RELATIONSHIP BETWEEN SOME PHYSICAL PROPERTIES AND HAND OF WOMEN'S SUITINGS

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ABSTRACT

A panel of 30 individuals evaluated 19 suiting fabrics, in terms of their friction, stiffness and compressibility, on 5-point scales. From these evaluations, satisfaction scores were derived for each property of every fabric as an estimate of the suitability of its hand for women's suiting fabrics. An assessment score was also derived from the same scale to determine a subjective estimate of the degrees of friction, stiffness and compressibility in each of the fabrics. The same properties were measured by standard objective laboratory methods. These measurements were correlated with the corresponding assessment scores. Those measurements which best correlated with subjective estimates of friction, stiffness and compressibility were range of frictional force during sliding, mean bending length and per cent compressibility, respectively.

The corresponding satisfaction scores were subsequently plotted as a function of the objective measurements. Quadratic curves were fit to the points. The points on the curves separating the positive scores (more satisfactory) from the negative scores (more unsatisfactory) were taken as the values for each property that would be given a positive evaluation. These values were 3 to 35 gm. range of frictional force during sliding, 1.5 to 3.5 cm. mean bending length and 6 to 20% compressibility.

An equation was formed to indicate general fabric satisfaction (S) from physical measurements of friction (X_1), stiffness (X_2) and compressibility (X_3). This equation was:

$$S = -46.6 + 0.312X_1 + 26.0X_2 + 2.517X_3 - 0.00846X_1^2 - 5.14X_2^2 - 0.100X_3^2$$

Weight and thickness were also suggested by the panel as being

influential to the evaluation of fabric hand for women's suitings. Thickness measurements, however, were not found to show a good relationship with subjective evaluations.

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INTRODUCTION

Fabric hand is a psychological response resulting from an evaluation, comparison or summation of fabric tactile and visual properties (13, 14, 24). Some tactile impressions of fabrics have been described by terms such as silky, soft, pliable, velvetty, lofty, springy, warm and boardy. Visual sensations have been termed smart, rough, streaky, shiney, crepey, clumsy, flannelly and lustrous.

To the consumer, fabric hand is an important aesthetic factor and a means of judging fabric quality. The look and feel of a fabric may be as influential to its purchase as factors such as cost, color, performance and care (10, 15, 20, 25). The technologist, similarly, bases many decisions on fabric hand, from selecting and grading fibres to producing and finishing fabrics (7).

In view of the commercial and technical significance of fabric hand, much research has been devoted to defining its descriptive terms and related physical properties. Some physical properties that have been isolated as being influential to fabric hand are friction (13, 16, 17, 30, 43), stiffness (13, 14, 15, 16, 17, 29, 30, 43), compressibility (13, 14, 15, 29, 30, 43), thickness (16, 17, 30) and warmth (14, 15, 43). Researchers have also attempted to replace subjective assessments of the properties with suitable laboratory techniques (1, 13, 30, 32, 33, 36, 44, 45).

Relatively little research, however, has dealt with the determination of those properties and their optimum measurements which are considered to be pertinent to particular end-uses. However, one end-use that has been investigated is that of suiting fabrics. Howorth (16, 17, 18) and Dreby (13) found that friction, stiffness and compressional properties influence the hand of suiting fabrics.

Howorth (18), in addition, postulated that the relationship between hand desirability and physical measurements is such that optimum measurements lie within an intermediate range. These ranges, however, were not investigated. Determination of ranges of values could be very useful to suiting fabric manufacturers, ultimately ensuring consumer satisfaction, by directing fabric finishing to achieve a desirable hand. Consequently, the objectives of this study were:

1. to determine those values of measured fabric friction, stiffness and compressional properties that would be subjectively evaluated as satisfactory for women's suitings.
2. to derive an index of the general satisfaction of any fabric for women's suitings in terms of its stiffness, friction and compressibility measurements.
3. to determine what other properties, if any, influence subjective evaluations of women's suitings and to determine the range in measurements of these properties, if any, that would be evaluated as satisfactory.

REVIEW OF LITERATURE

The literature on fabric hand and its many properties is very extensive. The review of literature, therefore, is confined to the properties considered most relevant to suiting fabrics - friction, stiffness and compressibility. Each of these properties is discussed separately in terms of influential factors, objective measurement and correlation of measurements with subjective assessments. Techniques of subjective assessment of fabric hand are also discussed.

I. FRICTION

Dreby (13) and Howorth and Oliver (16, 17, 18) found that the friction property is relevant to the hand of suiting fabrics. The term "friction" is used to refer to the visual and tactile characteristics of a fabric surface (10, 43), described by the scale of terms "harsh to slippery" (7, 43) and "rough to smooth" (7, 10, 14, 16, 17, 20, 25, 43).

Fabric friction (roughness) is increased when fibres protrude from the fabric surface (31, 41) and are randomly distributed (31), resistant to bending (8), uncrimped (44, 45) or short and thick (8, 44, 45). Fabric pliability also influences the friction property, since, if the fabric conforms to the contour of the fingers, it reduces pressure stimuli that give the feeling of roughness (13).

A number of techniques have been used in an attempt to objectively measure fabric friction. Huffington (19) pressed a soft rubber replica of a fabric surface against a hard smooth surface, the average pressure of the real area of contact being equated with roughness. Good correlation was obtained between this measurement and subjective estimates of friction. Other measurements that correlated with subjective assessments included the spectral distribution of sound produced by a fabric in friction (45), the force required to remove a yarn from a fabric (39) and coefficients of friction (13, 14).

To correlate coefficients of friction with subjective assessments, the human hand has been represented by various surfaces over which a fabric was drawn during friction measurement. Soft cowhide (14), leather, nylon brushes, bristle, goldbeaters' skin (18) and the same fabric (13) have been used, the latter two being most successful. Other workers (14, 27), however, concluded that coefficients of friction may not adequately describe a subjective evaluation of friction, since some panelists confuse smoothness with softness. Furthermore, two fabrics may feel differently even though their coefficients of friction are similar.

The perception of friction, however, was found to be related to the difference between the static and kinetic coefficients of friction (28, 35). A smaller difference was found to result in a smoother fabric. On the other hand, Howorth and Oliver (18) suggested that the rapid fluctuations in frictional force during sliding were more important than the mean level.

II. STIFFNESS

Stiffness has also been investigated as a factor of fabric hand in general and of suiting fabrics specifically. Like friction, fabric stiffness has been defined, described, measured and correlated with subjective assessments.

Stiffness refers to the ease with which a fabric is bent (30, 42, 43). The extremes of this property have been denoted by terms such as "pliable to stiff" (43), "soft to firm" (14) and "limp to stiff" (14, 30, 42).

Fabric stiffness is influenced by many factors such as fibre and yarn properties, fabric construction and finishing processes. Stiffness was found to increase in fabrics which contained fibres of large diameter (38), low elasticity, round cross-section, short length (14) or high resistance to bending (23, 32). Mechanical properties of fibres were thought to influence fabric stiffness by permitting only certain constructions during weaving and finishing (22). Yarns that were stiff (32, 37) or of low twist (12) were found to increase fabric stiffness. In addition, fabrics constructed in close weaves (30) or of heavy weights (14) have been stiffer. Pierce (30) mentioned a number of fabric finishing techniques that were found to increase fabric stiffness, namely, removal of natural wax in bleaching, swelling in mercerization, filling with starches, heavy printing and using sulfuric acid.

Objective measurements of fabric stiffness, in general, denote either the bending of a fabric under its own weight (bending length) or the force required to produce a given deflection (flexural rigidity). Of the several methods for measuring fabric stiffness that have been compared (1, 47), the best correlation with subjective assessments was obtained from the flexural rigidity as determined by the cantilever test and the Schiefer Flexometer (1). The former test was recommended for its convenience. Stiffness has also been assessed by a Planoflex which measures the total angle to which a fabric, supported on a flat surface, can be distorted to the right and to the left before bias wrinkles appear (13). This instrument was found by Abbott (1) and Dreby (13) to give good correlations with tactile rankings in similarly constructed fabrics.

III. COMPRESSIBILITY

The third property of importance to the hand of suiting fabrics was suggested by Dreby (13) to be compressibility, and by Howorth and Oliver (16, 17, 18) to be thickness. However, since the latter workers also found that compressibility was inversely related to thickness and others have defined compressibility as the change in thickness with increasing pressure (34, 36), the term "compressibility" appears to incorporate thickness. Compressibility has also been defined as the "ease of squeezing" (43) denoting softness or hardness to the touch (15, 43).

Factors contributing to fabric compressibility (softness) include fibres that are flexible (14, 46), crimped, non-uniform in cross-section or randomly aggregated in the fabric (34). Yarn properties found to increase fabric softness were non-uniformity in shape due to twisting (25), large and irregular diameter (14, 25), and low density (14). Fabric thickness, as previously mentioned, was found to be inversely related to compressibility (13, 14, 18). That is, as thickness is increased, a softer fabric is perceived. Fabric density, however, was also found to be important to this impression (14), since a dense fabric is not easily squeezed, regardless of its thickness.

Thickness has been incorporated into measurements of fabric compressibility. The Compressometer (36) was developed to measure the thickness and change in thickness of fabrics under increasing or decreasing pressures. The numerical value read from the Compressionmeter (13) is also a function of both compressibility and thickness. Both methods of measuring fabric compressibility were found to correlate with subjective assessments.

IV. SUBJECTIVE TESTING TECHNIQUES

The study of fabric hand, as previously mentioned, began with the elucidation of its descriptive terms and related properties. To obtain subjective responses to fabric hand, a number of techniques have been used in experimental work. These will be discussed in terms of panel composition, fabric selection and presentation, assessment procedures and rating scales.

The assessment of properties related to fabric hand may depend on the people taking part in the assessment, since it has been indicated that fabric aesthetics mean different things to different people (10, 20). General agreement, however, has been found among a reasonably large panel of 20 to 30 individuals (17, 18, 25). The ability to rate fabric hand has been observed in individuals of all kinds, ages and levels of training or experience (5, 6).

The selection of fabrics to be assessed has presented problems to some investigators. The specification of construction features or finishing processes was found to be lengthy and expensive (18) and, in another case, resulted in a fabric differing from usual garment fabrics (7). They, therefore, considered it desirable to use commercial fabrics.

Several procedures in presenting fabrics to panelists for assessment have been used in experimental work, such as using an 8 by 8 in. specimen cut from the fabric (7), including duplicate specimens (1), and randomizing the order of presentation of a series (7). In addition, a small number of specimens spaced at intervals of at least an hour resulted in consistent assessments (7). The stipulation of the fabric end-use to the panel has been recommended by several workers (17, 18, 20, 25, 40). The properties considered essential for one end-use may not be required for another, thus influencing a fabric assessment.

Assessments of fabric hand by the panelists of one study (40) were made by exploring the fabrics on the bias to integrate sensations from the warp and weft directions. Early experimental work (3, 21) had indicated that active movements of the fingers were necessary for accurate perception of a surface. Furthermore, ranking by touch produced a different order (40) and more uniform and decided opinions (1) than ranking by sight alone. To prevent any influence of fabric appearance on assessments, a number of devices were employed, including, a simple screen (18), blindfolding (1), a darkened room or curtain (24) and asking panelists to keep their eyes closed (7).

In assessing fabric hand, panelists have been asked to award the fabric a score on some arbitrary scale such as 0 (worst) to 6 (best) (18). This rating scale made possible the evaluation of large groups of fabrics with fewer observations. It has since been found that sensory centres in the human hand respond to fabric properties as polar pairs, such that opposite terms have opposite signs (1).

Another suggested method of rating fabric hand was to rank the fabrics in order, without assessing the magnitude of the difference (5, 25). Presenting the fabrics 2 at a time was best if the series included more than 6 fabrics (18). This paired comparison technique rated a series of fabrics in terms of the number of times each fabric was ranked higher in a pair. The detection of errors in ranking was also possible (25). The use of this technique in the judgment of fabric harshness (7) revealed difficulties such as fatigue and confusion to the panelists. They concluded that better discrimination was not afforded when pairs were judged.

EXPERIMENTAL METHODS AND MATERIALS

To determine the range in measurements of friction, stiffness and compressibility that would be satisfactory for women's suiting fabrics, it would be desirable to obtain typical consumer reactions to these properties. However, a structured laboratory situation offers greater efficiency in acquiring the necessary information. Therefore, in this study, a selected group of panelists evaluated a series of fabrics in terms of their suitability as to friction, stiffness and compressibility for women's suitings. From these subjective evaluations, satisfaction scores for the properties of every fabric were derived and related to corresponding objective laboratory measurements. From these relationships were determined the range in values of friction, stiffness and compressibility that would be satisfactory for women's suiting fabrics. An equation was formed to determine general fabric satisfaction in terms of the measurable physical quantities.

I. SUBJECTIVE EVALUATION OF FABRICS

Panel Selection

The fabrics were evaluated by a stratified group of panelists selected from female undergraduate students between the ages of approximately 18 to 21 years, and from male and female faculty of the School of Home Economics, University of Manitoba. The composition of the panel was as follows:

First year students	15
Second and third year students	10
Faculty	5
Total	30

The panel included both individuals whose interest and experience did not lie in the area of clothing and textiles as well as those having a great deal of experience and interest in the area. In this manner, it was assumed that a typical group of consumers was represented.

Fabric Selection and Preparation

For this evaluation, 19 commercially obtainable fabrics were selected from the files of the Department of Clothing and Textiles, School of Home Economics, University of Manitoba. This selection included fabrics of various fibre contents and constructions which offered a range from rough to smooth, stiff to limp and hard to soft. All of the fabrics were assumed to be appropriate for women's suitings except one which was selected for its high degree of stiffness and roughness. The fabrics are described in Appendix I.

An 8 by 8 in. specimen was cut from each fabric parallel to and at least 10% from the selvege edges, after a light pressing to remove wrinkles. Each specimen was coded with a 3-digit number from a table of random numbers. Numbers 153 and 200 were assigned to the same fabric (Fabric 6) which was evaluated twice. All fabric specimens were stored in an atmosphere of controlled temperature ($70 \pm 2^{\circ}F$) and relative humidity ($65 \pm 2\%$) until required for subjective evaluation and between assessments.

Before each evaluation period, 4 fabric specimens were removed from the controlled atmosphere and each was hung in a fabric evaluation box (FEB), designed to eliminate bias due to the visual appearance of the fabrics. Each FEB was constructed from plywood in the following dimensions - length, 4 in., width, 9 in., height, 12 in. The ends of the FEB were fitted with sliding doors. After hanging the specimen on the hook, the doors of the FEB were closed. The fabric code number was placed on the front, and each FEB was placed on a separate table in the clothing laboratory reserved for this experiment.

Evaluation Procedure

Upon entering the laboratory, 4 panelists were given a questionnaire (Appendix II) and instructed to assess the suitability of the hand of the fabrics for women's suitings in terms of friction, stiffness and compressibility. They were also asked to indicate a general evaluation and any other properties, if any, that influenced their general evaluations of the fabrics.

To make these evaluations, the panelists stood or sat in front of an FEB and opened the door which gave comfortable access to the hanging fabric specimen. The fabric could be handled in any manner necessary for the evaluation except by visual examination. Each panelist started with a different fabric specimen and performed the evaluations in a different order. This procedure randomized the influence of previous evaluations on subsequent ones. The 20 fabric specimens were thus evaluated in groups of 4 by each panelist during five, 10 min. periods between February 17 and March 10, 1969.

After evaluation by the panelists, each fabric specimen was visually examined by the experimenter for obvious deterioration.

The questionnaires were then treated in the following manner. For the 3 properties, the values -1, 0, +1, 0, -1 were assigned to the points of the scale checked by the panelists, such that -1 corresponded to the extreme ends of the scale ("much too") and 0 to the "slightly too" descriptive terms. The value +1 was assigned to the point of the scale that indicated a satisfactory amount of each property. Since this research began, this type of scale was independently suggested by Lundgren (24). For the general evaluation, the values +1, 0, -1 were assigned to "good", "fair", "poor" of the scale. These numerical values were then totalled over the 30 panelists for each evaluation, to produce a satisfaction score between +30 and -30. The scores for the repeated fabric specimen (Fabric 6) were determined by calculation of the mean of the two scores for each evaluation.

To confirm the importance of friction, stiffness, and compressibility to the hand of women's suiting fabrics, the correlation coefficients and significance of each were computed between the satisfaction score of each property and the general evaluation satisfaction score (Appendix III). An Olivetti Programma 101 Computer was used for these calculations.

II. PHYSICAL ANALYSIS OF FABRICS

As well as being evaluated subjectively, the 19 selected fabrics were analyzed by physical tests to measure the friction, stiffness and compressibility properties. Test specimens were cut from each fabric in the following manner:

1. no specimen was cut from within 10% of the selvege edge of the fabric.
2. no 2 specimens for any test included the same warp and weft yarns.
3. no wrinkles or folds were included.
4. care was taken to avoid contamination of the specimens with foreign matter.

All specimens were exposed to an atmosphere of controlled temperature ($70 \pm 2^{\circ}F$) and relative humidity ($65 \pm 2\%$) for at least 24 hours before testing.

Friction Analysis

The method used to determine the frictional characteristics of the fabrics was the Standard Method of Test for Coefficients of Friction of Plastic Film, ASTM D 1894-63 Method B (2).

Both surfaces of 2 specimens in each of the warp and weft directions were tested in the following manner. A fabric-wrapped metal sled was pulled across the same fabric (mounted on a horizontal platform), at a constant rate of 5 in./min. An Instron tester was used, with a full scale range of 500 grams. The machine was stopped after 5 in. of sliding and the following calculations were made:

1. static coefficient of friction (μ_s):

   $$\mu_s = \frac{A}{B}$$

   where A = initial load required to move the fabric-wrapped sled, in gm.

   B = gross sled weight, in gm.

2. kinetic coefficient of friction (μ_k):

   $$\mu_k = \frac{C}{B}$$

   where C = mean force during last 3 in. of sliding, in gm.

3. difference between static and kinetic coefficients of friction ($\mu_s - \mu_k$)

4. range of frictional force during last 3 in. of sliding, in gm.

Stiffness Analysis

The stiffness of each fabric was determined in accordance with "Method for the Determination of the Stiffness of Cloth", B.S. 3356:1961 (11).

Rectangular specimens, as stated in the method, were allowed to bend over the edge of a horizontal platform until the tip of the specimen reached a plane inclined at an angle of $41\frac{1}{2}^{\circ}$ below the horizontal.

The following stiffness measurements were made:

1. bending length (c): in cm., read from the scale, as indicated in the test procedure, the mean taken over the warp and weft directions.
2. flexural rigidity (G): in gm.-cm., calculated over the warp and weft directions using the following formula:

   $G = 10Wc^3$

   where W = weight, in gm./dm.^{2}, as determined by the Method of B.S. 2471:1954 (26).

Compressibility Analysis

Compressibility characteristics were determined by means of a Compressometer (36), using a 1 in.^{2} anvil at pressures of 0.1, 1.0 and 2.0 lb./in.^{2}. Each result was the mean of three such readings $\pm$.001 in. The following results were recorded:

1. mean difference in thickness (Δt): in in., when the pressure increased from 0.1 to 2.0 lb./in.^{2}.
2. standard thickness (t): in in., the mean of 3 compression readings taken at 1 lb./in.^{2}.
3. per cent compressibility (C): derived from the following formula:

$$C = \frac{\Delta t}{t} \times 100$$

III. ANALYSIS OF DATA

The physical measurement of each property that corresponded best with the panel estimate of the property was chosen to derive indexes that could be used to indicate general satisfaction of a given fabric for use as women's suiting material. The choice was made by converting the panel estimate of the degree of friction, stiffness and compressibility in each of the fabrics to a numerical scale. The procedure was similar to the derivation of the satisfaction scores. In this case, however, values of +2, +1, 0, -1, -2 were assigned to the points of the scale checked by the panelists (Appendix II) and totalled over the 30 panelists. This is referred to as the assessment score for each property. To analyze the consistency of the panel in assessing fabric properties, the duplicate assessment scores for Fabric 6 were compared by the Chi-square contingency test of independence using the Yates Correction for Continuity (Appendix IV). The general fabric evaluation was also compared by this method. The mean of the 2 scores for each property of Fabric 6 was used in subsequent calculations.

The friction assessment score for each fabric was correlated with both coefficients of friction, the difference between them and with the range of force during the last 3 in. of sliding. The stiffness assessment scores were correlated with bending length and flexural rigidity measurements. The compressibility assessment scores were correlated with thickness change, thickness and per cent compressibility of each fabric. The physical measurement of each property which correlated the highest with the panel estimate (assessment score) was chosen to plot against the subjective evaluation (satisfaction score).

Through these points, a quadratic curve ($Y = a + bX + cX^2$) was fit, Y being the satisfaction score and X the physical measurement of each property (Appendix V). The points separating positive values of Y (more satisfactory from negative values of Y (more unsatisfactory) were taken as the range of each property of fabric hand which would be evaluated as satisfactory for women's suitings.

To indicate general fabric satisfaction (S) for women's suitings in terms of the combined satisfaction of friction (Y_1), stiffness (Y_2) and compressibility (Y_3), a multiple regression equation of the type $S = a + bY_1 + cY_2 + dY_3$ was first determined. Simultaneous equations were solved (Appendix VI) using the satisfaction scores of each property and the general evaluation score for each fabric. The equations for the quadratic fit through the points were then substituted into the above equation. This formed a general equation to indicate general fabric satisfaction directly from the physical measurements of friction (X_1), stiffness (X_2) and compressibility (X_3). The resulting equation was of the type $S = a + bX_1 + cX_2 + dX_3 - eX_1^2 - fX_2^2 - gX_3^2$. The latter equation was compared with one formed using the data collected in the experiment rather than the predicted values of the quadratic equations. In this case, simultaneous equations were solved using the general fabric satisfaction score and the best estimated physical measurement for each property of every fabric. The resulting equation was of the type $S = a + bX_1 + cX_2 + dX_3$.

RESULTS AND DISCUSSION

The findings of this research, compiled by the preceding methods, are reported and discussed in terms of subjective evaluation of the fabric series, physical analysis of the fabric properties and relationship between the subjective evaluations and physical measurements.

I. SUBJECTIVE EVALUATION OF FABRIC SATISFACTION

After being handled by the panelists in the evaluation procedure, no fabric specimens showed any deterioration. The data, therefore, was collected as planned.

The satisfaction scores indicating the suitability of the selected properties of fabric hand for women's suitings, as evaluated by the panelists, appear in Table I. The scores for Fabric 6 are the means of the following scores obtained from the identical specimens coded as 153 and 200.

1. friction: +20 and +25
2. stiffness: -10 and -8
3. compressibility: +5 and +11
4. general evalaution: -11 and -1

The correlation coefficients between the satisfaction scores of each property and the general evaluation score of the fabrics were as follows:

friction: 0.60**

stiffness: 0.92***

** significant at the 1.0% level

*** significant at the 0.1% level

TABLE I

SATISFACTION SCORES INDICATING SUITABILITY OF HAND FOR WOMEN'S SUITINGS

FABRIC NUMBER	SATISFACTION SCORES			
	FRICTION	STIFFNESS	COMPRESS-IBILITY	GENERAL EVALUATION
1.	18	6	4	-4
2.	1	14	21	12
3.	20	20	17	20
4.	-4	-16	-4	-15
5.	21	-10	-4	-9
6.	24	-9	8	-6
7.	12	-16	-11	-19
8.	19	19	25	18
9.	-4	7	8	-5
10.	16	17	16	8
11.	7	6	10	-6
12.	3	5	2	-8
13.	6	10	4	-2
14.	28	20	21	18
15.	2	-14	-11	-14
16.	13	14	16	9
17.	20	22	16	16
18.	16	-9	-2	-6
19.	-28	-27	-24	-29

compressibility: 0.93***

These results confirmed that the three selected properties were relevant to the hand of women's suitings as suggested by Howorth (16, 17, 18) and Dreby (13).

II. SUBJECTIVE ASSESSMENT OF PHYSICAL CHARACTERISTICS OF FABRICS

The subjective estimates (assessment scores) of the measurements of friction, stiffness and compressibility of the fabrics appear in Table II. The scores for Fabric 6 are a mean of the following duplicate assessments:

friction:	+1 and -1
stiffness:	+38 and +38
compressibility:	+17 and +17

Analysis of the individual duplicate assessment scores and general fabric evaluation of the 30 panelists determined the following values of Chi-square, each with 1 degree of freedom:

friction assessment:	0.119
stiffness assessment:	0.051
compressibility assessment:	1.200
general fabric evaluation:	0.379

Since none of these values were higher than Chi-square at the 0.05 level of significance (3.841), it was concluded that there was no significant difference between the duplicate assessments of Fabric 6. It was assumed that the panel made reliable assessments of all fabrics.

*** significant at the level 0.1%

TABLE II

ASSESSMENT SCORES INDICATING SUBJECTIVE ESTIMATES OF PHYSICAL MEASUREMENTS

FABRIC NUMBER	ASSESSMENT SCORES		
	FRICTION	STIFFNESS	COMPRESSIBILITY
1.	-8	-20	-16
2.	-29	0	-3
3.	-8	2	-9
4.	32	44	28
5.	9	40	34
6.	0	38	17
7.	-5	-46	-39
8.	-11	5	-3
9.	32	-19	-22
10.	12	-7	-8
11.	23	-4	-8
12.	25	-21	-24
13.	-20	-16	-22
14.	2	6	1
15.	28	52	33
16.	17	16	14
17.	-10	-6	-10
18.	14	39	30
19.	-58	-57	-54

III. OBJECTIVE MEASUREMENT OF PHYSICAL CHARACTERISTICS OF FABRICS

The physical measurements of the 3 properties appear in Tables III (frictional characteristics), IV (stiffness characteristics) and V (compressional characteristics).

Certain of the frictional measurements (Table III) of Fabric 5 (a knit) and Fabric 9 (a bonded knit) are higher than would be expected. The test specimens on the platform stretched and wrinkled very badly when the sled was in motion, requiring an unrealistic force to pull the sled across. It was assumed that this method of friction measurement was unsuitable for knit fabrics.

IV. RELATIONSHIP BETWEEN SUBJECTIVE ASSESSMENTS AND PHYSICAL MEASUREMENTS

The correlation coefficients between the assessment scores (Table II) and each physical measurement of the corresponding properties are reported in Table VI. Low correlations were found between friction assessment and both coefficients of friction and the difference in coefficients. This latter finding does not agree with those of Roder (35) nor Olofsson and Gralen (28). The lack of a relationship between subjective assessments and coefficients of friction concurs with the conclusions of Morrow (27) and Hoffman and Beste (14). The high negative correlation (-.86) between friction assessment and range of frictional force during sliding is in agreement with the suggestion of Howorth and Oliver (18) that the fluctuations in force might be more important than the mean level.

Of the 2 stiffness measurements, the mean bending length correlated better with the stiffness assessment. This does not concur with the suggestion of Abbott (1) that flexural rigidity correlates best with

TABLE III

FRICTIONAL CHARACTERISTICS OF FABRICS

FABRIC	μ_s	μ_k	$\mu_s - \mu_k$	R(gm.)
1.	1.024	0.708	0.316	16.38
2.	0.848	0.565	0.283	21.25
3.	0.999	0.671	0.328	18.75
4.	0.974	0.394	0.580	12.00
5.	1.050*	0.736*	0.314*	40.00*
6.	0.981	0.801	0.180	14.13
7.	0.951	0.426	0.525	28.13
8.	1.097	0.741	0.356	20.50
9.	0.557*	0.476*	0.081*	27.88*
10.	0.832	0.253	0.579	14.88
11.	0.350	0.109	0.241	9.00
12.	0.691	0.453	0.238	17.63
13.	0.592	0.342	0.250	24.25
14.	1.212	0.699	0.513	15.75
15.	0.637	0.463	0.174	8.88
16.	1.166	0.604	0.562	13.63
17.	1.098	0.772	0.326	20.00
18.	0.986	0.610	0.376	12.38
19.	0.816	0.387	0.429	47.63

μ_s = static coefficient of friction

μ_k = kinetic coefficient of friction

R = range of frictional force during sliding

* = these values are unrealistic (p. 22)

TABLE IV

STIFFNESS CHARACTERISTICS OF FABRICS

FABRIC	WEIGHT ($gm./dm.^2$)	MEAN BENDING LENGTH (cm.)	MEAN FLEXURAL RIGIDITY (gm.-cm.)
1.	4.328	2.40	602
2.	2.700	2.49	416
3.	4.086	1.94	299
4.	1.526	1.70	74
5.	1.926	1.18	31
6.	1.802	1.44	52
7.	2.118	4.16	1525
8.	2.746	1.86	1766
9.	2.586	2.73	525
10.	2.110	2.61	372
11.	1.970	2.78	421
12.	1.730	2.25	198
13.	2.336	2.81	518
14.	2.698	1.68	127
15.	1.180	1.57	46
16.	2.220	1.44	66
17.	2.910	2.15	290
18.	1.370	1.54	50
19.	2.962	4.28	2313

TABLE V

COMPRESSIBILITY CHARACTERISTICS OF FABRICS

FABRIC	Δ t(in.)	t(in.)	C(%)
1.	0.0110	0.067	16.4
2.	0.0083	0.046	18.1
3.	0.0007	0.070	10.0
4.	0.0020	0.011	18.2
5.	0.0037	0.027	13.6
6.	0.0030	0.020	15.0
7.	0.0013	0.021	6.3
8.	0.0057	0.037	15.3
9.	0.0020	0.023	8.7
10.	0.0017	0.015	11.1
11.	0.0010	0.015	6.7
12.	0.0010	0.011	9.1
13.	0.0027	0.024	11.1
14.	0.0033	0.034	9.8
15.	0.0020	0.013	15.4
16.	0.0023	0.023	10.1
17.	0.0057	0.043	13.2
18.	0.0017	0.016	10.4
19.	0.0040	0.036	11.1

Δ t = change in thickness with increase in pressure from 0.1 to 2.0 p.s.i.
t = standard thickness at 1.0 p.s.i.
C = per cent compressibility

TABLE VI

CORRELATION BETWEEN ASSESSMENT SCORES AND CORRESPONDING PHYSICAL MEASUREMENTS

ASSESSMENT SCORE	PHYSICAL MEASUREMENT	CORRELATION COEFFICIENT
Friction	μ_s	-0.21
Friction	μ_k	-0.18
Friction	$\mu_s - \mu_k$	-0.06
Friction	R	-0.86***
Stiffness	c	-0.89***
Stiffness	G	-0.70**
Compressibility	Δt	-0.22
Compressibility	t	-0.28
Compressibility	C	-0.49*

* significant at the 5.0% level
** significant at the 1.0% level
*** significant at the 0.1% level

subjective assessments of stiffness.

Of the 3 compressibility measurements, the highest correlation was found between per cent compressibility and estimate of compressibility. This correlation coefficient would be lower if Fabric 19 were included. This fabric was eliminated because it was felt that its stiffness and roughness influenced the subjective assessment of its compressibility. Although Schiefer (36) stated that compressibility was important to the hand of fabrics, the correlation coefficient of -0.49 found in this experiment was not very high. This could be attributed to a confusion on the part of the panelists between "softness" and "limpness", to an error on the part of the experimenter in use or interpretation of the Compressometer, or to a malfunction of the instrument.

V. RELATIONSHIP BETWEEN SUBJECTIVE EVALUATIONS AND PHYSICAL MEASUREMENTS

On the basis of the most significant correlation with subjective estimate of the properties (assessment scores), the following physical measurements were selected to relate with the subjective evaluations (satisfaction scores):

friction:	range of frictional force during sliding
stiffness:	mean bending length
compressibility:	per cent compressibility

The satisfaction score for each property was plotted as a function of the corresponding physical measurement. Solution of simultaneous equations (Appendix V) determined the following quadratic curves of fit through the points:

friction: $Y_1 = -6.78 + 2.21X_1 - 0.057X_1^2$

stiffness: $Y_2 = -65.77 + 61.76X_2 - 12.20X_2^2$

compressibility: $Y_3 = -23.82 + 5.31X_3 - 0.207X_3^2$

Plots of these curves through the corresponding points of satisfaction scores and physical measurements are shown in Figures 1, 2 and 3. In these Figures it can be seen that all curves are concave to the abscissa, indicating that both very high and very low values of the properties were regarded as undesirable by the panel. In each Figure, a circled number refers to a fabric which was excluded from this curve fitting for reasons previously stated. The following approximate ranges of satisfactory measurements for women's suitings were determined from the graphs:

friction:	3 to 35 gm. range of frictional force during sliding
stiffness:	1.5 to 3.5 cm. mean bending length
compressibility:	6 to 20% compressibility

The physical measurements of a given fabric may determine the general fabric satisfaction (S) according to the equation:

$$S = -46.6 + 0.312X_1 + 26.0X_2 + 2.517X_3 - 0.00846X_1^2 - 5.14X_2^2 - 0.100X_3^2$$

This equation was found by substituting the quadratic curves of fit (p. 27) into the equation, $S = -6.68 + 0.141Y_1 + 0.421Y_2 + 0.474Y_3$. The latter formula relates general fabric satisfaction to the satisfaction of its friction (Y_1), stiffness (Y_2) and compressibility (Y_3).

The additional equation, derived from the general fabric evaluation score and best estimated physical measurement of each fabric, was:

$$S = 32.3 + 0.396X_1 - 13.25X_2 - 0.774X_3$$

In substituting hypothetical physical measurements of friction (X_1), stiffness (X_2) and compressibility (X_3) into this equation, very high or

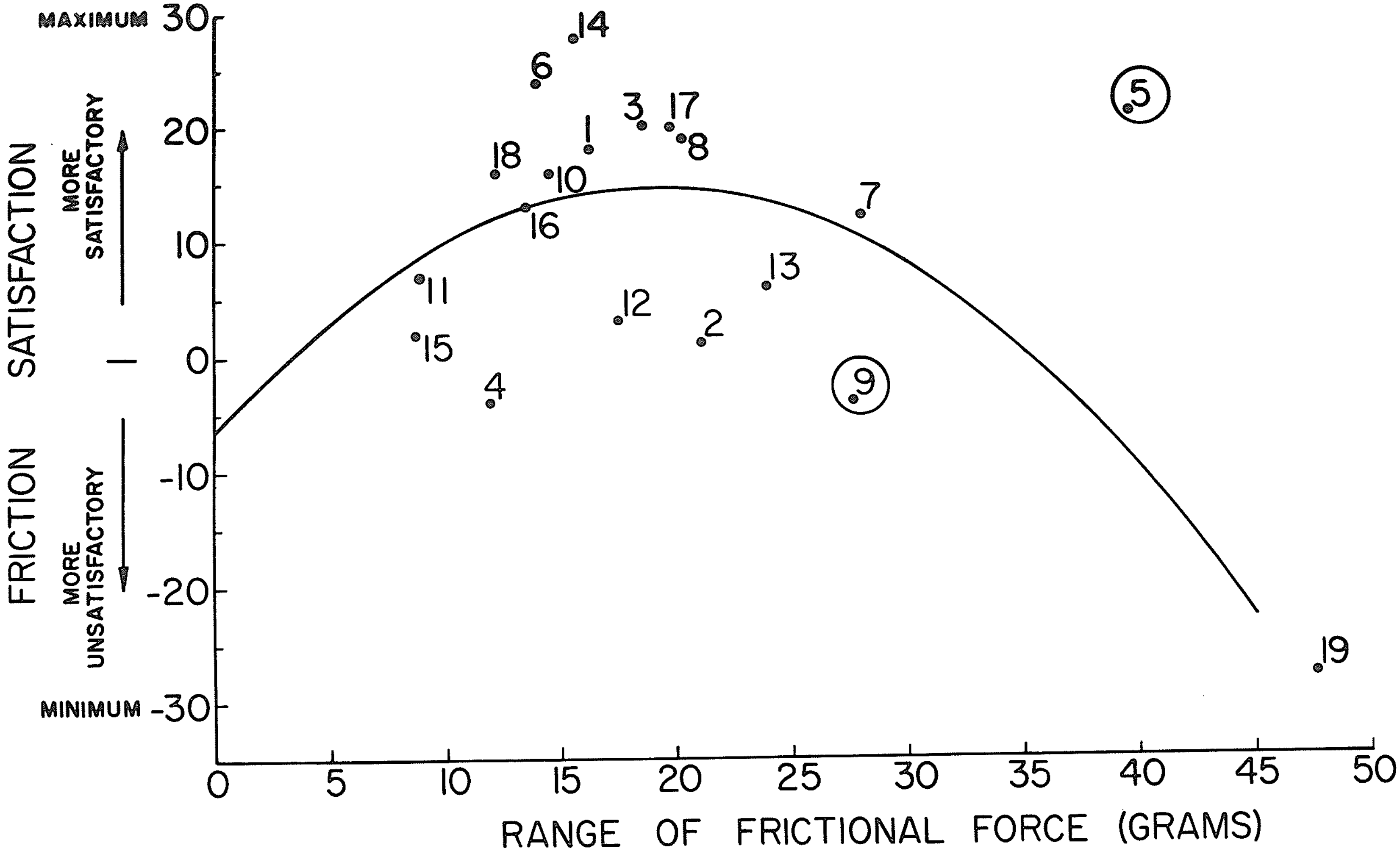

Figure 1. Quadratic Fit to Friction Force and Friction Satisfaction

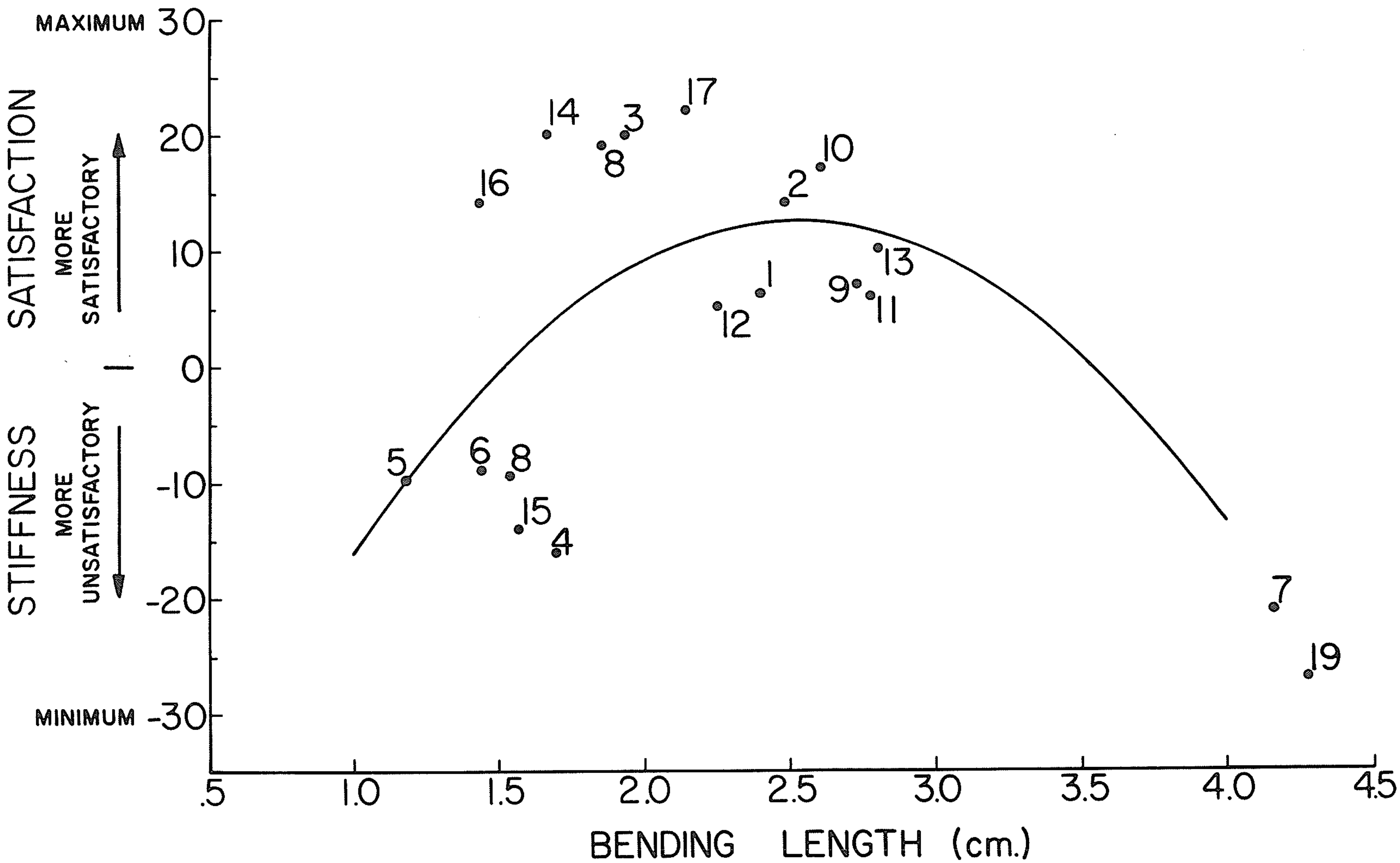

Figure 2. Quadratic Fit to Bending Length and Stiffness Satisfaction

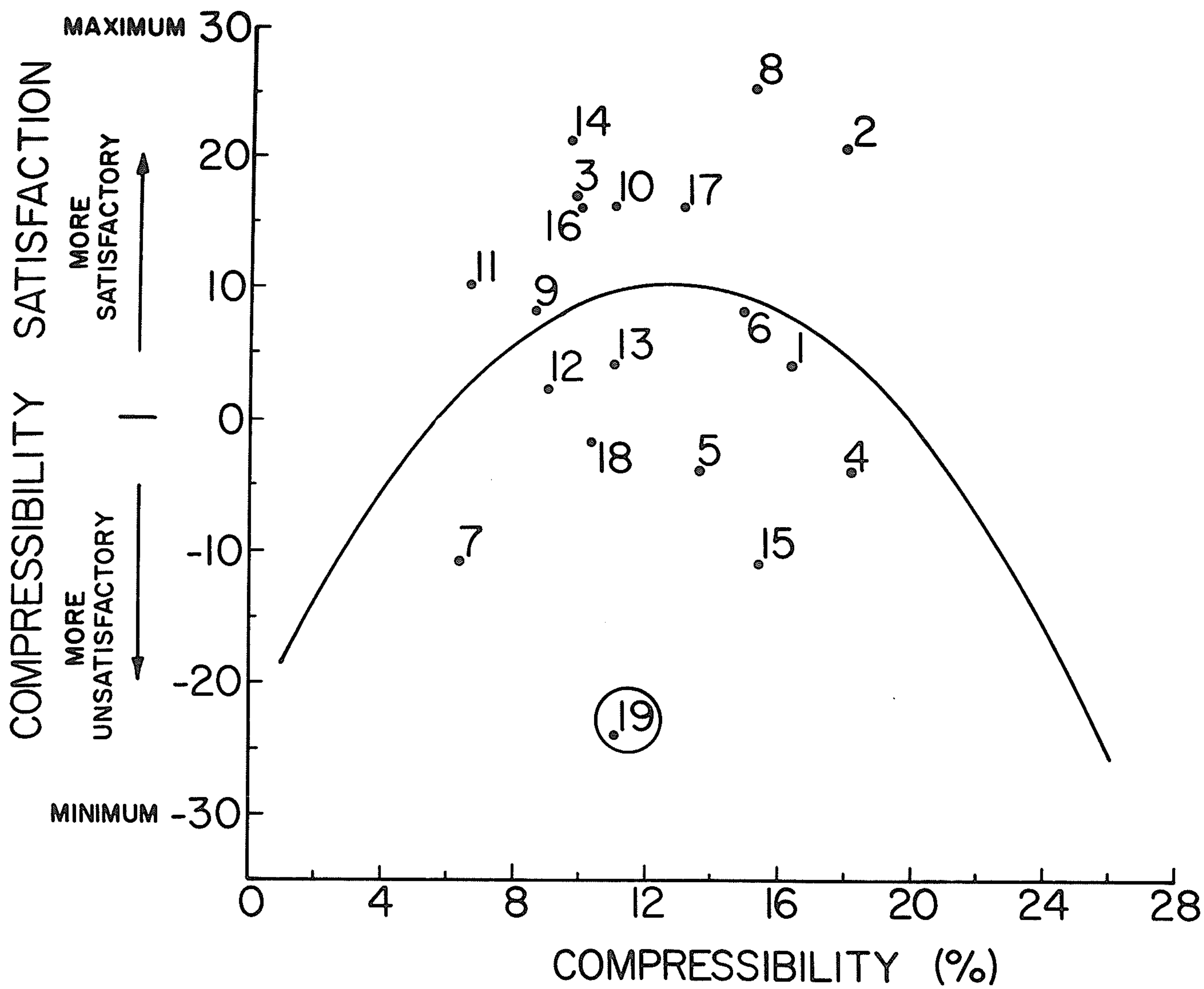

Figure 3. Quadratic Fit to Compressibility and Compressibility Satisfaction

very low measurements of any property resulted in a positive fabric satisfaction score. Since extremes in any property were not found to be favorably evaluated in this research (p.28) or by others (10, 24), this equation was unsuitable in predicting general fabric satisfaction. Substitution of the same hypothetical physical values into the former equation ($S = -46.6 + 0.312X_1 + 26.0X_2 + 2.517X_3 - 0.00846X_1^2 - 5.14X_2^2 - 0.100X_3^2$) resulted in negative satisfaction, which is the expected result. Substituting more moderate physical values resulted in a positive satisfaction score. The latter equation, therefore, would be more useful in determining general fabric satisfaction.

Additional properties which were frequently indicated by the panel as having influenced the general evaluation of fabric hand for women's suitings were weight and thickness. As these measurements were made for other property measurement (Tables IV and V), it was decided to construct graphs to predict those values of weight and thickness which would be evaluated as satisfactory for women's suitings. These values were:

weight:	2 to 5 $gm./dm.^2$	(Figure 4)
thickness:	0.005 to 0.044 in.	(Figure 5)

As can be seen in Figure 5, however, the relationship between general satisfaction and thickness is only slight. The quadratic curve of best fit goes neither far above nor far below the 0 satisfaction point of the scale. That is, fabrics would not be evaluated as highly satisfactory nor highly unsatisfactory on the basis of thickness measurements. It was, therefore, concluded that thickness would not influence a general evaluation of women's suitings. This is in contrast to the findings of Howorth (18).

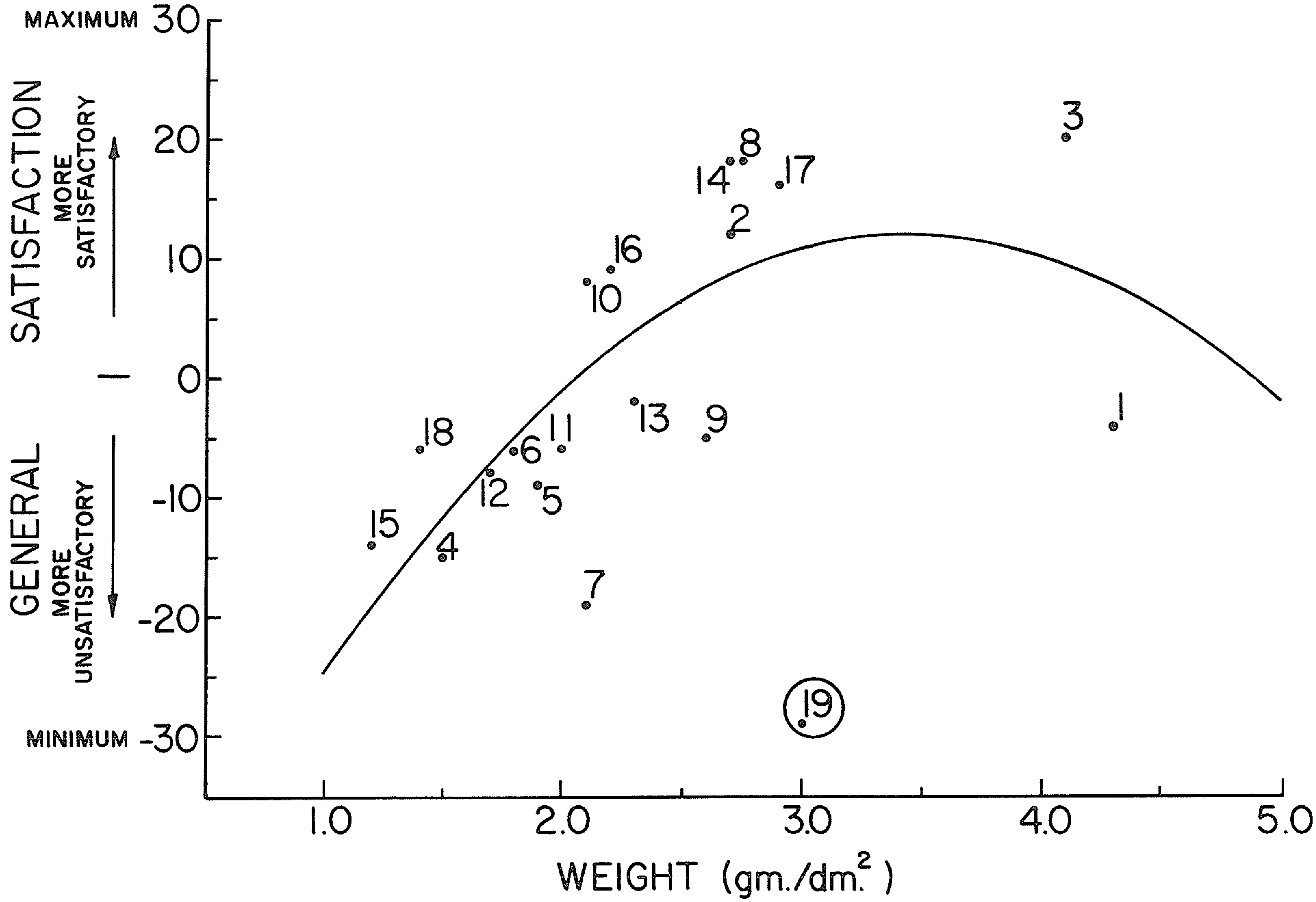

Figure 4. Quadratic Fit to Weight and General Satisfaction

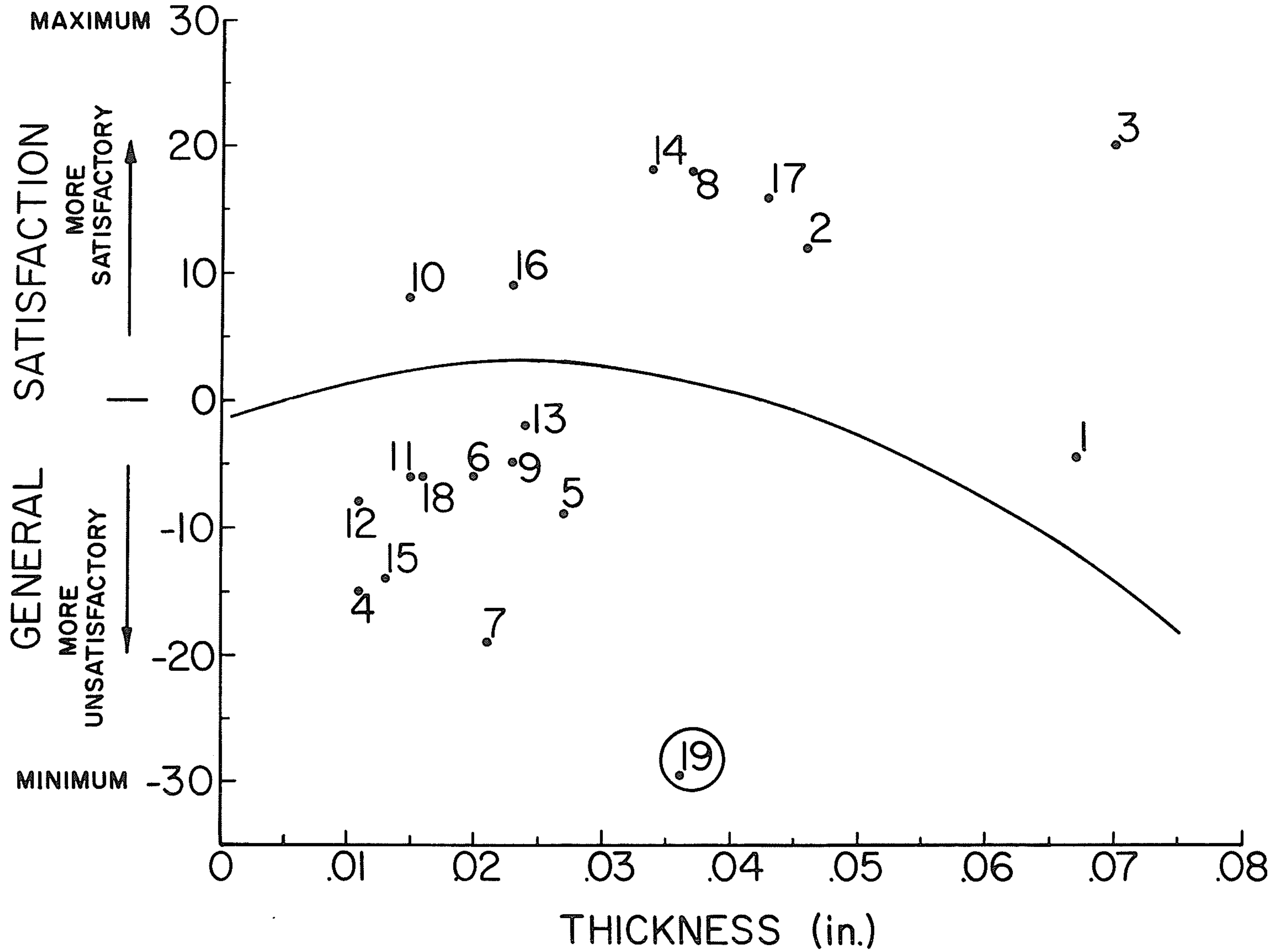

Figure 5. Quadratic Fit to Thickness and General Satisfaction

Additional comments frequently made by the panelists as influencing factors to the evaluation of the hand of suiting fabrics were: the season in which the suit is to be worn, drapability and tailorability of the fabric.

SUMMARY AND CONCLUSIONS

Nineteen commercially obtainable fabrics were evaluated by a panel of 30 individuals as to the satisfaction of the friction, stiffness and compressibility properties of hand for women's suitings. Values of -1, 0, +1, 0, -1 were assigned to the respective points of the scale checked by the panelists. A satisfaction score was determined for each property of every fabric by totalling the assigned values.

The 3 properties were measured instrumentally according to the following methods:

1. friction: Standard Method of Test for Coefficients of Friction of Plastic Film, ASTM, D 1894-63, Method B (2).
2. stiffness: British Standard Method for the Determination of the Stiffness of Cloth, B.S. 3356:1961 (11).
3. compressibility: Compressometer (36).

Various derived quantities of each property were determined by these methods.

To determine which physical measurement of each property was best related to a subjective estimate of the measurement, as assessment score was calculated. This time, the values +2, +1, 0, -1, -2 were assigned to the respective points of the scale and totalled over the 30 panelists. The following physical measurements correlated highest with subjective estimates:

friction:	range of frictional force during sliding
stiffness:	mean bending length
compressibility:	per cent compressibility

By solving quadratic curves of fit between subjective evaluations and physical measurements, the following values were determined to be the range between which the 3 properties would be given a positive evaluation, by the panel, for women's suitings:

3 to 35 gm. range of frictional force during sliding

1.5 to 3.5 cm. mean bending length

6 to 20% compressibility

Using the quadratic curves, a multiple regression equation was formed which could be used to determine the satisfaction (S) of any fabric for women's suitings in terms of its friction (X_1), stiffness (X_2) and compressibility (X_3) measurements. This equation was:

$$S = -46.6 + 0.312X_1 + 26.0X_2 + 2.517X_3 - 0.00846X_1^2 - 5.14X_2^2 - 0.100X_3^2$$

Many panelists also indicated that fabric weight and thickness influenced general evaluations. The range of these properties which would be evaluated as satisfactory for women's suitings were:

2 to 5 gm./dm.^{2} - weight

0.005 to 0.044 in. - thickness

Thickness, however, did not show a good relationship with subjective evaluations.

As a result of the comments of the panelists, observations during the procedure and analysis of the study, a number of considerations are recommended and further investigation suggested:

1. the evaluation of one property at a time to avoid the influence of extremes in one property on the evaluation of the others.
2. the development of a suitable method for measuring frictional characteristics of knits, since these fabrics are assumed to

be appropriate for women's suitings.

3. a distinction of the season in which a suit made from the fabric would be worn, since this was suggested as a factor influencing the suitability of fabric hand.

4. an evaluation of the suitability of fabrics with properties of friction, stiffness and compressibility within the measured ranges, to discover whether the ranges are accurate predictions of satisfaction scores.

5. the assessment of the same properties by a panel of women in other age groups, to determine whether the panel composition has any effect on the results.

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APPENDIXES

APPENDIX I

DESCRIPTION OF SUITING FABRICS

FABRIC NUMBER	CODE NUMBER	FIBRE CONTENT	WEAVE	MISCELLANEOUS INFORMATION
1.	126	Cotton & Wool	Plain	Coating
2.	600	Wool	Basket	
3.	415	Wool	Plain	
4.	746	50% Avril/50% Cotton	Twill	Wrinkle-free finish
5.	236	Wool	Knit	Jersey
6.	200/153	Wool	Plain	Worsted Crepe
7.	349	Cotton	Plain	Homespun; Little or no ironing
8.	407	Wool	Twill	
9.	534	Viscose	Plain	Bonded: Crease Resistant
10.	357	Cotton	Satin	Crease Resistant
11.	059	Viscose	Plain	Crease Resistant
12.	979	Cotton	Plain	Koratron finish
13.	104	50% Fortrel/50% Linen	Plain	Permanent press
14.	717	Wool	Plain	Doeskin
15.	370	Wool	Plain	Challis
16.	745	Wool	Plain	Broadcloth
17.	695	50% Wool/50% Rayon	Twill	
18.	527	55% Wool/45% Cotton	Twill	Viyella
*19.	545	Jute	Plain	Hesian Cloth

* Not a suiting fabric, included for high degree of roughness and stiffness.

APPENDIX II

FABRIC EVALUATION QUESTIONNAIRE

NAME:______________________________ DATE:____________________

Status: (Check one) Student_____ Year_____ Major____________________

Staff______ Department______________________

Directions: Please assess the suitability of the following fabrics for women's suitings. Handle them in any manner necessary for your evaluation, but do not look at them. Check the point on the scale that best describes your evaluation.

1. Frictional Property: Ease of slipping offered by the surface contour.

Sample	_____	_____	_____	_____
much too smooth	_____	_____	_____	_____
slightly too smooth	_____	_____	_____	_____
satisfactory	_____	_____	_____	_____
slightly too rough	_____	_____	_____	_____
much too rough	_____	_____	_____	_____

2. Stiffness Property: Ease of bending.

Sample	_____	_____	_____	_____
much too limp	_____	_____	_____	_____
slightly too limp	_____	_____	_____	_____
satisfactory	_____	_____	_____	_____
slightly too stiff	_____	_____	_____	_____
much too stiff	_____	_____	_____	_____

3. Compressibility: Ease of squeezing in the hand between the fingers.

Sample	_____	_____	_____	_____
much too soft	_____	_____	_____	_____
slightly too soft	_____	_____	_____	_____
satisfactory	_____	_____	_____	_____
slightly too hard	_____	_____	_____	_____
much too hard	_____	_____	_____	_____

4. (a) General Evaluation: Over-all assessment.

Sample	____	____	____	____
Good	____	____	____	____
Fair	____	____	____	____
Poor	____	____	____	____

(b) List, if any, other properties that may have influenced your evaluation.

SAMPLE:

____	____	____	____

APPENDIX III

Correlation Coefficient (r)

$$r = \frac{\sum XY - \frac{(\sum X \sum Y)}{n}}{\sqrt{\left[\sum X^2 - \frac{(\sum X)^2}{n}\right]\left[\sum Y^2 - \frac{(\sum Y)^2}{n}\right]}}$$

where X and Y = the variables to be correlated

n = number of pairs of observations

Significance of Correlation (t)

$$t = r\sqrt{\frac{n - 2}{1 - r^2}}$$

where r = correlation coefficient

n = number of pairs of observations

APPENDIX IV

Chi-square Contingency Test of Independence

$$\chi^2 = \frac{(|O - E| - 0.5)^2}{E}$$

where O = observed assessment scores

E = expected assessment scores*

E.g. Stiffness

Observed Scores

2nd \ 1st	-1,0,1	2	Total
-1,0,1	10	8	18
2	7	5	12
Total	17	13	30

Expected Scores

2nd \ 1st	-1,0,1	2	Total
-1,0,1	10.2	7.8	18.0
2	6.8	5.2	12.0
Total	17.0	13.0	30.0

$$\chi^2 = 0.3^2 \left(\frac{1}{10.2} + \frac{1}{7.8} + \frac{1}{6.8} + \frac{1}{5.2} \right)$$

$$= 0.051$$

* $E = \frac{\text{Row Total x Column Total}}{\text{Grand Total}}$

APPENDIX V

Simultaneous equations for the determination of a, b and c in

$Y = a + bX + cX^2$

$$\sum Y = na + b\sum X + c\sum X^2$$

$$\sum XY = a\sum X + b\sum X^2 + c\sum X^3$$

$$\sum X^2Y = a\sum X^2 + b\sum X^3 + c\sum X^4$$

where n = number of pairs of readings

Y = satisfaction score

X = physical measurement value

APPENDIX VI

Simultaneous Equations for determination of a, b, c, d, in the multiple regression equation:

$$S = a + bY_1 + cY_2 + dY_3$$

$$na + b\sum Y_1 + c\sum Y_2 + d\sum Y_3 = \sum S$$

$$a\sum Y_1 + b\sum Y_1^2 + c\sum Y_1Y_2 + d\sum Y_1Y_3 = \sum Y_1S$$

$$a\sum Y_2 + b\sum Y_1Y_2 + c\sum Y_2^2 + d\sum Y_2Y_3 = \sum Y_2S$$

$$a\sum Y_3 + b\sum Y_1Y_3 + c\sum Y_2Y_3 + d\sum Y_3^2 = \sum Y_3S$$

where S = general fabric satisfaction score

Y_1 = friction satisfaction score

Y_2 = stiffness satisfaction score

Y_3 = compressibility satisfaction score

n = number of fabrics tested