned, therefore, indicates a constant amount of moisture in the air, provided the temperature is kept constant, but the amount of moisture for 65 per cent relative humidity increases with increase in temperature.

There are no recognized standard atmospheric conditions under which tests should be made. From recent experiments and work upon the subject, a suitable atmosphere and probably very near the normal conditions is one of 65 per cent relative humidity at a temperature of 20° C (68° F).

6. NEED OF STANDARDIZING TENSILE-STRENGTH APPARATUS

There are in this country at least five different makes of testing machines employed in determining the tensile strength of yarns. Each make is practically a distinct type of instrument which makes it impossible for the user of one machine to compare his results with the results obtained upon other machines.

Differences in tensile strength are produced by the following causes: (1) Different length of test specimens; (2) the method of clamping and the speed of the machine; (3) the variations of the speed when the specimen is being tested.

All tests should be made under the standard atmospheric conditions, and the instrument employed should be calibrated often, errors along the scale must be noted, and the proper correction made during a test. The incorrect reading of an instrument would perhaps give more erroneous results than any change which might occur by the atmosphere.

It is, therefore, very desirable that standard methods of testing and accurate testing machines be employed by manufacturers and testing laboratories.

7. LENGTH OF TEST SPECIMENS AS AFFECTING DETERMINATIONS OF TENSILE STRENGTH

A matter of great dispute and one of extreme importance is the determination of the proper length of yarns under test for tensile strength. In this investigation the specimens tested were 4 inches in length, measured between the jaws of the testing machine. This length was taken as a special investigation showed that specimens 4 inches or more in length will give the same breaking stress, with the exception that the greater the length the more numerous are the weak places. The machine employed for this determination should be run at a standard speed and at a uniform rate.

8. DISCUSSION OF YARN COUNTS

TABLE 1

Cotton Yarns (Singles) Count Variation.

[Figures marked with an asterisk (*) are the average of 20 determinations; all others are the average of 10 determinations. Figures in the last column were obtained by taking the lowest test as the basis of calculation.]

Bureau of Standards mark	Yarn count at 65% relative humidity at 70° F	Count variation of yarn			
		Average variation from correct yarn count		Greatest difference in each series of determinations of count	
		Counts	Per cent	Counts	Per cent
J	25.60	1.35	5.27	1.83	7.28
*C	35.8	.70	1.95	3.1	9.01
*F	37.5	.90	2.40	3.7	10.42
G	39.52	1.07	2.69	1.89	4.91
L	48.71	.84	1.72	1.20	2.51
*E	51.8	.60	1.15	3.9	7.72
H	61.90	1.00	1.61	1.79	2.94
A-1	63.75	3.61	5.66	7.14	11.80
*A-2	66.0	1.24	1.88	6.2	9.82
*B	66.8	1.47	2.20	6.9	10.81
D-1	90.55	4.07	4.49	6.22	7.04
D-2	94.04	1.84	1.96	3.54	3.84
*D-3	94.5	1.12	1.18	6.1	6.64
I	96.35	2.77	2.87	5.08	5.43
Average		1.61	2.65	4.18	7.15

TABLE 2

Cotton Yarns (Two-Ply) Count Variation.

[Ten determinations in each case]

Bureau of Standards mark	Yarn count at 65% relative humidity at 70° F	Count variation of yarn			
		Average variation from correct yarn count		Greatest difference in each series of determinations of count	
		Counts	Per cent	Counts	Per cent
Mill Q	13. 6/2	1. 2	8. 82	1. 8	14. 04
Q	14. 7/2	1. 1	7. 48	1. 8	12. 85
Q	17. 2/2	. 9	5. 23	1. 7	10. 43
M	19. 8/2	. 5	2. 52	. 9	4. 85
O	24. 6/2	. 5	2. 03	. 8	3. 46
M	28. 5/2	. 6	2. 10	1. 2	4. 34
O	28. 7/2	. 8	2. 79	1. 6	5. 77
Q	30. 1/2	1. 6	5. 31	3. 1	10. 83
Q	34. 6/2	1. 4	4. 04	2. 4	7. 14
M	35. 4/2	1. 2	3. 39	2. 1	6. 06
O	B–38. 7/2	1. 1	2. 84	1. 8	4. 86
O	A–39. 8/2	1. 7	4. 36	2. 4	6. 51
N	39. 3/2	. 7	1. 78	1. 2	3. 18
O	48. 1/2	2. 2	4. 57	3. 9	8. 40
Q	49. 3/2	1. 7	3. 44	3. 3	6. 91
N	50. 0/2	1. 4	2. 80	2. 8	5. 82
P	50. 7/2	3. 1	6. 11	5. 8	12. 16
O	55. 8/2	2. 0	3. 58	3. 1	5. 72
Q	57. 4/2	3. 6	6. 27	6. 4	11. 72
N	57. 7/2	1. 1	1. 90	1. 8	3. 11
P	78. 2/2	3. 0	3. 83	4. 3	5. 73
N	79. 8/2	. 8	1. 00	2. 0	2. 53
P	96. 0/2	5. 0	5. 20	9. 2	10. 02
Average		1. 6	3. 97	2. 4	7. 24

Of the 200 tests performed upon one-ply yarns (singles), as shown in Table 1, the variation from an average is 2.65 per cent. There seems to be little or no difference as to uniformity between carded and combed yarns, or that it is more difficult to spin with evenness the higher or lower counts.

We will now examine Table 2, in which 230 tests were made upon two-ply yarns to determine the variations from an average. Here the variation is 3.97 per cent, with the lower numbers having a slight advantage in uniformity over the higher counts.

Small differences were, however, found between carded and combed yarn as to evenness.

TABLE 3

Cotton Yarns (Two-Ply)—Variation in Yarn Counts by Mills

Bureau of Standards mark	Yarn count at 65% relative humidity at 70° F	Variation of yarn count			
		From average		Between the highest and lowest test	
		Counts	Per cent	Counts	Per cent
Mill M	19.8	0.5	2.52	0.9	4.85
M	28.5	.6	2.10	1.2	4.34
M	35.4	1.2	3.39	2.1	6.06
Average		.77	2.67	1.4	5.08
Mill N	39.3	.7	1.78	1.2	3.18
N	50.0	1.4	2.80	2.8	5.82
N	57.7	1.1	1.90	1.8	3.11
N	79.8	.8	1.00	2.0	2.53
Average		1.0	1.87	1.95	3.66
Mill O	24.6	.5	2.03	.8	3.46
O	28.7	.8	2.79	1.6	5.77
O	B–38.7	1.1	2.84	1.8	4.86
O	A–39.8	1.7	4.36	2.4	6.51
O	48.1	2.2	4.57	3.9	8.40
O	55.8	2.0	3.58	3.1	5.72
Average		1.38	3.36	2.27	5.69
Mill P	50.7	3.1	6.11	5.8	12.16
P	78.2	3.0	3.83	4.3	5.73
P	96.0	5.0	5.20	9.2	10.02
Average		3.7	5.05	6.4	9.30
Mill Q	13.6	1.2	8.82	1.8	14.04
Q	14.7	1.1	7.48	1.8	12.85
Q	17.2	.9	5.23	1.7	10.43
Q	30.1	1.6	5.31	3.1	10.83
Q	34.6	1.4	4.04	2.4	7.41
Q	49.3	1.7	3.44	3.3	6.91
Q	57.4	3.6	6.27	6.4	11.72
Average		1.64	5.80	2.9	10.60

TABLE 4

Cotton Yarns (Singles)—Errors Found in Manufacturer's Marks Obtained upon 13 Different Cops or Bobbins Supplied by Mills of Good Reputation in the United States

Bureau of Standards mark	Manufacturer's mark (yarn count)	Yarn count at 65% relative humidity at 70° F	Error in manufacturer's mark	
			Count	Per cent
J	25	25.60	+0.60	+ 2.40
C	40	35.80	−4.20	−10.50
F	40	37.50	−2.50	− 6.25
G	40	39.52	− .48	− 1.20
L	50	48.71	−1.29	− 2.58
E	60	51.84	−8.16	−13.60
H	60	61.90	+1.90	+ 3.16
A-1	70	63.75	−6.25	− 8.92
A-2	70	66.00	−4.00	− 5.71
B	70	66.80	−3.20	− 4.57
I	95	96.35	+1.35	+ 1.42
D-1	100	90.55	−9.45	− 9.45
D-2	100	94.04	−5.96	− 5.96
Average				5.82

The yarns employed as shown in Table 4 were supplied by three mills, and for convenience we will designate them as Mills Nos. 1, 2, and 3. In the following table is given the mill and the different yarns which it submitted:

TABLE 5

SUMMARY OF TABLE 4.

Bureau of Standards mark	Mill No. 1		Bureau of Standards mark	Mill No. 2		Bureau of Standards mark	Mill No. 3	
	Mill mark	Error in mill mark		Mill mark	Error in mill mark		Mill mark	Error in mill mark
C	40/1	−4.2	F	40/1	−2.5	J	25/1	+0.60
B	70/1	−3.2	E	60/1	−8.2	G	40/1	−0.5
A-1	70/1	−6.3	D-1	100/1	−9.4	L	50/1	−1.3
A-2	70/1	−4.0	D-2	100/1	−5.9	H	60/1	−1.9
						I	95/1	+1.3
Average		4.4	Average		6.5	Average		1.1

TABLE 6

Cotton Yarns (Two-ply)—Error in Manufacturer's Mark

[Plus signs indicate two yarns which test above the spinner's mark. S. M.=strict middling; C.=combed; Cd.=carded; C. P.=combed peeler; and C. Eg.=combed Egyptian]

Character of cotton	Bureau of Standards mark	Manufacturer's mark (yarn count)	Yarn count at 65% relative humidity at 70° F	Error in manufacturer's mark	
				Count	Per cent
S. M.	Mill Q	14/2	13.6	0.4	2.94
Warp yarns	Q	16/2	14.7	1.3	8.84
Do	Q	20/2	17.2	2.8	16.20
C. $1\frac{1}{8}$"	M	20/2	19.8	.2	10.10
C. P. $1\frac{1}{4}$"	O	26/2	24.6	1.4	5.69
C. $1\frac{1}{8}$"	M	30/2	28.5	1.5	5.26
Cd. P. $1\frac{1}{8}$"	O	30/2	28.7	1.3	4.53
	Q	30/2	30.1	+.1	3.32
	Q	36/2	34.6	1.4	4.04
C. $1\frac{1}{8}$"	M	36/2	35.4	.6	1.69
C. P. $1\frac{1}{4}$"	O	B-40/2	38.7	1.3	3.35
Cd. P. $1\frac{3}{16}$"	O	A-40/2	39.8	1.7	4.27
C. $1\frac{1}{16}$"	N	40/2	39.3	.7	1.78
Cd. P. $1\frac{1}{4}$"	O	50/2	48.1	1.9	3.95
S. M. $1\frac{3}{16}$"	Q	50/2	49.3	.7	1.42
C. $1\frac{1}{16}$"	N	50/2	50.0	.0	.00
C. P. $1\frac{1}{4}$"	P	50/2	50.7	+.7	1.39
Cd. P. $1\frac{1}{4}$"	O	60/2	55.8	4.2	7.52
S. M. $1\frac{1}{4}$"	Q	60/2	57.4	2.6	4.53
C. $1\frac{1}{16}$"	N	60/2	57.7	2.3	3.98
C. Eg. $1\frac{3}{8}$"	P	80/2	78.2	1.8	2.30
C. $1\frac{1}{16}$"	N	80/2	79.8	.2	2.50
C. P. $1\frac{3}{8}$"	P	100/2	96.0	4.0	4.16
Average					4.71

9. DISCUSSION OF THE INFLUENCE OF HUMIDITY UPON THE YARN COUNT AND THE YARDAGE.

TABLE 7

Cotton Yarn (Singles)—Influence of Humidity upon the Yarn Count and Yardage

SECTION A.—BELOW NORMAL HUMIDITY

Bureau of Standards mark	Yarn count at relative humidity of—		Increase between 65% and 45% relative humidity	
	65%	45%	Yarn count	Yards per pound
F	36.36	36.83	0.47	394.8
L	49.92	50.62	.70	588.0
E	54.46	55.20	.74	621.6
A	68.82	69.83	1.01	848.4
D	81.51	82.65	1.14	957.6

SECTION B.—ABOVE NORMAL HUMIDITY

Bureau of Standards mark	Yarn count at relative humidity of—		Decrease between 65% and 85% relative humidity	
	65%	85%	Yarn count	Yards per pound
F	36.36	34.77	1.59	1335.6
L	49.92	47.79	2.13	1789.2
E	54.46	52.26	2.20	1848.0
A	68.82	65.99	2.83	2377.2
D	81.51	78.26	3.25	2730.0

SECTION C.—BETWEEN 45 PER CENT AND 85 PER CENT RELATIVE HUMIDITIES

Sample	Yarn count at relative humidity of—		Decrease in count of yarn		Decrease in yards per pound		Increase in weight (per cent)
	45%	85%	Count	Per cent	Yards	Per cent	
F	36.83	34.77	2.06	5.59	1730	5.59	5.97
L	50.62	47.79	2.83	5.59	2377	5.59	5.94
E	55.20	52.26	2.94	5.32	2470	5.32	5.62
A	69.83	65.99	3.84	5.49	3226	5.49	5.82
D	82.65	78.26	4.39	5.32	3688	5.32	5.61
Average				5.46		5.46	5.79

In calculating the percentage variation of yarn counts and yards per pound, the result found at 45 per cent relative humidity was taken as the basis of computations; example:

Yarn count at 45 per cent relative humidity..... 36.83
Yarn count at 85 per cent relative humidity..... 34.77

Difference in count..... 2.06

$\frac{2.06 \times 100}{36.83} = 5.59$ per cent variation.

TABLE 8

Cotton Yarns (Two-Ply).—Influence of Humidity upon Yarn Count and Yardage

SECTION A.—BELOW NORMAL HUMIDITY

Bureau of Standards mark	Yarn count at relative humidity of—		Difference between 65% and 45% relative humidity	
	65%	45%	Yarn count	Yards per pound increase in two-ply
Mill Q	13.6	13.7	0.1	42
Q	14.7	14.9	.2	84
Q	17.2	17.4	.2	84
M	19.8	20.1	.3	126
O	24.6	24.9	.3	126
M	28.5	29.0	.5	210
O	28.7	29.2	.5	210
Q	30.1	30.2	.1	42
Q	34.6	34.9	.3	126
M	35.4	36.0	1.4	588
O	B-38.7	39.2	.5	210
N	39.3	39.8	.5	210
O	A-39.8	40.5	.7	294
O	48.1	48.6	.5	210
Q	49.3	51.8	2.5	1050
N	50.0	50.5	.5	210
P	50.7	51.5	.8	336
O	55.8	57.0	1.2	504
Q	57.4	58.3	.9	378
N	57.7	58.5	.8	336
P	78.2	78.5	.3	126
N	79.2	80.7	1.5	630
P	96.0	97.6	1.6	672
Average			.70	

SECTION B.—ABOVE NORMAL HUMIDITY

Bureau of Standards mark	Yarn count at relative humidity of—		Difference between 65% and 85% relative humidity	
	65%	85%	Yarn count	Yards per pound decrease in two-ply
Mill Q	13.6	13.1	0.5	210
Q	14.7	14.3	.4	168
Q	17.2	16.6	.6	252
M	19.8	19.2	.6	252
O	24.6	23.7	.9	378
M	28.5	27.8	.7	294
O	28.7	27.9	.8	336
Q	30.1	28.9	1.2	504
Q	34.6	33.5	1.1	462
M	35.4	34.4	1.0	420
O	B-38.7	37.7	1.0	420
N	39.3	38.3	1.0	420
O	A-39.8	38.9	.9	378
O	48.1	46.3	1.8	756
Q	49.3	48.1	1.2	504
N	50.0	48.4	1.6	672
P	50.7	48.9	1.8	756
O	55.8	54.0	1.8	756
Q	57.4	55.8	1.6	672
N	57.7	55.4	2.3	966
P	78.2	74.7	3.5	1470
N	79.2	77.2	2.0	840
P	96.0	92.7	3.3	1386
Average			2.26	

SECTION C.—DIFFERENCE BETWEEN EXTREME RELATIVE HUMIDITIES

Bureau of Standards mark	Yarn count at relative humidity of—		Difference in count, percentage count, and yards per pound between 45% and 85% relative humidity		
	45%	85%	Count	Per cent	Yards per pound in two-ply
Mill Q	13.7	13.1	0.6	4.38	252
Q	14.9	14.3	.6	4.03	252
Q	17.4	16.6	.8	4.60	336
M	20.1	19.2	.9	4.48	378
O	24.9	23.7	1.2	4.82	504
M	29.0	27.8	1.2	4.14	504
O	29.2	27.9	1.3	4.45	546
Q	30.2	28.9	1.3	4.30	546
Q	34.9	33.5	1.4	4.01	588
M	36.0	34.4	1.6	4.65	672
O	B-39.2	37.7	1.5	3.83	630
N	39.8	38.3	1.5	3.77	630
O	A-40.5	38.9	1.6	3.95	672
O	48.6	46.3	2.3	4.73	966
Q	51.8	48.1	3.7	7.14	1554
N	50.5	48.4	2.1	4.16	882
P	51.5	48.9	2.6	5.05	1092
O	57.0	54.0	3.0	5.26	1260
Q	58.3	55.8	2.5	4.29	1050
N	58.5	55.4	3.1	5.30	1302
P	78.5	74.7	3.8	4.84	1596
N	80.7	77.2	3.5	4.34	1050
P	97.6	92.7	4.9	5.02	2058
Average			2.04	4.67	

10. DISCUSSION OF TWISTS

TABLE 9

Cotton Yarns (Singles)—Variation of Twist in Yarns

Kind of yarn	Bureau of Standards mark	Yarn count or number	Twist of yarns in 10 determinations	
			Average per inch	Variation from average
Combed (warp)	J	25.6	13.6	1.4
Do	G	39.5	21.7	3.3
Do	L	48.7	25.7	7.3
Do	H	61.9	24.4	3.6
Combed (sea island)	D-2	94.0	24.4	4.6
Combed (filling)	I	96.3	22.4	5.6
Carded peeler	F	36.4	15.0	1.0
Do	E	54.5	18.4	6.4
	A	68.8	21.0	5.0
Do	D-1	90.5	23.4	4.6
Average				4.28

All twist determinations were made upon specimens 1 inch in length. The sample marked "L" was tested again in another set of 10 determinations, and the greatest variation from the average was 7.3 twists.

TABLE 10

Cotton Yarns (Two-Ply)—Variation of Twist in Yarns

[Ten determinations made in each case]

Bureau of Standards mark	Yarn count or number (singles)	Twist of yarn	
		Average per inch	Greatest variation from average
Mill Q	13.6	12.1	2.8
Q	14.7	14.7	1.1
Q	17.2	14.0	1.7
M	19.8	15.3	1.2
O	24.6	15.5	1.0
M	28.5	18.8	2.0
O	28.7	20.5	0.8
Q	30.1	18.0	1.0
Q	34.6	18.0	1.6
M	35.4	21.2	3.2
O	B-38.7	21.1	1.0
O	A-39.8	21.5	2.2
N	39.3	23.9	1.8
O	48.1	21.8	3.3
Q	49.2	26.7	3.7
N	50.0	26.7	2.4
P	50.7	22.8	2.6
O	55.8	23.9	2.3
Q	57.4	32.6	4.1
N	57.7	30.3	2.0
P	78.2	27.5	1.0
N	79.8	33.6	2.6
P	96.0	41.1	3.6
Average			2.13

The above twist per inch is that number in which one yarn is folded over the other and is not the twist of each ply or single yarn.

The following figures are the average of 10 determinations. The yarns were first exposed to an atmosphere containing 65 per cent relative humidity at a temperature of 70° F for several hours; then tests were made in this same atmosphere. All yarn-count determinations were obtained upon carefully reeled 120-yard lengths. The tensile-strength tests were made upon single yarns, the length between the jaws of the machine being 4 inches, and the speed of the lower clamp holding the yarn under test was 9 inches per minute.

11. DISCUSSION OF YARN COUNT, TWIST, TENSILE STRENGTH

TABLE 11

Cotton Yarns (Singles)—Yarn Count, Twist, and Tensile Strength

Character of cotton	Bureau of Standards mark	Yarn count at 65% relative humidity at 70° F	Twist per inch	Tensile strength	
				Grams	Ounces
Combed (warp)	J	25.6	13.6	274.90	9.69
Do	G	39 5	21.7	263.60	9.29
Do	L	48.7	25.7	209.90	7.40
Do	H	61.9	24.4	187.90	6.62
	A	63.7	23.6	91.70	3.23
Combed peeler	D-1	90.5	21.9	84.45	2.97
Do	D-2	94.0	24.4	86.60	3.05
Do	I	96.3	22.4	63.65	2.24

TABLE 12

Cotton Yarn (Two-ply)—Yarn Count, Twist, and Tensile Strength

Character of cotton	Bureau of Standards mark	Yarn count at 65% relative humidity at 70° F	Twist per inch	Tensile strength	
				Grams	Ounces
S. M	Mill Q	13.6	12.1	1249	44.05
Warp yarns	Q	14.7	14.7	1145	40.39
Do	Q	17.2	14.0	893	31.49
Combed, $1\frac{3}{8}$″	M	19.8	15.3	1084	38.23
Combed, $1\frac{1}{4}$″	O	24.6	15.5	952	33.58
Combed, $1\frac{1}{8}$″	M	28.5	18.8	786	27.72
Carded, $1\frac{1}{8}$″	O	28.7	20.5	729	25.71
	Q	30.1	18.0	586	20.67
	Q	34.6	18.0	499	17.60
Combed, $1\frac{1}{8}$″	M	35.4	21.2	706	24.90
Combed, $1\frac{1}{4}$″	O	B-38.7	21.1	600	21.16
Combed, $1\frac{5}{16}$″	N	39.3	23.9	663	23.39
Carded, $1\frac{3}{16}$″	O	A-39.8	21.5	522	18.41
Carded, $1\frac{1}{4}$″	O	48.1	21.8	483	17.03
$1\frac{3}{16}$″	Q	49.3	26.7	410	14.46
Combed, $1\frac{15}{16}$″	N	50.0	26.7	522	18.41
Combed, $1\frac{1}{4}$″	P	50.7	22.8	489	17.25
Carded, $1\frac{1}{4}$″	O	55.8	23.9	382	13.47
	Q	57.4	32.6	367	12.94
Combed, $1\frac{1}{16}$″	N	57.7	30.3	464	16.37
Combed, $1\frac{3}{8}$″	P	78.2	27.5	306	10.79
Combed, $1\frac{1}{16}$″	N	79.8	33.6	310	10.93
Combed, $1\frac{3}{8}$″	P	96.0	41.1	279	9.84

12. DISCUSSION OF SINGLE STRAND TESTS WITH THOSE OF THE LEA DETERMINATIONS

TABLE 13

Cotton Yarns (Singles)—Tensile Strength and Variation in 10 Individual Yarn Determinations

[The lowest determination taken as the basis of calculation]

Bureau of Standards mark	Yarn count at 65%, relative humidity at 70° F	Average tensile strength		Maximum variation of any determination from average tensile strength			Greatest difference in each series of determinations of tensile strength		
		Grams	Ounces	Grams	Ounces	Per cent	Grams	Ounces	Per cent
J	25.6	274.9	9.69	45.1	1.59	16.4	90.0	3.17	39.1
G	39.52	263.6	9.29	28.4	1.00	10.8	52.0	1.83	21.7
L	48.71	209.9	7.40	30.1	1.06	14.3	57.0	2.01	31.1
H	61.90	187.9	6.62	34.9	1.23	18.6	64.5	2.27	42.1
A	63.75	91.7	3.23	36.3	1.27	39.6	50.0	1.76	64.1
D–1	90.55	84.4	2.97	26.9	.95	31.9	45.0	1.58	78.3
D–2	94.04	86.6	3.05	28.4	1.00	32.8	50.0	1.76	76.9
I	96.35	63.6	2.24	24.3	.86	38.2	38.0	1.34	76.0
Average.	.....	.....	.....	31.8	1.12	25.3	55.8	1.96	53.7

TABLE 14

Cotton Yarns (Singles)—Tensile Strength upon 120 Yards or One-lea Skeins

[A "lea" is a skein of cotton yarn 120 yards in length and wound upon a reel having a circumference of 1½ yards]

Bureau of Standards mark	Yarn count at 65%, relative humidity at 70° F	Tensile strength			
		Per 120 yards or lea test		Calculation for single yarn	
		Kilograms	Pounds	Grams	Ounces
J	25.6	34.95	76.90	218.5	7.70
G	39.5	29.83	65.63	189.2	6.67
L	48.7	20.91	46.00	130.7	4.61
H	61.9	17.94	39.47	112.2	3.95
D–2	94.0	9.41	20.70	58.8	2.07
I	96.3	7.62	16.77	47.7	1.68

TABLE 15

Cotton Yarns (Singles)—Comparison of Tensile Strength of Yarn Determined by Tests of Individual Yarns and as Calculated from Lea Tests

Bureau of Standards mark	Yarn count at 65% relative humidity at 70° F	Single yarns calculated from (lea) breaks		Individual yarn tests		Difference (per cent)
		Grams	Ounces	Grams	Ounces	
J	25.6	218.5	7.70	274.9	9.69	25.8
G	39.5	189.2	6.67	263.6	9.29	39.4
L	48.7	130.7	4.61	209.9	7.40	60.5
H	61.9	112.2	3.95	187.9	6.62	67.4
D-2	94.0	58.8	2.07	86.6	2.97	47.2
I	96.3	47.7	1.68	63.6	2.24	33.3
Average						45.6

The percentage difference as shown in the above table gives an average increase in strength of 45.6 per cent in favor of the individual yarn tests.

The tensile strength of various sizes of cotton yarns (singles) is illustrated in Fig. 1. The upper curve gives the results of tests

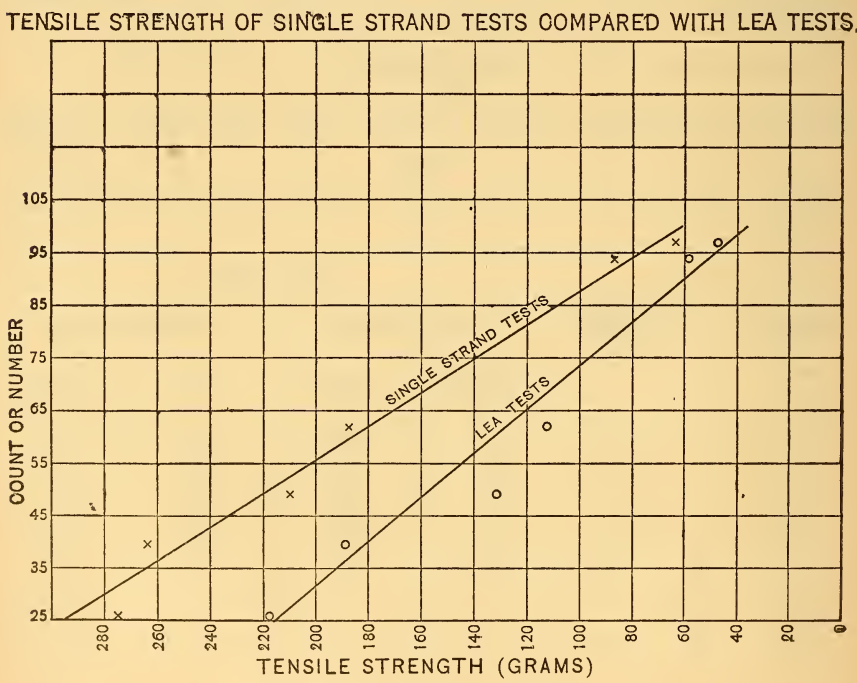

Fig. 1

made upon single strands while the bottom curve represents what a single strand will test when made upon 120 yards or lea test; that is, 160 strands broken at one time.

As previously stated, the single-strand method gives an average tensile strength of about 45 per cent higher than 120 yards (lea) method. It is shown graphically in Fig. 1 that the 120 yards (lea) tests are almost parallel to those of the individual yarn strand results. The objection, however, to breaking at one time 120 yards in the form of a skein is that one or more strands will break before the whole, thereby reducing the tensile strength. The result, therefore, does not give the total actual tensile strength of all of the yarns under test in the lea method.

In the single-strand method, where at least 10 separate tests are made, each test represents the actual tensile strength of a length of yarn, and also shows the uniformity in which the yarn is manufactured. This latter result is extremely important to the manufacturer in order that he may keep a check upon his spinning room, to the weaver who purchases yarn, and to the ultimate consumer of fabric who desires uniformity of strength throughout the goods.

13. DISCUSSION OF THE TENSILE STRENGTH OF ONE-PLY "SINGLES" AND "TWO-PLY" YARNS

TABLE 16

Tensile Strength of Two-Ply Yarns Furnished by Five Different Mills

[Sixty-five per cent relative humidity at 70° F]

Manufacturers' yarn count	Tensile strength in grams of yarns furnished by—				
	Mill M	Mill N	Mill O	Mill P	Mill Q
14	.....	.....	.....	.....	1249
16	.....	.....	.....	.....	1145
20	1084	.....	.....	.....	893
26	.....	.....	952	.....	.....
30	786	.....	729	.....	586
36	706	.....	.....	.....	499
40	.....	663	A522	.....	.....
40	.....	.....	B600	.....	.....
50	.....	552	483	489	410
60	.....	464	382	.....	367
80	.....	310	.....	306	.....
100	.....	.....	.....	279	.....

TABLE 17

Tensile Strength of "Singles" Compared with "Two-ply" Yarns

[Singles] Yarn count at 65%, relative humidity at 70° F	Tensile strength of singles		[Two-ply] Yarn count at 65%, relative humidity at 70° F	Tensile strength of two-ply	
	Grams	Ounces		Grams	Ounces
25.6	275	9.70	24.6	952	33.58
39.5	264	9.31	39.6	592	20.88
48.7	210	7.40	48.7	446	15.73
61.9	188	6.63	57.7	464	16.37
96.3	64	2.25	96.0	279	9.84
Average....	200	7.05	Average...	546.6	19.28

If we multiply the average tensile strength of the singles by two the result is 400 grams, which would be the strength of two-ply yarns if it was a direct proportion. Comparing the strength of the singles, calculated in terms of two-ply, with the actual results obtained upon the two-ply yarn, the latter is about 37 per cent stronger than the former.

A direct proportion of the above averages show that the two-ply yarns are 2.73 times stronger than the singles.

Each result in the following table represents the average of 80 tests at each stated humidity in Section A, and 30 tests at each stated humidity in Section B upon individual yarns.

14. DISCUSSION OF THE INFLUENCE OF HUMIDITY UPON THE TENSILE STRENGTH

TABLE 18

Cotton Yarns (Singles)—Influence of Humidity Upon the Tensile Strength, Showing the Tensile Strength at Five Relative Humidities

SECTION A

45%		55%		55%		75%		85%	
Grams	Ounces	Grams	Ounces	Grams	Ounces	Grams	Ounces	Grams	Ounces
122.4	4.32	119.2	4.19	126.3	4.45	137.3	4.84	140.3	4.93

SECTION B

127.1	4.48	124.3	4.38	125.4	4.42	134.0	4.72	144.5	5.09

The figures given in Section A, covering 400 individual tests, were obtained upon the following yarn counts: Nos. 25, 40, 49, 62, 93, and 96.

The figures given in Section B, covering 150 individual tests, were obtained upon the following yarn counts: Nos. 36, 30, 34, 69, and 81. This Section B series of tests was made one month later than those of Section A in order to verify the results obtained at that time.

Combining the figures as set forth in sections A and B, Table 18, the following averages are obtained:

TABLE 19

Cotton Yarns (Singles)—Tensile Strength at Four Relative Humidities

55%		65%		75%		85%	
Grams	Ounces	Grams	Ounces	Grams	Ounces	Grams	Ounces
121.75	4.29	125.85	4.43	135.65	4.78	142.4	5.02

The percentage increase in strength as the relative humidity is increased is as follows:

Relative humidity	Increase in strength
From 55 to 65 per cent	3.4 per cent
From 65 to 75 per cent	7.8 per cent
From 75 to 85 per cent	5.0 per cent
From 55 to 85 per cent	17.0 per cent

The above calculation was based in each case upon the tensile strength at the lower humidity.

TABLE 20

Cotton Yarns (Two-Ply)—Detailed Tensile Strength at Five Relative Humidities

Mill	Correct count	45%	55%	65%	75%	85%
M	19.8	988	916	1084	1059	1121
M	28.5	784	810	786	884	827
M	35.4	670	700	706	735	725
N	39.3	617	665	663	684	699
N	50.0	474	511	552	519	606
N	57.7	455	432	464	458	476
N	79.8	303	300	310	335	335
O	24.6	877	874	952	979	1009
O	28.7	698	689	729	781	793
O	B–38.7	524	530	522	550	560
O	A–39.8	591	610	600	640	662
O	48.1	418	437	483	512	537
O	55.8	360	345	382	383	413
P	50.7	473	469	489	493	546
P	78.2	296	325	306	314	325
P	96.0	254	288	279	277	274
Q	13.6	1128	1060	1249	1223	1303
Q	14.7	1073	1083	1145	1184	1150
Q	17.2	882	910	893	1040	1031
Q	30.1	569	618	586	632	677
Q	34.6	463	527	499	507	477
Q	49.3	268	421	410	400	434
Q	57.4	257	259	365	321	354
Average....grams..		573	599	628	648	666
Average....ounces..		20.21	21.13	22.15	22.85	23.49

TABLE 21

Cotton Yarns (Two-ply)—Influence of Humidity upon the Tensile Strength, Showing the Tensile Strength at Five Relative Humidities

Each result in the following table represents in grams and ounces the average of 230 tests upon individual yarns, making in all a total of 1150 determinations:

45%		55%		65%		75%		85%	
Grams	Ounces	Grams	Ounces	Grams	Ounces	Grams	Ounces	Grams	Ounces
573	20.21	599	21.13	628	22.15	648	22.85	666	23.49

Percentage increase in strength as the relative humidity is increased is as follows:

Relative humidity	Increase in strength
From 45 to 55 per cent	4.54 per cent
From 55 to 65 per cent	4.84 per cent
From 65 to 75 per cent	3.18 per cent
From 75 to 85 per cent	2.77 per cent
From 55 to 85 per cent	11.18 per cent
From 45 to 85 per cent	16.23 per cent

The above tests were made on two-ply yarns ranging in size from 13 to 100, inclusive.

Table 18 represents a total of 550 tests made upon singles, and Table 20 gives the results of 1150 determinations obtained upon two-ply yarns. It is shown in both tables that the greatest tensile strength was obtained at 85 per cent relative humidity. With one exception the tensile strength increased with an increase of relative humidity. Upon examining Table 18 it will be seen that there was a gradual increase in strength from 55 to 85 per cent relative humidity, and that for some unknown reason the tensile strength at 45 per cent relative humidity was greater than that at 55 per cent relative humidity.

The two-ply yarns, however, gained in strength at 55 per cent relative humidity over that at 45 per cent. By taking as a basis 55 per cent relative humidity it is shown that the singles are influenced more than the two-ply yarns.

Considering as the basis of calculation the atmospheric condition of the air at 55 per cent relative humidity as the lowest humidity, 85 per cent the highest, and the temperature remaining constant at 70° F, the strength of singles was increased to the extent of 17 per cent and the two-ply yarns by 11 per cent.

15. DISCUSSION OF THE SIZING IN YARNS

TABLE 22

Cotton Yarns—Percentage Sizing in Yarns Tested

Bureau of Standards mark	Singles		Bureau of Standards mark	Two-ply	
	Sample marked	Percentage sizing		Sample marked	Percentage sizing
J	25/1	0.94	Mill Q	16/2	1.78
G	40/1	.57	R	30/2	2.48
L	50/1	1.51	O	30/2	1.42
H	60/1	.51	N	40/2	1.84
A	70/1	1.17	P	100/2	1.98
I	95/1	1.70			
Average		1.06	Average		1.90

It will be seen from the above results that the singles contained an average of about 1 per cent and the two-ply yarns about 2 per cent.

16. DISCUSSION OF THE ACCURACY OF YARN REELINGS

The accuracy with which the yarn count can be made on 20 specimens of 30 yards each taken consecutively from same cop of cotton yarn is shown herewith.

The specimens consisted of six cops obtained from two different sources. One set consisted of two cops of filling and a bobbin of warp yarn. The other set consisted of two cops of carded warp yarns and one combed filling yarn.

Twenty consecutive lengths of 30 yards each were cut from each cop by reeling on an ordinary yarn reel 1½ yards in circumference. They were marked serially and placed in an atmosphere at a relative humidity of 65 per cent at 75° F for two hours. They were then weighed by an observer No. 1 on an analytical balance to the nearest tenth of a milligram and the counts obtained in the usual manner. Two days later the specimens were taken to another laboratory, weighed on another balance by a different observer, and the values computed. This latter laboratory had no humidity control, so that the relative air humidity is only known by the general condition of the atmosphere upon that day. It was approximately 75 per cent, as shown by instruments in other portions of the Bureau, or about 10 per cent higher than when the first weighings were made. This would account for the almost constant increased weight obtained by observer No. 2. The results showed that the weighings can be made and duplicated by different observers with a high degree of accuracy.

To determine the accumulative error which might occur in weighing the small samples separately and consequently the error in the yarn count arising from using 30-yard samples, the 20 specimens in each case were weighed collectively and the results of this particular yarn are entered at the foot of the page.

The variation from the average given in the following table is due to the lack of uniformity in the yarn itself rather than errors of observation. The latter must be small in comparison with the former, and it is evident that the yarn counts can be deter-

mined even upon small specimens with an accuracy much greater than it can be manufactured.

Only one series of tests are given in this paper, as the same procedure was followed in each case, and the results shown in Table 24 illustrates yarn in which the greatest yarn-count variation and experimental error in weighing was found.

TABLE 23

Weaving Yarn (Singles)—Weighing Determinations by Two Observers

Specimen	Weight in grams		Yarn count		Yarn-count variation from the average	
	Observer 1	Observer 2	Observer 1	Observer 2	Observer 1	Observer 2
1	0.2487	0.2465	65.9	65.7	0.0	0.5
2	.2454	.2462	66.0	65.8	.1	.4
3	.2515	.2420	67.0	66.9	1.1	.7
4	.2492	.2496	65.0	64.9	.9	1.3
5	.2430	.2436	66.6	66.5	.7	.3
6	.2551	.2560	63.5	63.3	2.4	2.9
7	.2460	.2469	64.9	65.6	1.0	.6
8	.2497	.2506	64.9	64.6	1.0	1.6
9	.2374	.2384	68.2	67.9	2.3	1.7
10	.2472	.2480	65.5	65.3	.4	.9
11	.2513	.2519	64.4	64.3	1.5	1.9
12	.2474	.2482	65.5	65.3	.4	.9
13	.2401	.2409	67.5	67.2	1.6	1.0
14	.2412	.2420	67.1	66.9	1.2	.7
15	.2462	.2468	65.8	65.6	.1	.6
16	.2481	.2488	65.3	65.1	.6	1.1
17	.2379	.2386	68.1	67.9	2.2	1.7
18	.2351	.2358	68.9	68.7	3.0	1.5
19	.2393	.2502	67.7	67.4	1.8	1.2
20	.2323	.2331	69.7	69.5	3.8	3.3
Average			65.9	66.2	1.3	1.24

Weight of 20 samples weighed together =4.8792 grams; count=66.4
Weight of 20 samples weighed individually=4.8210 grams; count=66.1

Experimental error in weighing =0.0582 gram; count=00.3

The results given in the following table are averages of 40 tests made upon 120 yards each and 40 tests made upon 30 yards each. The size of the yarns employed were Nos. 25, 40, 49, 62, 65, 90, 94, and 95.

TABLE 24

Summary of Comparative Tests upon 120-Yard Lengths and 30-Yard Lengths—Total Average Count made of Tests

120-yard skeins (count)	30-yard skeins (count)	Difference (count)
64.78	65.30	0.52

From a large number of determinations we have thus far found that the yarn count variation within the cop or bobbin itself is usually much greater than differences found between 120 and 30 yard lengths.

17. SUMMARY

The principal results of this investigation are as follows:

1. In this series of tests it appears that two-ply yarns were nearer the spinner's number than the one-ply yarns (singles).

2. That one-ply yarns (singles) are produced with greater uniformity in size than two-ply yarns.

3. It is not more difficult to spin coarse yarns to the required size than fine yarns.

4. With small changes in the relative humidity of the atmosphere, such as from 45 per cent to 85 per cent, the size of a 36/1 yarn may vary as much as two counts, and an 80/1 yarn over four counts; or, in other words, 5.5 per cent in each case. The two-ply yarns are not as susceptible to changes due to humidity in the atmosphere, although they vary from one-half a count on 10/2 yarn to almost five counts on 96/2 yarn, with an average of 4.5 per cent on all sizes. Greater differences in relative humidity are common in this country than those used in this work, and if the extremes were employed, much greater variation in yarn count would have been obtained.

5. Under the conditions outlined in No. 4, the yardage in one-ply yarns (singles) can be increased or decreased from 1700 to 3700 yards per pound, or 5.5 per cent, according to size of the yarn. The two-ply yarns can be changed in yardage by the humidity of the atmosphere, the difference in length ranging between 250 to 2000 yards per pound, or about 4.5 per cent.

6. The irregularity in spinning of the twist in the one-ply yarns (singles) is very apparent, but the folding or twisting of two yarns in a two-ply yarn can be accomplished with greater uniformity, as shown in Tables 9 and 10.

7. The tensile strength of yarn depends upon the kind of fiber, length of staple, and its treatment in manufacture. Tables 13 to 17, inclusive, are interesting for the particular yarns employed. The results of the "lea" method compared with the single-strand method of determining the tensile strength, fully outlined on pages 21 to 23, inclusive, indicate the superiority of the single-strand method.

8. The tensile strength of cotton yarns increases with an increase of moisture up to 85 per cent relative humidity (the highest point reached in this investigation). The one-ply yarns (singles) are influenced more than the two-ply yarns. Calculating from 55 per cent to 85 per cent relative humidities, the singles increase 17 per cent and the two-ply yarns increase 11 per cent in tensile strength. Further tests were made with the two-ply yarns, and the results given in Table 21 show that the strength can be increased more than 16 per cent between a relative atmospheric humidity of 85 per cent and a relative atmospheric humidity of 45 per cent.

9. The quantity of sizing in the various makes of one-ply yarns (singles) varied from 0.5 per cent to 1.5 per cent, while the two-ply yarns ranged from 1.5 per cent to 2.5 per cent.

10. The yarn counts can be determined upon small specimens with an accuracy much greater than it can be manufactured. A 30-yard length is sufficient in determining the size of a yarn, as it was found that the yarn count variation within the cop or bobbin itself is usually much greater than differences found between 120-yard and 30-yard lengths.

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