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FACTORS AFFECTING THE SOFTNESS OF SILK-WOOL FABRICS

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For the purpose of estimating their tactile properties by means of hands and lips, 26 varieties of fabrics have been manufactured from different woolwefts which are plain-woven into the same silk warp. The lips test seems slightly more reliable than the hand test. In addition, the softness of the unrelaxed fabrics exhibits high positive correlations with their softness after wet-relaxation and felting. But the correlation between the softness of a fabric and that of its raw wool assembly is not very high because the former is additionally dependent on the variations of weave density, yarn evenness, tex, twist factor and ply number; besides, an interaction between twist factor and tex appears to modify the softness of the singles' fabrics. Nevertheless, the weft/cm alone accounts for 84.0% of the variations of fabric softness within their present ranges of variation.

The tactile sensation of textile materials is usually estimated by a subjective type of mild compression test[1,2] in which a fibre assembly is squeezed by hands. The results are expressed in such words as soft, warm, lofty, crisp, firm, harsh, boardy, dead, lively, wiry, spongy, springy, lean, waxy, dry and muss-resistant.[3] For example, the handle of Merino, Southdown and Lincoln wools are generally known as soft, spongy and harsh respectively. As discussed in man-made fibres, however, the wide variations of softness displayed by different fibres are largely attributable to their difference in substrate, which is evident from the large variations of their Young's modulus at 1% extension.

Fabric design, durability and price are often considered in trade situations but a fabric softness mainly determines the consumers' opinion of the fibre types. Because of its great significance in end-uses, the softness of handle mostly governs the buyers' preference for the apparel materials. This somewhat undefinable quality of a fabric is particularly desired in the dress materials of women and children. Hence, a definite knowledge of the factors determining the tactile property of a fabric could be of great interest to the manufacturers. Accordingly, this study purports to decipher the contributions of fibre, yarn and fabric qualities to the softness of handle manifested by a variety of silk-wool fabrics at different stages of their finishing.

Pure silk is, however, too costly for general use by the common people of East Pakistan. As a consequence, a stock of various silk clothes which are estimated at nearly rupees 9 lacs, has been left unsold during recent years at the lone silk factory of East Pakistan whilst its annual maintenance normally costs about rupees 2 lacs.[4] Although the yarns produced in it are easily sold, sometimes by exporting the to West Pakistan, the stock of fabrics creates many economic problems such as those of idle capital, space and preservation in the factory. Thus it seems necessary to find additional uses for the silk fabric. Unfortunately, the uses of silk are limited by its rapid slackening due to high creep under the stress-strain of usual wear and tear. This difficulty may be overcome by suitable coupling of silk with wool because the latter normally exhibits felting shrinkage during any wet-cleaning. Such a blend may find outlets in the military dress materials where wool *per se* is highly valued.[5] Thus a fabric of silk and wool fibres, both being nonflammable, may suit wide variety of end-uses, particularly, because it will possess certain desirable attributes which could not be developed by using any one of them alone.

Whilst silk is well known for highly desirable fabric handle and low filament friction, its handle mainly results from the supple filament characteristics. On the other hand, shrink-proofing of wool by alcoholic potash increases fibre friction and stiffness, and impairs its softness of handle.[1,6,8] But the natural variation of fibre friction displayed by the wide variety of raw wools is rather small and practically independent of the large difference of their softness,[9] therefore, the inferior handle of the shrink-resisted wools may arise from the increase of fibre stiffness and the resulting high resistance to bulk compression noted elsewhere[10] too. This inference agrees well with the additional observation that the variation of loose wool compressibility is largely accounted for by the fibre diameter and crimp frequency which, in turn, govern the softness of handle.[9] But an anomalous effect of crimp frequency can arise from visual bias if it is allowed to prevail upon the hand test of raw wools.[11] Thus the softer handle displayed by the fabrics of relatively high-crimp[12,13] wools tends to disappear on their wet-finishing[14] that restores most of the fibre crimps removed by the processing stress. It, therefore, appears desirable to investigate the reproducibility and validity of the hand test when it is administered in presence of the visual bias for fibre crimp.

Experimental

The materials studied here comprised a mulbery silk of the multivoltine race commonly found in East Pakistan and four apparel-type Australian wools. It may be pointed out that the observed variation of fabric softness is mainly dependent on the characteristics of wool fibres and their weft yarns.

Fibre Properties.—Diameter of the wool fibres was measured by a projection microscope at a magnification of 500× following the standard procedure recommended by the Technical Committee of International Wool Textile Organisation. But the softness scores of the raw wools have been obtained from a previous observation.[9] However, at least 10 fibres were drawn at random from each wool for determining the average coefficient of static friction in wet state by the capstan method[15] incorporating a horn cylinder of 0.6 mm dia.

Yarn Tex and Irregularity.—The yarn tex was estimated as mass in g per kilometre yarn length obtained by weighing ten 110-metre hanks conditioned at 65% r.h. and 21°C. However, a previous analysis[9] demonstrated that the coefficient of variation of the total number of fibres in a yarn cross-section could be an absolute measure of yarn irregularity. Accordingly, at least twenty 0.2-mm long yarn sections were cut at random from metric intervals of each sample. Each section was examined by a microscope at the magnification of 200× in order to estimate the coefficient of variation of the number of fibres therein.

Fabric Manufacture.—About 40 cm long fabric was plain-woven with each weft by means of a commercial model Matsuoka power loom incorporating 2220 ends within 96.5 cm beam and 94.0 cm reed giving 91.5 cm wide grey-fabric. Whilst a R42/2 denier organzine comprised the ends, the wefts were secured as follows.

Four singles of the nominal count 200 tex and twist 2.4 turns/cm each were spun from Merino, Southdown, Ryeland and Border Leicester wools in a woollen ring frame. In addition, the Merino wool was processed in a shortened Bradford system to produce 9 singles denoted by the nominal tex/twist factor such as 90/2.5, 90/2.0, 90/1.7, 60/2.5, 60/2.0, 60/1.7, 30/2.5, 30/2.0 and 30/1.7. All the singles were individually laid into 2-ply and twisted by 168 turns/metre with the aid of a commercial type Matsuoka throwing machine, the ply twist being always opposite to the direction of the single's twist. Finally, the specifications of the wefts were used to identify the corresponding fabrics.

Fabric Characteristics.—Since the warp density is constant in all the fabrics, the number of weft/cm has been taken as a reasonable index of weave density. It was estimated by counting all the wefts in a 2.5-cm fabric length which had been flattened under a magnifying glass. The sample weft/cm was obtained from an average of at least 6 random observations covering the entire fabric width.

The surface friction was, however, estimated on a dry fabric by the stick-slip technique[16] which involved recording the maximum tension developed when a polished surface of metal (35 cm^2 under a force of 105 g) was dragged at a fixed rate on the smooth fabric surface. Although the weft-way friction was slightly higher than that along the warp-way as expected, the average coefficient of static friction exhibited by the 26 fabrics ranged from 0.14 to 0.17. This variation, when compared with the large differences of the other parameters examined here, was quite negligible and therefore, deleted from the succeeding analyses.

Relaxation and Felting.—All the fabrics were soaked in a 0.02% soap-soda solution at room temperature and left there unstrained for 24 hr in order to release any processing strains. They were rinsed with distilled water and air-dried for the subsequent testing. Later on, the fabrics were washed in the same liquor thereby producing area shrinkage from 4 to 20% of their relaxed area, rinsed and air-dried as before.

Hand and Lips Testing.—For the purpose of applying the results to situations arising in the trade, the softness testing was always carried out in presence of the appraisers' vision. Six appraisers were initially instructed to sort out each of the 26 fabrics in order of their softness as revealed to the hands alone. The softest fabric was assigned a score of 1 and the harshest, a score of 26. Mean of the 6 scores given to each fabric was termed its handle score, H. The same group of 6 judges were allowed some time to forget their hand scores completely and then advised to rank the 26 fabrics in order of softness by using their lips only. The results thus obtained was called the lips score, L. Both the tests were applied before and after relaxation, and after felting of the 26 silk-wool fabrics.

Results and Discussion

In view of the significance of visual bias for fibre crimp[11] the reproducibility and validity of the fabric softness scores have been examined here in order to ensure an objective analysis of the results.

Reproducibility.—The softness score of each fabric has been split into 2 halves by drawing at random and averaging any 3 of the 6 scores assigned to it; the coefficient of correlation (r) between the split-half scores has been estimated as an index of reproducibility. A high correlation given by $r=0.8$ or more is generally considered to imply satisfactory reproducibility of the measurements. Here, the split-half analysis (Fig. 1) shows satisfactory reproducibility for the handle scores of the unrelaxed ($r=0.963$) fabrics but these scores for the relaxed ($r=0.733$) and felted ($r=0.730$) fabrics appear to be barely reproducible. Admittedly, in harmony with previous results[12–14] the low reproducibility indicates some difficulty of distinguishing the softness of the relaxed and the felted fabrics; the difficulty may be associated with the consequent reduction in the differences of fabric bulkiness and weave density which are likely to be the relevant cues in the test situations. Nevertheless, the lips scores definitely demonstrate (Fig. 2) high reproducibility at all the stages of fabric finishing.

Validity.—This attribute shows whether a test measures what it purports to estimate. Satisfactory validity of the subjective testing for fabric softness by either hands or lips has been clearly demonstrated (Fig. 3) through the high correlation between the handle (H) and lips (L) scores observed at the 3 stages (pooled $r=0.898$) of the 26 fabrics. Therefore, the present analysis can be generalised to similar industrial situations. In practice, however, there is high likelihood of using the hands and lips together for judging the fabric softness; accordingly, a comprehensive estimator of the fabric softness (S) has been defined as follows.

$$S=(H+L)/2 \quad (1)$$

where S is an inverse measure of the fabric softness. Whilst the 1 ply fabrics indicated by the notations 60/1.7, 60/2.5 and 30/2.5 have exhibited the highest softness in the unrelaxed, relaxed and felted stages respectively, the lowest softness has always been manifested by the 2-ply fabric of Border Leicester wool.

Relaxation and Felting.—The relaxation cniefly involves crimp recovery that may vary directly with the magnitude of fibre descrimping here. The spinning twist removes considerable amount of fibre crimps so that the finer yarns possessing more twist in a given mass may exhibit higher crimp recovery during wet relaxation. Thus, Fig. 4 presents relatively high values of the softness score, S of those (relaxed) fabrics which are made up of the finer wefts. This point conforms to the observations of harsher handle of the crimpier wools[1,9] and of the wetrelaxed fabrics produced

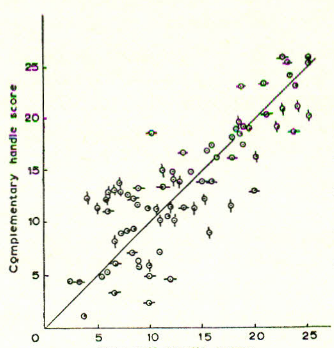


Fig. 1.— Correlation between split-half handle scores estimated before (⊙) and after (-⊙-) relaxation, and on washing (⦶) of the 26 silk-wool fabrics; $r=0.963$ for points ⊙, $=0.733$ for points -⊙- and $=0.730$ for ⦶

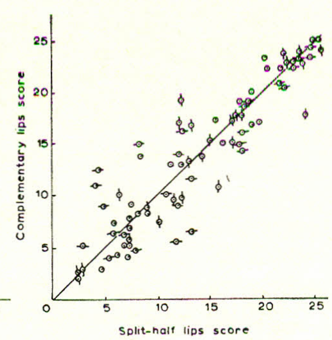


Fig. 2.—Correlation between split-half lips scores recorded before (⊙) and after (-⊙-) relaxation, and on washing (⦶) of the 26 silk-wool fabrics; $r=0.974$ for points ⊙, $=0.851$ for points -⊙- and $=0.925$ for ⦶.

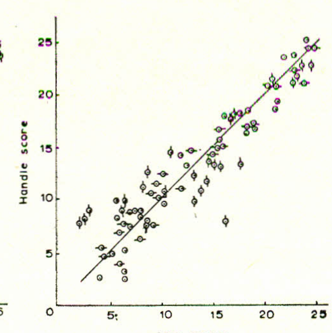


Fig. 3.—Correlation between handle and lips scores obtained before (⊙) and after (-⊙-) relaxation and on washing (⦶) of the 26 silk-wool fabrics; $r=0.960$ for points ⊙, $=0.888$ for points -⊙- and $=0.851$ for ⦶, and $r=0.898$ or pooled points.

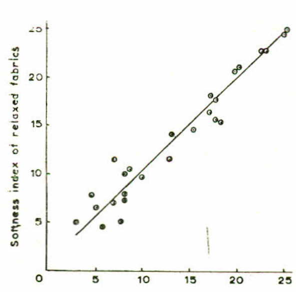


Fig. 4.—Correlation between fabric softness noted before and after relaxation of the 26 silk-wool clothes, $r=0.970$.

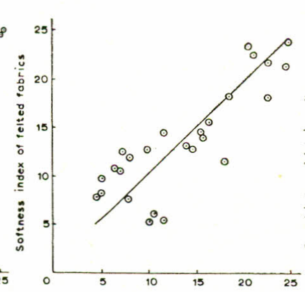
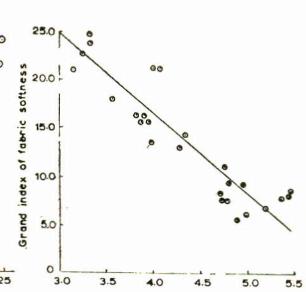


Fig. 5.—Correlation between fabric softness estimated after relaxation and on washing of the 26 silk-wool fabric $r=0.839$



Eig. 6.—Correlation between fabric softness and square root of the number of weft per cm $r=0.916$.

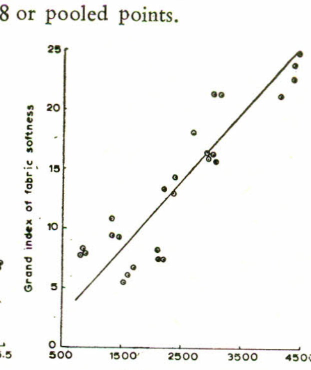


Fig. 7.— Correlation between farbic softness and weave density at unit tex, $r=0.900$.

thereof.[14] It may also be pointed out that the vraiation associated with the crimp recovery is partly responsible for the scattering of results in Figs. 4 and 5. The correlation of the S's between the unrelaxed and relaxed fabrics (r=0.970) when compared with that (r=0.839) between the relaxed and felted fabrics shows additional difficulty of estimating the softness of the felted fabrics as illustrated before. In view of the high correlations, however, the succeeding analyses deal with the grand inddex of overall fabric softness, S_g as defined below.

$$S_g = \tfrac{1}{3}\sum^{3} S = \tfrac{1}{3}\sum^{3}\left(\frac{H+L}{2}\right) \qquad (2)$$

where the summation extends overall observations at the 3 stages of fabric finishing and the notations are as pointed out earlier.

Raw Wool and Yarn Qualities.—For further insight into the tactile behaviour, the grand index of fabric softness has been compared with the relevant qualities of wool fibre and its yarn in Table 1. The softness index is strongly correlated with yarn irregularity and fibre diameter but its correlation with the softness score of raw wool is medicore; as expected,[1,8,9] fibre friction is unlikely to be a significant factor in determining fabric softness. Although fibre fineness affects yarn irregularity which, in turn, varies directly with the grand index of fabric softness, the softness of raw wool may be significantly modified by the influences of yarn and fabric structures as indicated succeedingly.

Yarn Tex, Twist Factor and Ply Number.—Results set out in Table 2 show that the grand index of fabric softness increases progressively with higher tex and twist factor in case of the 2-ply fabrics whereas these relations are certainly complicated in the 1-ply samples. Whilst the softness index of the latter increases initially and finally decreases with the progressive rise of twist factor, the phenomenon is paralleled, surprisingly, by the effect of twist factor on fibre crimp of these particular singles.[17] For instance, the increase of twist factor initially imposes artificial crimps on the fibres of yarn surface and subsequently, produces lateral cohesive pressures to remove original crimps of the inner fibres. These opposing functions of a twist factor mostly explain the present results, suggesting an interaction between the single's tex and twist factor, because the high crimp increases the softness index as noted before. The observed tex-effect (Table 2), however, denotes that very high yarn tex would mitigate the decrimping effect of twist factor by reducing the gradient of the lateral cohesive pressure to such an extent that the artificial crimping of the surface fibres is highly under-compensated. Such an under-compensation, on the other hand, may arise from insufficient number of the inner fibres that are subjected to the lateral cohesive pressures in the singles of very low tex. Thus, 1-ply fabrics exhibit relatively high index of softness at the extremely high and low yarn texes.

In agreement with the foregoing, the 2-ply fabrics always manifest higher index of softness than that of their 1-ply counterparts as shown in

TABLE 1.—CORRELATION OF FABRIC SOFTNESS INDEX WITH FIBRE AND YARN QUALITIES.

Sample characteristics	Merino	South-down	Ryeland	Border Leices-ter
Sg of 1-ply fabrics	15.7	18.0	21.3	21.3
Sg of 2-ply fabrics	21.1	22.6	23.7	24.7
Yarn irregularity, %	15.0	16.2	18.7	22.2
Fibre dia.	20.4	26.5	31.6	36.8
Coeff. fibre friction, Av.	0.36	0.34	0.45	0.46
Raw wool softness index	1.8	8.8	14.2	9.5

TABLE 2.—DISTRIBUTION OF FABRIC SOFTNESS INDEX WITH YARN TEX AND TWIST FACTOR.

		Single's nominal tex, 1-ply				Single's nominal tex, 2-ply			
		90	60	30	Total	90	60	30	Total
Single's	2.5	7.5	6.1	7.8	21.4	16.0	13.4	10.9	40.3
Nominal	2.0	8.2	6.8	8.4	23.4	16.3	14.3	9.4	40.0
Twist factor	1.7	7.5	5.4	8.0	20.9	15.9	13.0	9.3	38.2
Total		23.2	18.3	24.2		48.2	40.7	29.6	

TABLE 3.—VARIATION OF FABRIC SOFTNESS INDEX WITH YARN PLY NUMBER.

Fabrics	90/2.5	90/2.0	90/1.7	60/2.5	60/2.0	60/1.7	30/2.5	30/2.0	30/1.7
1-Ply	7.5	8.2	7.5	6.1	6.8	5.4	7.8	8.4	8.0
2-Ply	16.0	16.3	15.9	13.4	14.3	13.0	10.9	9.4	9.3
Differ	8.5	8.1	8.4	7.3	7.5	7.6	3.1	1.0	1.3

Table 1 and 3. The untwisting of single, high yarn tex and ease of crimp recovery[18] associated with 2-ply weft can explain most of the variation in fibre crimp underlying the observed difference of fabric softness due to ply number. In addition, the artificial crimping under the said influence of yarn geometry greatly depends on the fibre bending propensity which is a function of fibre diameter. This suggests a between-breed variation of the ply-effect on fabric softness (cf. Table 1).

Weave Structure.—The grand index of fabric softness has been studied as a function of weft/cm (w) in Fig. 6. The most interesting observation of this study is that despite the wide variation of yarn tex and fibre qualities, the square root of 'w' accounts for 83.9% of the variations of the softness index, S_g according to the empirical equation 3 of graph 6 and standard error of prediction ± 2.5 units of S_g.

$$S_g = 47.94 - 7.94\sqrt{w} \quad (3)$$

The linear relation of Fig. 6 will parallel that between the objective measurements of fabric liveliness and square root of fabric stiffness in a variety of textile fibres[3] if the former represents the fabric softness and the latter, $\sqrt{w}$ as expected in this analysis. Besides, the effects of 'w' and yarn tex (t) appear to suggest the importance of their product, 'tw' in determining fabric softness as in Fig. 7. This parameter which becomes equal to 'w' when the tex is unity, represents the weave density at constant yarn mass per unit length. Thus it is an index of fabric stiffness that accounts for 81.0% of the variation of S_g according to the empirical equation 4 of Fig. 7 and the standard error of prediction ± 2.7 units of S_g.

$$S_g = 1.47 + 0.005(t.w.) \quad (4)$$

In view of S_g being an inverse measure of fabric softness, the equation 4 suggests that fabric softness will increase with fewer weft/cm if the yarn tex is constant. Such situations, in practice, may arise from bulkier yarns which are generally made up of the crimpier wools. The bulkiness due to fibre crimp may, therefore, increase fabric softness in agreement with trade opinion[1,19] even though the crimpier wools are usually harsher in handle[1,9] Thus, the weave effect seems to be more important than the effect of crimp in governing the softness of fabric handle. Eventually, the equations 3 and 4 could be useful for predicting fabric softness from the objective measurements of weft/cm and yarn tex within their indicated ranges of variations encountered in this analysis.

Conclusions

Of the various factors influencing the subjective assessment of fabric softness, fabric stiffness, as represented by weave density or its multiplication product with yarn tex, appears to be the most important physical attribute. Whilst the stiffness of a random fibre assembly is greatly modified by the yarn and fabric structures, the dependence of fabric softness on yarn tex, twist factor and ply number may arise mainly from their direct effects on fibre crimp. This is quite expected from a negative correlation observed between fabric softness and the fibre crimp level; but the crimp-effect is overwhelmed by the paramount influence of weave density in such a way that bulkiness due to high-crimp eventually promotes softness of fabric handle. Fabric softness, in addition, increases with yarn evenness and fibre fineness although it is quite independent of fibre friction.

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