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# STRENGTH AND ELONGATION OF SILK YARNS AS AFFECTED BY HUMIDITY

E. Max Schenke and Howard E. Shearer[1]

ABSTRACT

Silk hosiery yarns varying in number of threads from 2 to 9 and in number of turns of twist per inch from 5 to 36 were tested for breaking strength and breaking elongation at 70° F after various periods of exposure in relative humidities from 33 to 86 percent. The strengths of the yarns were not affected significantly by changes in relative humidity between 33 and 55 percent. The yarns were weaker above 55-percent relative humidity. The elongations of the yarns increased with an increase in relative humidity of the air. The elongation, on the average, increased 1 percent with an increase in relative humidity from 33 to 43 percent, and 1.9 percent with an increase in relative humidity from 76 to 86 percent. The average strength of all yarns was 3.41 g per denier when tested under standard conditions. This figure seems to be independent of the size of the yarn, although the strength of a given size varies with the amount of twist. Some data are given on the breaking strength and elongation of one-thread raw silk.

CONTENTS



## I. INTRODUCTION

In a previous report [2] the authors showed that the moisture content of silk yarn is chiefly dependent upon the relative humidity of the atmosphere with which the silk is in equilibrium. The fact that this moisture affects the properties of the silk is well known to the hosiery and silk industry. For example, if the humidity is low, the silk will be harsh and brittle, resulting in the production of sleazy knitted fabric, and manufacturing difficulties will be increased by the generation of static electric charges. If the humidity is too high, the troubles are almost as great. The silk will have a tendency to stretch and become limp, resulting in the production of tight and loose loops in the fabric and in unpredictable dimensions. There is also the danger of corrosion of needles, and of loss of silk through the growth of mildew. Manufacturers, therefore, prefer to knit in an atmosphere having a relative humidity of 65 to 75 percent.

[1] Director of Research and Research Associate, respectively, at the National Bureau of Standards, representing the National Association of Hosiery Manufacturers.

[2] E. Max Schenke and Howard E. Shearer, *Moisture content of thrown silk affected by threads and twist*, Southern Knitter (Jan. 1940).

Two of the important properties of silk yarn are its strength and breaking elongation. The present work shows how these properties are affected by differences in the relative humidity of the air and the consequent differences in the moisture content of the silk.

## II. MATERIAL

Preliminary data on the strength and breaking elongation were obtained on 13/15 denier, one thread, raw silk, furnished by two hosiery manufacturers. Each manufacturer furnished 4 samples of 10 skeins each.

For the main part of the work thrown silk yarns of 2 to 9 threads and a variety of twists were used as indicated in table 1.[3] Seventeen of these yarns were made from 1 bale of 1934 spring crop, nominal 13/15 denier, 87 percent of Japan silk, and 1 yarn made from China silk of the same denier.[4] After soaking in sulfonated olive oil by the open-tub method, portions of the silk were thrown into yarns of specified numbers of threads and twists. These yarns were wound on cones. One dozen cones were wound for each combination of thread and twist, and 3 cones of each thread and twist were selected from which to secure the test skeins.

TABLE 1.—*Size of thrown silk*

| Number of threads | Twist per inch | Denier per thread at 65-percent relative humidity | Denier per thread, ovendry | Denier per thread of boiled-off silk, oven-dry |
|---|---|---|---|---|
| 2 | 25 | 15.4 | 14.1 | 10.4 |
| 2 | 36 | 15.7 | 14.3 | 10.5 |
| 3 | 20 | 14.9 | 13.7 | 9.9 |
| 3 | 30 | 14.9 | 13.7 | 9.9 |
| [a] 3 | 30 | 16.1 | 14.8 | 10.9 |
| 4 | 10 | 15.2 | 14.0 | 9.9 |
| 4 | 18 | 15.7 | 14.4 | 10.4 |
| 4 | 36 | 15.8 | 14.5 | 10.4 |
| 5 | 6 | 14.7 | 13.5 | 9.8 |
| 5 | 15 | 15.3 | 14.1 | 10.1 |
| 5 | 20 | 15.9 | 14.7 | 10.5 |
| 5 | 36 | 16.2 | 15.0 | 10.7 |
| 7 | 10 | 15.0 | 13.8 | 9.6 |
| 7 | 15 | 15.7 | 14.5 | 10.3 |
| 7 | 36 | 16.9 | 15.6 | 11.5 |
| 9 | 6 | 15.1 | 13.9 | 9.9 |
| 9 | 15 | 15.4 | 14.2 | 10.2 |
| 9 | 36 | 16.8 | 15.5 | 11.3 |

[a] China silk.

## III. TEST PROCEDURE

Five test skeins of yarn, each weighing approximately 2.5 g, were wound from different portions of each cone selected. The skeins of thrown and raw silk were kept in a small conditioning room, where the moisture condition could be maintained at any predetermined figure within ±2 percent relative humidity, and the temperature held con-

[3] The samples are from the same yarns for which humidity data have already been presented. (See footnote 2.)

[4] The "denier" of a silk yarn is the weight of a 450-m length expressed in 1/20-g units.

stant at 21° ±2° C. The conditioning equipment changed the air in the room about twice a minute. Both humidity and temperature were continuously recorded on a hygrothermograph, which was checked with a sling psychrometer each time a set of determinations was made.

The yarns were first conditioned at the lowest relative humidity (33 percent). Breaking strength and ultimate elongation tests were made approximately 6 hours after the yarns were placed in the 33-percent relative humidity atmosphere. Ten individual tests were made on single ends selected from three skeins of each yarn. These tests were repeated at approximately 24, 48, and 72 hours. Thus 40 tests were made on each combination of thread and twist at one humidity. It required about 72 hours for the silks to reach equilibrium, as indicated by their attaining constant weight.[5] After tests at one humidity had been completed, the humidity was increased and the silk again tested after the same time intervals. Tests were made at 33-, 43-, 50-, 55-, 65-, 76-, and 86-percent relative humidity. The test skeins were kept in airtight containers during the interval required to increase the relative humidity of the rooms to the next highest level.

Tests were made on a single-end[6] breaking-strength machine, operating at a jaw speed of 12 inches per minute, with an initial distance of 10 inches between jaws.

## IV. TEST RESULTS

The data from the preliminary tests of the samples of single-thread raw silks submitted by two hosiery manufacturers are given in tables 2 and 3. The irregularity of the strengths (table 2) of the one-thread silk is so great that no conclusions may be drawn as to the effect of the moisture condition of the silk upon its strength. There is also considerable irregularity in the breaking elongations (table 3), but the averages of the elongations of all eight samples at each relative humidity show a definite trend for the elongation to increase as the relative humidity increases.

TABLE 2.—*Single-end breaking strength of one-thread raw silk*

| Sample number | Percentage of relative humidity | | | | | | |
|---|---|---|---|---|---|---|---|
| | 33 | 43 | 50 | 55 | 65 | 76 | 86 |
| | *g* | *g* | *g* | *g* | *g* | *g* | *g* |
| 4653-K | 52 | 40 | 55 | 45 | 44 | 41 | 36 |
| 5728-K | 54 | 58 | 53 | 48 | 53 | 40 | 36 |
| 5781-K | 63 | 43 | 51 | 53 | 65 | 56 | 52 |
| 5800-K | 53 | 42 | 38 | 46 | 42 | 47 | 45 |
| 1-AG | 52 | 47 | 51 | 47 | 34 | 34 | 32 |
| 2-AG | 41 | 40 | 58 | 50 | 62 | 49 | 52 |
| 3-AG | 40 | 46 | 46 | 50 | 52 | 42 | 44 |
| 4-AG | 50 | 40 | 38 | 38 | 47 | 46 | 31 |
| Average | 51 | 45 | 49 | 47 | 50 | 45 | 41 |

[5] E. Max Schenke and Howard E. Shearer, *Moisture content of thrown silk affected by threads and twist*, Southern Knitter (Jan. 1940.)

[6] In the textile industry the term "single-end breaking strength" designates the strength of a single yarn. This is to distinguish from the older practice of applying the breaking load to a skein which consists of a large number of the individual yarns.

TABLE 3.—*Breaking elongation of one-thread raw silk*

| Sample number | Percentage of relative humidity | | | | | | |
|---|---|---|---|---|---|---|---|
| | 33 | 43 | 50 | 55 | 65 | 76 | 86 |
| | % | % | % | % | % | % | % |
| 4653–K | 21.4 | 17.2 | 20.1 | 21.5 | 23.0 | 21.1 | 25.8 |
| 5728–K | 15.2 | 19.3 | 18.5 | 20.1 | 20.3 | 21.5 | 27.0 |
| 5781–K | 17.6 | 19.5 | 20.6 | 21.2 | 24.1 | 25.3 | 26.1 |
| 5800–K | 16.7 | 20.9 | 20.7 | 21.5 | 24.5 | 22.4 | 27.1 |
| 1–AG | 16.8 | 16.9 | 19.5 | 21.7 | 23.6 | 22.7 | 23.8 |
| 2–AG | 19.8 | 17.3 | 19.2 | 18.8 | 23.3 | 20.4 | 27.5 |
| 3–AG | 18.7 | 20.4 | 18.7 | 20.3 | 24.0 | 22.2 | 24.0 |
| 4–AG | 16.1 | 16.1 | 17.7 | 18.9 | 21.7 | 23.6 | 23.7 |
| Average | 17.8 | 18.5 | 19.4 | 20.5 | 23.1 | 22.4 | 25.7 |

Table 4 gives the strengths of the 2- to 9-thread yarns. The strengths given are the averages of the strengths observed at 6, 24, 48, and 72 hours after exposure at a particular humidity. A few tests made after 3 hours' exposure at these various relative humidities indicated that the strengths thus observed were not significantly different from the strengths after 72 hours' exposure. Apparently most of the change in strength with a change in relative humidity took place within the first 3 hours of exposure to the new humidity. There was likewise no indication that the strengths were significantly different at 6, 24, 48, or 72 hours' exposure at any one humidity. Therefore only the averages are given since no systematic variation in strength with time of exposure was found. The average of the strengths of all yarns after 72 hours' exposure at each humidity is given at the bottom of table 4.

TABLE 4.—*Average single-end breaking strength of thrown silk at various relative humidities*

| Yarn No. | Number of threads | Twist per inch | Percentage of relative humidity | | | | | | | Average strength, all humidities |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 33 | 43 | 50 | 55 | 65 | 76 | 86 | |
| | | | *g* | *g* | *g* | *g* | *g* | *g* | *g* | *g* |
| 1 | 2 | 25 | 101 | 113 | 107 | 104 | 102 | 101 | 85 | 102 |
| 2 | 2 | 36 | 107 | 104 | 117 | 116 | 112 | 99 | 91 | 106 |
| 3 | 3 | 20 | 161 | 160 | 153 | 156 | 156 | 149 | 133 | 153 |
| 4 | 3 | 30 | 142 | 157 | 156 | 155 | 160 | 150 | 128 | 150 |
| 5 | [a] 3 | 30 | 169 | 178 | 178 | 173 | 164 | 170 | 148 | 169 |
| 6 | 4 | 10 | 200 | 198 | 206 | 210 | 197 | 197 | 182 | 199 |
| 7 | 4 | 18 | 220 | 230 | 230 | 215 | 217 | 203 | 183 | 214 |
| 8 | 4 | 36 | 204 | 213 | 221 | 210 | 196 | 199 | 170 | 202 |
| 9 | 5 | 6 | 270 | 263 | 273 | 263 | 251 | 252 | 246 | 260 |
| 10 | 5 | 15 | 287 | 289 | 293 | 284 | 276 | 276 | 243 | 279 |
| 11 | 5 | 20 | 263 | 261 | 258 | 267 | 270 | 261 | 244 | 261 |
| 12 | 5 | 36 | 265 | 276 | 278 | 265 | 273 | 238 | 208 | 258 |
| 13 | 7 | 10 | 384 | 378 | 365 | 360 | 363 | 333 | 315 | 357 |
| 14 | 7 | 15 | 407 | 382 | 380 | 400 | 413 | 388 | 348 | 388 |
| 15 | 7 | 36 | 362 | 373 | 385 | 374 | 364 | 345 | 306 | 358 |
| 16 | 9 | 6 | 498 | 519 | 518 | 507 | 474 | 483 | 427 | 489 |
| 17 | 9 | 15 | 510 | 519 | 508 | 500 | 510 | 484 | 459 | 499 |
| 18 | 9 | 36 | 482 | 476 | 478 | 480 | 477 | 453 | 428 | 468 |
| Average | | | 280 | 283 | 284 | 280 | 277 | 266 | 241 | |
| Average strength of yarns tested at 72 hours | | | 280 | 285 | 283 | 282 | 274 | 262 | 240 | |

[a] China silk.

Figure 1 gives the strengths of each of the yarns of table 4 at each of the relative humidities, and the average strength of all 18 yarns at each relative humidity. This figure shows that with variation in

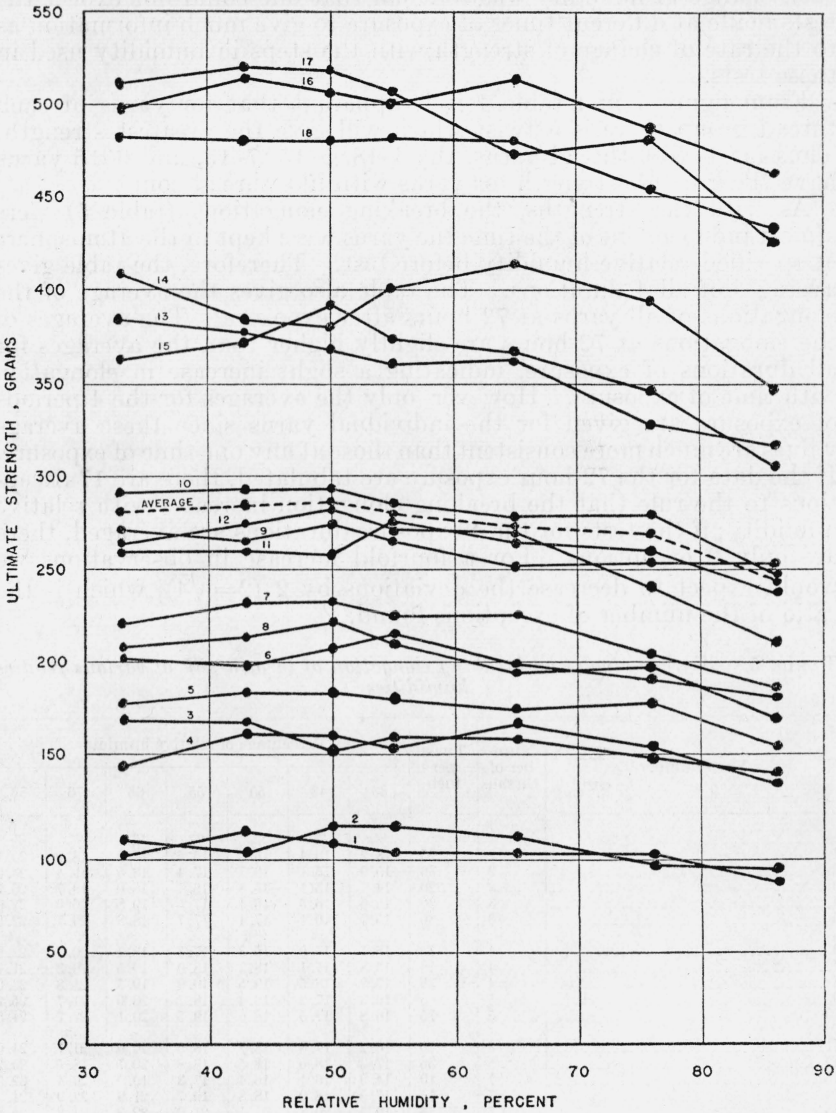


FIGURE 1.—*The single-end breaking strength of thrown silk yarns at various relative humidities.*

humidity the trend of the strength of each combination of thread and twist was the same.

The average strengths of all yarns varied little, if at all, with variation of relative humidity from 33 to 55 percent. The least and greatest average strengths within this range of humidities, 280 g at 33 and 55 percent and 284 g at 50 percent, were practically within

the experimental error of results. With increase in relative humidity beyond 55 percent, however, there is a continual decrease in strength. It should be noted that the change in strength which accompanied each change in humidity was so small that one could not expect the tests made at different times of exposure to give much information as to the rate of change of strength with the steps in humidity used in these tests.

From figure 1 and table 4 it is apparent that for yarns of each thread group there is a twist which will give the greatest strength. Thus for 4- to 9-thread yarns, the 4–18, 5–15, 7–15, and 9–15 yarns have the greatest strength for yarns with like thread count.

As with the strengths, the breaking elongations (table 5) were almost independent of the time the yarns were kept in the atmosphere at specified relative humidity before test. Therefore, the table gives averages of all 4 durations. The table also gives the average of the elongations of all yarns at 72 hours after exposure. The averages of the elongations at 72 hours are slightly higher than the averages for all durations of exposure, indicating a slight increase in elongation with time of exposure. However, only the averages for the 4 periods of exposure are given for the individual yarns since these average values are much more consistent than those at any one time of exposure. If the data for the 72-hour exposure are tabulated, there are 17 exceptions to the rule that the breaking elongation increases with relative humidity; if the tests for the 4 exposure durations are averaged, there are only 9 exceptions. For a fourfold increase in observations we would expect to decrease the deviations by 2 ($2=\sqrt{4}$), which is the ratio of the number of exceptions found.

TABLE 5.—*Average single-end breaking elongation of thrown silk at various relative humidities*

| Yarn number | Number of threads | Twist per inch | Percentage of relative humidity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 33 | 43 | 50 | 55 | 65 | 76 | 86 |
| | | | % | % | % | % | % | % | % |
| 1 | 2 | 25 | 13.2 | 15.4 | 15.0 | 15.5 | 17.0 | 18.9 | 20.1 |
| 2 | 2 | 36 | 15.9 | 15.1 | 16.7 | 17.4 | 18.5 | 19.4 | 23.0 |
| 3 | 3 | 20 | 14.1 | 15.1 | 15.8 | 16.1 | 18.0 | 19.7 | 20.7 |
| 4 | 3 | 30 | 15.6 | 16.5 | 16.4 | 17.5 | 19.8 | 20.6 | 22.0 |
| 5 | [a]3 | 30 | 15.7 | 16.1 | 17.4 | 17.7 | 18.8 | 20.7 | 22.6 |
| 6 | 4 | 10 | 15.1 | 15.9 | 16.8 | 17.3 | 18.4 | 20.7 | 22.8 |
| 7 | 4 | 18 | 15.8 | 17.1 | 18.3 | 18.0 | 19.5 | 20.3 | 21.7 |
| 8 | 4 | 36 | 17.2 | 18.5 | 19.5 | 19.0 | 19.5 | 21.8 | 23.0 |
| 9 | 5 | 6 | 16.3 | 17.9 | 18.4 | 18.7 | 20.6 | 21.7 | 25.2 |
| 10 | 5 | 15 | 16.8 | 17.5 | 18.6 | 19.5 | 20.1 | 22.7 | 24.5 |
| 11 | 5 | 20 | 16.2 | 17.8 | 18.2 | 18.6 | 20.0 | 21.7 | 24.0 |
| 12 | 5 | 36 | 17.3 | 18.6 | 18.5 | 18.8 | 20.7 | 18.5 | 20.2 |
| 13 | 7 | 10 | 14.9 | 16.1 | 16.4 | 17.3 | 19.0 | 20.4 | 22.5 |
| 14 | 7 | 15 | 17.9 | 18.0 | 18.8 | 19.7 | 21.9 | 22.9 | 24.7 |
| 15 | 7 | 36 | 19.5 | 20.8 | 21.1 | 21.0 | 22.3 | 24.8 | 25.5 |
| 16 | 9 | 6 | 16.1 | 17.4 | 18.3 | 18.8 | 20.1 | 22.9 | 24.6 |
| 17 | 9 | 15 | 18.2 | 19.0 | 19.4 | 19.5 | 20.6 | 22.8 | 25.1 |
| 18 | 9 | 36 | 20.8 | 21.0 | 22.4 | 23.2 | 24.0 | 25.8 | 29.1 |
| Average | | | 16.5 | 17.5 | 18.2 | 18.6 | 20.0 | 21.5 | 23.4 |
| Average elongation of yarns tested at 72 hours | | | 16.6 | 17.6 | 18.2 | 18.7 | 20.1 | 21.9 | 23.7 |

[a] China silk.

Figure 2 gives the yarns having the highest and the lowest breaking elongation and the average breaking elongation of all 18 yarns of table 5 at each relative humidity. This figure shows that with varia-

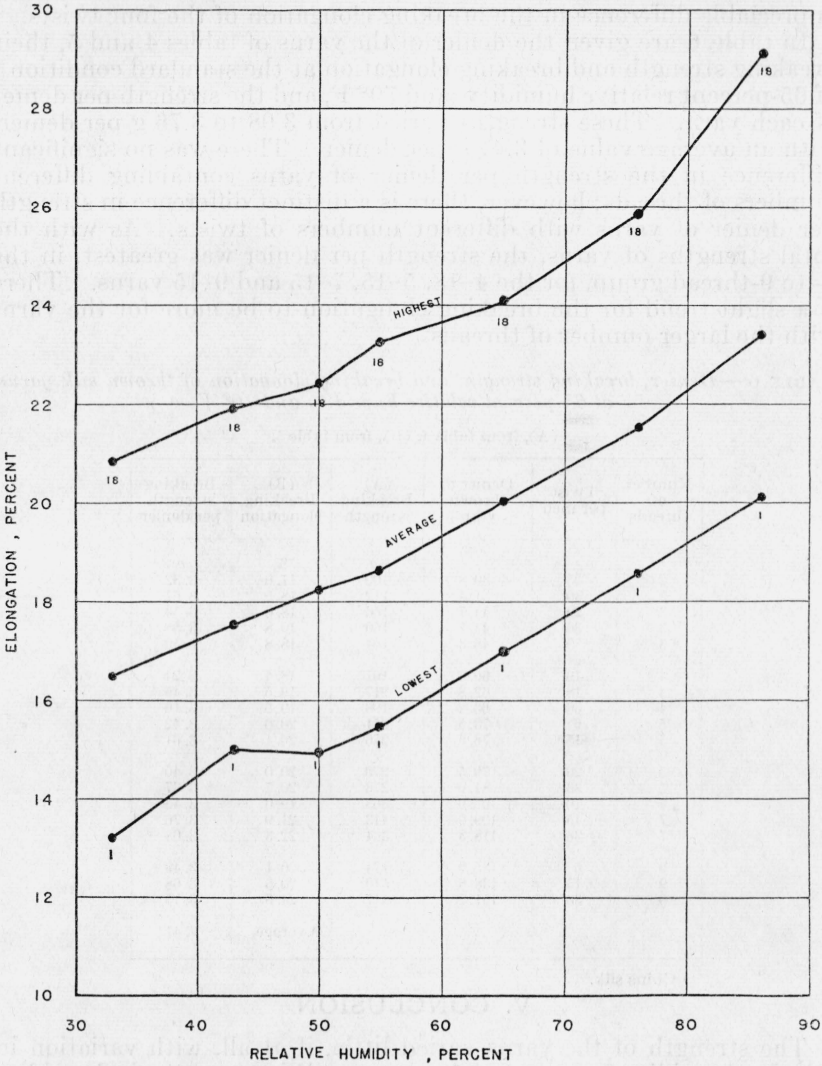


FIGURE 2.—*The single-end breaking elongation of thrown silk yarns at various relative humidities.*

tions in humidity the trend of the elongation of the combinations of thread and twist is the same.

The breaking elongation increases with the relative humidity, but the increase is larger as the relative humidity increases. Thus, from 33- to 43-percent relative humidity the elongations increased from 16.5 to 17.5 percent (a difference of 1 percent), whereas from 76- to 86-percent relative humidity the elongations increased from 21.5 to

23.4 percent, or almost twice as much difference in percent (1.9 percent).

There is a distinct trend for the breaking elongation to increase with the twist in all but the five-thread yarn. In this yarn there was no appreciable difference in the breaking elongation of the four twists.

In table 6 are given the denier of the yarns of tables 4 and 5, their breaking strength and breaking elongation at the standard condition [7] of 65-percent relative humidity, and 70° F, and the strength per denier of each yarn. These strengths varied from 3.08 to 3.76 g per denier, with an average value of 3.41 g per denier. There was no significant difference in the strength per denier of yarns containing different numbers of threads; however, there is a distinct difference in strength per denier of yarns with different numbers of twists. As with the total strengths of yarns, the strength per denier was greatest, in the 4- to 9-thread group, for the 4–18, 5–15, 7–15 and 9–15 yarns. There is a slight trend for the breaking elongation to be more for the yarns with the larger number of threads.

TABLE 6.—*Denier, breaking strength, and breaking elongation of thrown silk yarns, at 65 percent relative humidity and 70° F*

(A), from table 4; (B), from table 5.

| Number of threads | Twist per inch | Denier of thrown yarn | (A) Breaking strength | (B) Breaking elongation | Breaking strength per denier |
|---|---|---|---|---|---|
| | | | *g* | % | *g* |
| 2 | 25 | 30.8 | 102 | 17.0 | 3.32 |
| 2 | 36 | 31.4 | 112 | 18.5 | 3.67 |
| 3 | 20 | 44.7 | 156 | 18.0 | 3.50 |
| 3 | 30 | 44.7 | 160 | 19.8 | 3.58 |
| [a] 3 | 30 | 48.3 | 164 | 18.8 | 3.40 |
| 4 | 10 | 60.8 | 197 | 18.4 | 3.24 |
| 4 | 18 | 62.8 | 217 | 19.5 | 3.46 |
| 4 | 36 | 63.2 | 190 | 19.5 | 3.10 |
| 5 | 6 | 73.5 | 251 | 20.6 | 3.42 |
| 5 | 15 | 76.5 | 276 | 20.1 | 3.61 |
| 5 | 20 | 79.5 | 270 | 20.0 | 3.40 |
| 5 | 36 | 81.0 | 273 | 20.7 | 3.37 |
| 7 | 10 | 105.0 | 363 | 19.0 | 3.46 |
| 7 | 15 | 109.9 | 413 | 21.9 | 3.76 |
| 7 | 36 | 118.3 | 364 | 22.3 | 3.08 |
| 9 | 6 | 135.9 | 474 | 20.1 | 3.49 |
| 9 | 15 | 138.6 | 510 | 20.6 | 3.68 |
| 9 | 36 | 151.2 | 417 | 24.0 | 3.15 |
| | | | | Average | 3.41 |

[a] China silk.

## V. CONCLUSION

The strength of the yarns varied little, if at all, with variation in relative humidity from 33 to 55 percent. With increase in humidity beyond 55 percent the strength decreased more rapidly as the humidity increased. The strength at 86-percent relative humidity was approximately 86 percent of that at 55-percent relative humidity, while the elongation was approximately 26 percent greater. The strength per denier was independent of the number of threads in the yarns, but did vary with the number of twists.

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[7] Federal Specification CC-T-191a requires that textile tests be made at a temperature of 70° F and 65-percent relative himidity.