THE EFFECT OF PERSPIRATION ON THE BREAKING STRENGTH OF SELECTED SILK FABRICS

by

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INTRODUCTION

Problem

For the home economist the problem of the deterioration of weighted silk has grown in importance since 1920 when the subject was first brought before the American Home Economics Association. Since 1928 when a general conference of manufacturers and consumers was called to consider the whole situation some work has been done. Of the several agents that may be responsible for deterioration of weighted silks, perspiration is considered one of the most important. The purpose of this study was to determine, if possible, the effect of perspiration on the breaking strength of some weighted silk fabrics and to discover a reason for the change in the strength of the fibre.

Review of Literature

Investigations already made seem to point to the following factors in human perspiration as affecting silk:

pH, bacterial growth, sodium chloride content, and temperature of aging. Trotman (1) says that perspiration consists of sebum from the sebaceous glands and of sweat from the suderiferous glands. The following is the average composition as given by Mandel (2):

Water	982 parts per million
Sodium chloride . .	2.9 - 13.5 parts per million
Organic Matter . .	1.4 parts per million

The organic matter consists chiefly of traces of proteins, urea, neutral fats, and volatile fatty acids. The specific gravity varies from 1.001 to 1.100. Trotman found that the foreign matter in sweat is chiefly bacteria and epithelial tissue and he states that the exact composition of sebum is not known, but it does contain fats, soaps, cholesterin, epithelial tissue, albuminous matter, part of which is casein, inorganic salts, and traces of organic acids such as acetic, butyric, caprylic, and caproic. The composition of perspiration varies with age, sex, physical condition, diet, race, and other factors. The amount of secretion depends upon temperature and condition of the body, nature and quality of food ingested, and presence or absence of chemicals which have a stimulating effect upon the glands. It

has long been known that the parts of a silk garment subject to saturation with perspiration break before the other parts. Reasons for the effect of perspiration on silk are hard to determine. Trotman thinks the explanation may be found in the amphoteric nature of silk and in the apparent "amphoteric" nature of perspiration. In summarizing the work of several investigators he says that some consider the acid action of perspiration the chief cause of deterioration, that others consider the alkalinity the factor most responsible, and that still others feel the explanation is found in the combined effect of acid and alkali.

The results for pH of fresh perspiration as obtained by different investigators vary. Trotman says that copious perspiration is always alkaline while McSwiney (3) reports values on the acid side. Marchionini (4) claims that the hydrogen ion concentration is rarely ever high enough to give a pH lower than six. Investigators agree however that there is a rise in pH on aging. McSwiney found that a rise in pH was related to a rise in ammonia nitrogen and a corresponding decrease in urea nitrogen. Trotman calls attention to the fact that bacteria develop well on garments saturated with perspiration. He says that in the presence of heat furnished by the body the perspiration completes the

conditions necessary for bacterial growth and that some develop best in an alkaline media while others multiply most rapidly in acid. However, Johnson (5) says, "silk is remarkably free from attack by molds and bacteria, although not entirely so."

Investigators seem to agree that the constituent of perspiration which is supposed to have a most destructive effect on weighted silk is sodium chloride. Johnson (6) claims that weighted silks in particular are strongly affected by perspiration. One theory as explained by Trotman is that chlorine formed by the oxidation of hydrochloric acid, produced by the hydrolysis of sodium chloride, may react with the proteins to form chloramines, or else the chloride ion from the hydrochloric acid unites directly with the silk. Another theory by Goldman, Hubbard, and Schoffstall (7) suggests that some reversal of the weighting process may result from the action of sodium chloride on weighted silk. They thought that stannic chloride might be formed in sufficient concentration to tender silk. They used synthetic perspiration which contained ten grams of sodium chloride per liter and found no tendering of the silk after two and one-half months of exposure to standard atmospheric conditions.

According to Johnson (5) perspiration has less effect on vegetable fibres than on silk, hence the composition of the silk must be one of the important factors to be considered. Silk is a protein. Raw silk is composed of fibroin, the silk filament, and sericin, the silk gum. Quoting from Vignon, Matthews, (8) gives the composition of fibroin as follows:

	Per cent
C	48.3
H	6.5
N	19.2
O	26.0

Recently Morley and Sisely (9) reported that the sulfur content of degummed silk varied from 0.026 per cent to 0.30 per cent and that of the gum from 0.1 to 0.49 per cent. Quoting from Mulder, Matthews, gives the composition of sericine as follows:

	Per cent
C	42.6
H	5.90
N	16.50
O	35.00

The reactions of silk are in general those of other proteins. He says silk is a highly absorbent fibre and readily becomes impregnated or wetted by water which causes a swelling of the fibres. Substances dissolved in the water are rather readily taken up by the silk. However, Johnson (6) claims that it is not permanently affected by H_2O at ordinary temperatures, but does show a decrease in breaking strength with an increase of moisture. The strength returns when the excess moisture evaporates. In a further discussion of properties of silk he states that white silk placed in an oven and heated to 110.5°C for 15 minutes acquires a pale yellow color, and that the action of acids on silks depends largely on the concentration and type of acid. Dilute hydrochloric acid attacks silk, especially when hot. Hydrofluoric acid sometimes damages weighted silks. Silks readily absorb dilute acids from solutions. Dilute alkalies evidently do little damage as neither borax nor ammonium carbonate will harm silk.

APPARATUS AND METHODS

Apparatus

This problem involved a number of physical and chemical tests. To determine the thickness of the fabric a Randall and Stickney automatic thickness gauge which measures to 0.001 of an inch was used. The twist was found by means of an E Pluribus Unum twist counter. The yarns were counted with the aid of Lowinson's thread counting micrometer. The breaking strength of silk was measured in a Scott testing machine of the inclination balance type, 100 pounds capacity. Materials were dried to constant weight in weighing bottles placed in an Emerson conditioning oven regulated to 93°C. All gravimetric determinations were made on a chainomatic balance. Perspiration and fabric to be aged at 0°C were placed in a Kelvinator and those to be aged at 35°C were placed in an electric oven. Relative humidity was determined with a sling psychrometer. Barometric readings as observed by the United States Weather Station were recorded for the days on which breaking strengths were taken. A heat cradle of the type used for

pathological cases in a hospital was used for collecting perspiration. The pH of the perspiration was obtained by means of the quinhydrone electrode, ammonia nitrogen by means of Nessler determinations, total nitrogen by the Kjeldahl method, sodium chloride volumetrically, and the specific gravity at 20°C by use of a psychnometer. Clarified samples were prepared by filtering through clay under 25 pounds pressure. Specimens of fabric were sterilized in an autoclave.

Selection and Preparation of Silk

Two pieces of medium grade, undyed, simple weave silk which contained different per cents of weighting were selected for the experimental work. One piece was piqué and the other a flat crépe.

Breaking strength was chosen as the means of measuring deterioration of silk fibres. The specimens for testing the breaking strength were prepared according to standard specifications (10)for the strip method in Specification No. 345-A, Bureau of Standards. Each set consisted of forty pieces. Ten pieces of the fabric were used to test the breaking strength of the warp threads and ten were used to test the strength of the filling threads. Ten

pieces cut from the warp had the middle three inches of filling yarns removed, and ten pieces cut in the filling direction had the middle three inches of warp yarns removed.

Collection of Perspiration

It was decided to use human rather than synthetic perspiration since that would more nearly approximate conditions which really occur.

The following technique was used in collecting the samples of perspiration. The subject was given a tub bath for 15 minutes. A temperature of 45°C was maintained. She was thoroughly rinsed in distilled water, dried with a sterile towel, and put on a rubber sheet which had been cleaned, rinsed with distilled water, and dried. A heat cradle containing electric lights was placed over her and covered with blankets. The lights were turned on for 30 minutes. The temperature of the air surrounding the patient was kept at 40° to 50°C for 30 to 40 minutes. The perspiration was poured from the sheet into a flask surrounded with ice. The pH and ammonia determinations were made as quickly as possible because decomposition seemed to take place very rapidly. The specific gravity and sodium chloride content were determined also. For the latter determination 1 cc of perspiration was measured with a blood

pipette. It was diluted with 10 cc of water, an excess of 0.01976 N silver nitrate added, and back titrated with 0.00985 N potassium thiocyanate with ferric alum as an indicator.

Perspiration used to determine the change in pH and ammonia nitrogen while aging was kept under toluene in small glass stoppered weighing bottles.

Preparation of Specimens for Testing

The previously prepared specimens were saturated, each set in a separate dish, and dried on a glass surface under an electric fan. Conditions were varied as follows:

Set I. - Untreated specimens for controls

Set II. - Saturated with distilled water -- no aging

Set III.- Saturated with fresh unfiltered perspiration -- no aging

Set IV. - Saturated with fresh unfiltered perspiration -- aged 15 days at 35°C

Set V. - Saturated with fresh unfiltered perspiration -- aged 15 days at 0°C

Set VI. - Saturated with fresh filtered perspiration -- aged 15 days at 35°C

Set VII. - Saturated with fresh filtered perspiration -- aged 15 days at 0°C

Set VIII.- Untreated except that it and Sets VI and VII were sterilized by heating for 30 minutes at 115°C under 15 pounds of pressure.

Set I was broken untreated to determine the breaking strength of the fabric without experimental treatment. Set II was treated with distilled water to determine the effect of water alone on the fabrics. Set III was saturated with fresh unfiltered perspiration immediately after making the partial analyses of the perspiration, and was used to determine the immediate effect on the breaking strength of the fabric. Sets IV and V were treated with fresh unfiltered perspiration, and aged for 15 days, Set IV at 35°C and Set V at 0°C. While 35°C is slightly below body temperature, it is favorable for the growth of bacteria as well as for many chemical changes. Sets VI and VII were sterilized in an autoclave at 115 to 118°C under 15 to 18 pounds pressure for 30 minutes. They were then saturated in fresh filtered perspiration and allowed to age for 15 days, Set VI at 35°C and Set VII at 0 C. No bacteriological examinations were made.

INVESTIGATION

Determination of Breaking Strength

The breaking strength machine was adjusted so that the initial distance between the jaws was three inches. An average of ten specimens was recorded. In the case of the yarn specimens the breaking strength in pounds per yarn was calculated. The results are recorded in Table I. No attempt was made to control temperatures or humidity. Temperatures varied from 23.5°C to 29°C and the relative humidity from 20 to 34.

Table I.-- Breaking Strength of Silk Fabrics

Set	Picks: Fabric: Pounds per inch	Picks: Yarn: Pounds per yarn	Ends: Fabric: Pounds per inch	Ends: Yarn: Pounds per yarn	Perspiration sample	pH of perspiration when saturated	pH of perspiration when broken	NaCl per cent
				Piqué				
1.	32.3	0.317	74.3	0.126	- - -	- - -	- - -	- - -
2.	30.6	0.332	68.4	0.145	H_2O	- - -	- - -	- - -
3.	27.6	0.300	68.6	0.145	1	7.02	7.02	0.2936
4.	30.6	0.325	70.6	0.125	1	- - -	- - -	- - -
5.	31.8	0.355	64.9	0.154	1	- - -	- - -	- - -
6.	31.3	0.342	67.3	0.095	3	6.47	6.51	0.1941
7.	35.7	0.352	70.2	0.125	3	6.47	7.27	0.1941
8.	28.6	- - -	71.3	- - -	- -	- - -	- - -	- - -
				Crêpe				
1.	19.9	0.190	67.1	0.118	- - -	- - -	- - -	- - -
2.	23.7	0.216	67.1	0.179	H_2O	- - -	- - -	- - -
3.	20.2	0.211	63.1	0.166	4,5	6.39 (4) 5.74 (5)	6.78 (4) 5.74 (5)	0.1860 (4) 0.3721 (5)
4.	19.2	0.155	57.4	0.100	2	6.78	6.76	0.1965
5.	22.2	0.192	64.5	0.126	2	6.78	5.65	0.1965
6.	17.65	0.203	46.2	0.052	4	6.39	6.62	0.1860
7.	19.6	0.234	49.5	0.089	4	6.39	7.50	0.1860
8.	16.78	- - -	50.89	- - -	- -	- - -	- - -	- - -

Analyses

The physical analyses of the fabric were made according to standard specifications (11) of the American Society for Testing Materials. The results are given in Table II.

Table II.— Physical Tests

	Piqué		Crêpe	
1. Weave	Figure		Plain	
2. Width	39 4/16 in.		38 7/16 in.	
3. Thickness	0.010 in.		0.0083 in.	
4. Oz/yd^2	4.6		4.75	
	Picks	Ends	Picks	Ends
5. Thread count . . .	91	194	85	124
6. Twist	70	0	75	0
7. Ply	Single	Single	Single	Single
8. Yarn size	2.36	1.84	1.32	0.46

Dr. Wm. D. Appell (12) of the Bureau of Standards defines weighting as any substance present in silk fabric except fibroin. Total weighting was determined by the Kjeldahl method for total nitrogen. Vignon's value, given in Matthews, 19.2 per cent nitrogen was used to calculate the per cent of weighting. The specimens used for the nitrogen

determination had all water soluble weighting removed, so that figures for total weighting and hydrogen fluoride soluble weighting are comparable. The per cent of hydrogen fluoride soluble weighting is lower than that calculated from total nitrogen. All hydrogen fluoride soluble weighting may not have been removed in the one treatment given the fabric. The hydrogen fluoride soluble weighting was determined according to the standard suggested by Appell. As recommended by the different groups studying the silk weighting situation (13), all calculations for weighting were based on the fabric as purchased.

Solutions containing the water soluble weighting were tested qualitatively. Standard methods were used to test for zinc, barium, calcium, sulphate, and chloride ions. Iodine was used to test for the starch, and the glue, gelatin, and dextrin were precipitated with alcohol. The colloidal solution containing the water soluble weighting gave a more or less opaque appearance. The particles did not settle, but when the solution was concentrated by evaporation, they were precipitated out in narrow white concentric rings on the evaporating dish. This material, though very finely divided, did not seem to be soluble in water,

cold concentrated hydrochloric acid, nor cold 48 per cent hydrofluoric acid. It precipitated like a clay which had been colloidally divided.

After the solution of water soluble weighting had stood a short time, a slide for microscopic examination was prepared from material on the surface of the solution. Yellowish globules seemed to float about like oil. It seemed quite probable that emulsified oils had been used in the finishes on the fabrics. Analyses for weighting are shown in Table III.

Table III.-- Analyses for Weighting

Kind	Piqué	Crépe
1. H_2O sol	7.7 per cent	10.4 per cent
Starch	Present	Present
Cl-	Present	Present
2. Clay	Present	Present
3. Oil	Present	Present
4. H F sol	48.1 per cent	59.2 per cent
Sn	Present	Present
5. Total N_2	51.55 per cent total	60.92 per cent total

A sample of the perspiration which was used to saturate a set of fabric was placed in a weighing bottle and kept for aging under the same conditions as the fabric. The pH and ammonia nitrogen determinations on the aged perspiration were made at the same time that the aged fabric was broken.

Data on the collection and analyses of perspiration are given in Table IV.

Table IV.— Collection and Analyses of Perspiration

Date	Sample	vol. in cc	sp. g.	pH at once	pH 15 days 0°C	pH 15 days 35°C	NH_3 Mg/100 at once	NH_3 Mg/100 15 days 0°C	NH_3 Mg/100 15 days 35°C	Na Cl per cent	Time in tub Minutes	Time in bed Minutes	Age	Fabric	Sets
March 14	1	126	1.0415	7.02	--	--	2.99	--	--	0.2956	15	25	32	Pique	3,4,5
March 17	2	209	1.0408	6.78	6.76	5.65	3.23	2.29	2.29	0.1965	15	40	32	Crepe	4,5
March 24	3	235	1.0017	6.47	6.51	7.27	2.02	2.43	2.47	0.1941	15	30	32	Pique	6,7
March 25	4	270	1.0015	6.39	6.62	7.50	2.58	2.08	1.96	0.1860	10	40	32	Crepe	6,7 3 (Yarns)
April 10	5	150	1.0016	5.74	--	6.35	2.84	--	3.17	0.3721	10	40	32	Crepe	3 (Fabric)

DISCUSSION OF RESULTS

The ammonia nitrogen, the pH, and the sodium chloride content varied. Samples of perspiration kept for 15 days showed an increase in pH except in one case. In sample No.2, both the pH and the ammonia nitrogen determinations for the aged specimens seem to be inconsistent with other values. There was a greater rise in pH for perspiration kept at 35°C than for that at 0°C. The loss in strength was greater at 35°C for both yarns and fabric in both silk samples except for the fabric cut in the warp direction of Set IV, piqué.

Contrary to expectations the total breaking strength of crêpe fabric, Sets VI and VII, saturated with filtered perspiration was lower than that for Sets IV and V saturated with unfiltered perspiration. The breaking strengths of the yarns and fabric of Sets VI and VII of piqué were higher than the sets saturated with unfiltered perspiration and kept at corresponding temperatures. From the results of the aged fabrics treated with filtered and with unfiltered perspiration, it does not seem probable that bacterial action was of most significance. Even though Johnson (5)

does say silk is completely destroyed by a one-half per cent solution of sodium chloride in twelve months, the deterioration due to sodium chloride content could not be the explanation for Sets VI and VII of the crépe. It happened that these were saturated with perspiration of a lower sodium chloride content than Sets IV and V.

The initial pH of the perspiration used to saturate Sets VI and VII was lower than for Sets IV and V. The initial pH of the specimens used to saturate Sets VI and VII of the crépe was lower than that for Sets VI and VII of the piqué. The rise in pH due to aging was also greater in the case of the perspiration used on the crépe. Work done by Johnson and his students(14, 15) on the isoelectric point of silk makes it seem possible that this change in pH crossed the isoelectric point of the weighted silk and if it did that fact might explain the difference in results for the two fabrics.

CONCLUSIONS

1. The results show that aging with perspiration causes a decrease in the breaking strength of the two weighted silk fabrics used and that the decrease is greater when the higher temperature is maintained.

2. This study would indicate that the variation in pH is a greater determining factor in the tendering of silk than variations in sodium chloride content.

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