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AREA SHRINKAGE DUE TO RELAXATION AND FELTING OF PLAIN-WOVEN SILK-WOOL FABRICS

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Observations on a variety of silk-wool fabrics reveal that the rate of relaxation shrinkage falls off significantly with higher yarn tex, ply number and fabric stiffness. The fabric felting rate, however, shows highly significant negative correlation with the stiffness parameter and yarn tenacity. The effects of yarn tex and twist factor on felting rate seem to be significant in case of the 1-ply fabrics but they are nonsignificant in the 2-ply fabrics. Although the 2-ply coarse fabric shows lower felting rate than that of the 1-ply counterpart, the ply effect may reverse its sense in fine cloths due, perhaps, to the influence of higher plying and weaving strain on the finer wefts. Finally, the rank correlation of loose wool felting rate with yarn and fabric felting rates appear to be highly significant if the relevant singles are slightly untwisted by any means.

Previous work[1] has indicated that silk-wool fabrics will enable more East Pakistani silk to be used in utility-apparelling. The loom-state fabrics will have certain relaxation and felting shrinkages; it would be convenient to know what these will be because this will help the manufacturer choose those conditions of spinning and weaving which will produce a finished fabric that is close to what he wants. The variables altered here before measuring the relaxation and felting are the wool single's (a) count, (b) twist, (c) ply number, (d) tenacity and (e) fibre quality, and (f) fabric stiffness.

The relaxation shrinkage also known as crimp recovery[2] occurs in the recently manufactured yarns and fabrics when they are left freely, particularly in the wet state, due to the release of processing strain and hygral expansion. Fabric relaxation is mainly a function of yarn relaxation together with some effect attributable to the stress of knitting[3] or weaving which, in turn, may depend upon the tightness of fabric construction or its stiffness index. As the yarn shrinkage may depend on its ply number, tex and twist factor[4] which chiefly account for the area shrinkage of knitted fabrics[3,5] a definite knowledge of their influence on the behaviour of woven fabrics seems highly desirable.

A washing test on the fabrics is too costly for quality control and process development in the textile factory because, in this case, a representative sample of fabric must be produced from a raw wool before the area shrinkage can be estimated for ascertaining the suitable conditions of its processing. The available felting test of loose wools could be economical for this purpose if its results agree with those obtained by washing the resultant fabrics. The agreement may be possible in a limited variation of fibre qualities[6,7] but the forecasting of felting shrinkage from its measurement at the preceeding stages of processing could be erroneous[7–10] due to the differential changes[11–13] of the relevant fibre attributes. Hence, 4 widely different wools have been studied here to distinguish the manufacturing conditions which are amenable to accurate prediction of fabric felting rate, from those that increase the error of prognosis.

Experimental

Loose Wools, Yarns and Knitted Fabrics.—The Merino (20.4μ), Southdown (26.5μ) Ryeland (31.6μ) and Border Leicester (36.8μ) wools and their woollen slubbings were tested by Aachener Filtz test[14] for obtaining the % reduction of specific volume[8] as a measure of felting rate. These wools were also processed to produce woollen singles of nominal count 200 tex and twist 2.4 turns/cm; each yarn was untwisted by 0.8 turn/cm with the aid of a Universal twist frame. Duplicate samples of 158 cm^2 cloths were manually plain-knitted from the original single at 1 cm loop length, 4 wales and 4 courses per cm^2. Besides, the Merino wool was spun for obtaining the 9 worsted singles of nominal tex/twist factor given by 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. After their relaxation, five 15-cm specimens of each yarn were separately enclosed by Terylene tubes and washed alongwith the fabrics by using 1600 hand-squeezings in a 0.02% soap-soda solution at room temperature for estimating their felting rates.

Yarn Qualities.—They were measured at 65% r.h. and 21°C. Yarn tex, mass per kilometre, was estimated from ten 110-metre hanks. For obtaining its twist factor, the single's twist was measured by a Goodbrand twist tester. Its tenacity was estimated from forty 50-cm yarns tested by an Uster automatic strength tester which was set to break each yarn within 20$\pm$2 sec.

Silk-wool Fabrics.—The said normal 13 singles were individually laid into 2-ply and twisted by 168 turns/metre with the aid of a commercial model Matsuoka throwing machine. Both the

1 and 2 plies were used as wefts for making 26 varieties of fabrics from a R42/2 denier organzine of native mulberry silk. Each cloth was plain-woven up to 40 cm by a Matsuoka power loom having 2220 ends in 96 cm beam.

Fabric Stiffness.—Due to its significance in determining fabric shrinkage,[15] the weave density was obtained before wet relaxation; the warp density being always constant, weft/cm represents the variation of weave density here. It was estimated by counting all the wefts over 2.5 cm long fabric flattened under a magnifying glass and using at least 6 random observations covering the entire fabric width. The weft/cm which varied from 10 to 30, gave the stiffness index, S.

The product of weave density and yarn tex (w.t) may represent fabric stiffness[1] which, according to common experience, also increases with yarn twist factor, f. Therefore, $S=k_1$ (w.t) (1) when f is constant so that $k_1=k.f$ where k_1 and k are constants. Furthermore,

$$S=k_2.f \quad (2)$$

if w.t is constant, hence, $k_2=k$ (w.t) and

$$S=k\ (\text{w.t.})\ f \quad (3)$$

by combining the equations 1 and 2. The stifiness parameter 'w.t.f' for both the 1 and 2-ply fabrics was calculated by using the original single's twist factor because the plying twist generally compensates for the consequent untwisting of the single. This substitution was always followed by statistical adjustment for any variation due to ply number.

Relaxation and Felting of Silk-wool Fabrics.—Coloured thread was sewn to mark out three 250 cm^2 specimens of each fabric for measuring their dry areas under a pressure of 2 g/cm^2. The specimens were tagged and submerged for 24 hr relaxation in a 0.02% soap–soda solution at room temperature. They were rinsed with distilled water, air-dried and calendered for estimating the relaxed area as before. The relaxation shrinkage was expressed as a percentage of the initial fabric area. The specimens were then manually washed for 4 hr in the alkaline liquor. They were rinsed, air-dried and calendered for usual measurement of felting shrinkage on the basis of the relaxed fabric area. The results were quite reproducible.

Results and Discussions

Relaxation.—The analysis of variance of the data (Table 1) shows a significant tex-effect on relaxation shrinkage of the silk-wool fabrics; the effect of twist factor is rather nonsignificant. Student ratio (t-test) demonstrates a significant effect of ply number. But the rapid rise of relaxation shrinkage with lower tex is quite opposite to the sense of tex-effect noted in the knitted fabrics.[3] This may be due to the difference of yarn meandering between the knitted and woven fabrics.

In conformity with the behaviour of coarse cloths studied here, the relaxation rate of 1-ply fine fabric is greater than that of its 2-ply counterpart (Table 1) but the ply-effect could be reversed significantly in yarn relaxation.[4] This discrepancy may suggest that high ply number normally increases the decrimping of wool fibre[16] as well as the fabric stiffness; the former generally increases relaxation shrinkage but the latter tends to decelerate the process. The relaxation shrinkage (R) has, therefore, been studied as a function of the stiffness index (S) in Fig. 1 empirical equation 4 can be used to predict R with a standard error of ± 2.0 units.

$$\hat{R}=19.78-0.105\sqrt{S} \quad (4)$$

Moreover, S accounts for 58.7% of the variations of R, the former varying from 114.3 to 39.1 units and the latter from 16.7 to 6.1%. The uncontrolled variations of fibre qualities and processing strain may explain the large scattering of results in Fig. 1; nevertheless, the correlation ($r=-0.766$) between R and S is highly significant. As to the physical interpretation of the correlation, most of the fabric relaxation attainable at a given temperature[17] and pH[18] occurs before its stiffening due to fibre swelling. The stiffness obviously retards subsequent relaxation that may, therefore, survive to create the problems of dimensional stability during end-uses.[19] Thus, the initial fabric stiffness, S can inhibit the relaxation shrinkage; it may also be a good guide to quality control of fabrics.

TABLE 1.—EFFECTS OF SINGLE'S TEX, TWIST FACTOR AND PLY NUMBER ON THE RELAXATION SHRINKAGE (%) OF THE SILK-WOOL FABRICS.

Nominal twist factor	Nominal tex, 1-ply			Total	Nominal tex, 2-ply			Total
	90	60	30		90	60	30	
2.5	12.8	13.8	16.7	43.3	11.3	12.9	14.3	38.5
2.0	10.8	14.2	15.0	40.0	10.7	11.8	12.9	34.4
1.7	9.2	15.5	14.6	39.3	9.7	12.1	10.4	32.2
Total	32.8	43.5	46.3		31.7	36.8	37.6	

Overall standard error, $\pm$ 0.70 / 0.56

Tex-effect $F_{2,4}=8.5$*, Significant at 95% / $=12.2$*, Significant at 95%

Twist factor effect $F_{2,4}=0.69$, Nonsignificant / $=2.74$, Nonsignificant

Ply number effect $t_{16}=1.78$,* Significant at 95% confidence level

Loose Wool, Yarn and Fabric Felting.—In harmony with observations on yarn felting,[4] the 2-ply fabrics manifest (Table 2) significantly lower felting rates than those of their 1-ply counterparts. Thus, an early report[20] of higher felting rate of woollen fabric than that of the comparable worsted fabric may imply an indirect effect due to their difference of ply number; this is because, other studies[21,22] have revealed a higher felting rate of the latter as expected from a significant effect of greater processing strain observed here subsequently. It may enhance fabric felting rate up to the extent of straining the constituent wool fibres.

The felting rates of 2-ply woven fabrics (Table 2) exhibit significant rank-correlation (r_s=1.00) with those of the corresponding knitted fabrics, untwisted singles, slubbings and raw wools, and fabrics knitted from shrink-resisted single.[8] Here, the plying and manual knitting have slightly untwisted the singles. Hence, the correlation appears to be highly significant only when the related singles are untwisted. This point agreeing well with a previous inference,[3] suggests the paramount importance of fibre quality in determining the felting rate at all the stages of manufacturing wool assemblies though it differs from an early generalisation.[9]

As observed elsewhere,[7] the significant rank-correlation between the felting rates of the normal woollen single and its woven fabric (Table 2) agreed well with the highly significant correlation between the felting rate of all the singles and that of their silk-wool fabrics. Graphical analysis of the correlation, however, revealed an inverse relationship between yarn tenacity and fabric felting rate in harmony with Speakman's point of view[23] which was originally put forward to explain an anomalous effect of fibre length. The present results (Fig. 2) show a high negative correlation between the worsted singles' tenacity (T) and square root of their fabric felting rate (F), T accounting for 88.4% of the variations of $\sqrt{F}$. The empirical equation 5 of Fig. 2 may be used to predict $\sqrt{F}$ with an accuracy of ± 0.17 unit.

$$\sqrt{\hat{F}} = 5.943 - 0.383\, T \qquad (5)$$

Comparative Significance of Tenacity and Stiffness Index.—In the 9 samples of Merino single, the correlations between tenacity, T and fabric stiffness index, S (r=0.914), between S and fabric felting rate, F (r= −0.847) and between F and T (r=−0.956) are highly significant. But the partial correlation between F and S on adjusting T ($r_{FS.T}$ = 0.225) is not significant whereas that between F and T on controlling S ($r_{FT.S}$ = −0.838) is highly significant. Hence, T is more important than S in affecting the fabric felting rate. The succeeding analysis, however, shows that S which does not need any separate measurement, could be a good estimator of the fabric felting shrinkage even though the high correlation between S and F is largely due to the strong positive correlation between T and S. Both of them may be rheologically associated with fibre strength characteristics and yarn geometry.

Ply Number, Yarn Tex and Twist Factor.—In contrast to the behaviour of the coarser fabrics (Table 2), the 2-ply fabrics of the relatively fine yarns show (Table 3) significantly higher felting rates than those of their 1-ply counterparts, the average increments of felting rate from 1 to 2 ply fabrics varying directly with the tex and twist factor. The opposing trends of ply-effect may arise from the difference of processing strain because the fixed tensions of the present plying and weaving have definitely strained the fine worsted singles much more (Hooke's law) than the coarse woollen singles. This variation of processing strain may also overwhelm the effects of yarn tex and twist factor because they are significant in 1-ply fabrics but non significant in case of 2-ply fabrics. Nevertheless, the felting rate, *per se*, always increases with lower tex and/or twist factor in agreement with previous observations on the knitted fabrics.[3]

TABLE 2.—FELTING RATE (%) OF THE INDICATED 4 WOOLS AT VARIOUS STAGES OF MANUFACTURE ALONGWITH THEIR RANK-ORDER AS BRACKETED.

Stages of Manufacture	Merino	Ryeland	Southdown	Border Leicester
Raw Wool	86.8 (1)	77.2 (3)	68.9 (4)	83.3 (2)
Slubbings	84.3 (1)	74.4 (3)	48.7 (4)	82.0 (2)
Untwisted single	45.8 (1)	35.8 (3)	33.5 (4)	40.1 (2)
Single's knitted fabric	31.4 (1)	19.3 (3)	14.9 (4)	22.3 (2)
2-Ply woven fabric	10.9 (1)	5.8 (3)	4.0 (4)	6.0 (2)
Single's woven fabric	13.7 (1)	12.2 (2)	10.4 (3)	8.4 (4)
Woollen single	37.4 (1)	28.0 (2)	24.8 (3)	20.4 (4)

Woven fabric's ply number effect, t_3=4.09*, Significant at 95% Level

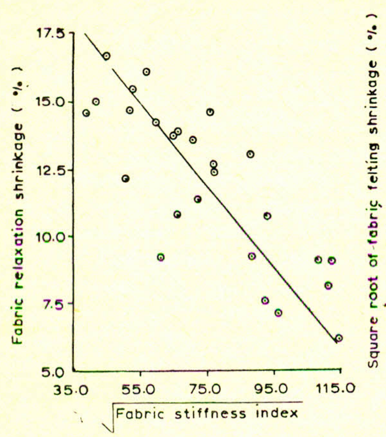

Fig. 1.-Correlation between square root of fabric stiffness index and relaxation shrinkage (adjusted for ply effect) of silk-wool fabrics; $r = -0.766$

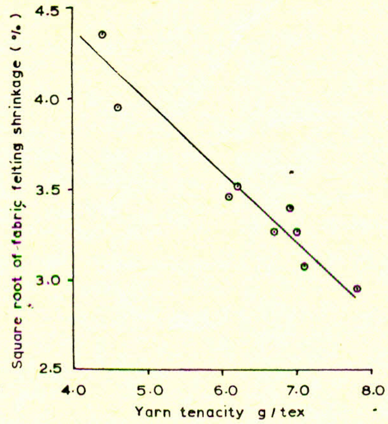

Fig. 2.-Correlation between worsted single's tenacity and square root of the corresponding fabric felting shrinkage; $r = -0.940$

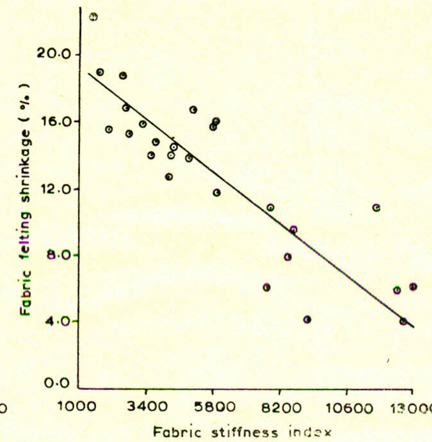

Fig. 3.-Correlation between fabric stiffness index and felting shrinkage (adjusted for ply effect) of silk-wool fabrics; $r = -0.843$

Table 3.—Influences of the Single's Tex, Twist Factor and Ply Number on the Felting Rate (%) of the Silk-wool Fabrics.

Nominal twist factor	Nominal tex, 1-ply 90	60	30	Total	Nominal tex, 2-ply 90	60	30	Total
2.5	8.6	9.4	12.2	30.2	10.8	15.6	15.8	42.2
2.0	10.7	10.7	15.7	37.1	15.9	13.8	16.8	46.5
1.7	11.5	12.0	19.0	42.5	16.6	14.4	18.7	49.7
Total	30.8	32.1	46.9		43.3	43.8	51.3	
Overall standard error, ±				0.52				1.0

Tex-effect $F_{2,4}=24.8^{**}$, Significant at 99% | $=1.66$, Nonsignificant
Twist factor effect $F_{2,4}=12.1^{*}$, Sig. | $=1.18$, Nonsignificant
Ply number effect $t_{16}=2.41^{*}$, Significant at 95% level of confidence

Stiffness Index.—The index of fabric stiffness, S shows (Fig. 3) highly significant negative correlation ($r = -0.843$) with fabric felting rate, F. This relation is paralleled by a high negative correlation ($r = -0.929$) between loose wool felting rate and specific resistance to bulk compression of a wide variety of raw wools.[24] Physically, fibre stiffness generally resists any force of bending, which is statistically estimated as the specific resistance to bulk compression. Thus, the factors affecting loose wool felting rate could be somewhat similar to those governing fabric felting rate. In addition, the empirical equation 6 of Fig. 3 can be used to predict fabric felting rate with an accuracy of ±2.74 (%).

$$\hat{F} = 19.42 - 0.0011S \qquad (6)$$

Within their present ranges of variation, S accounts for 71.1% of the variations of F. The scattering of results in Fig. 3 is quite expected from large experimental error associated with the stratifications of data according to fibre quality and processing system. Moreover, differentiation of equation 3 by parts shows that the errors of estimating the components of S tend to add together, in the worst case, when they cannot cancel out each other; such a situation increases the error of estimating the stiffness index, S.

Conclusions

Relaxation shrinkage of silk-wool fabric is largely controlled by fabric stiffness although it may be affected by the variations of yarn tex and ply number. The stiffness parameter is negatively correlated with fabric felting rate but the yarn tenacity appears to be a primary factor affecting the felting shrinkage. A strong influence of processing strain may sometimes overwhelm the usual effects of yarn tex and ply number whilst fibre quality may significantly affect felting rate of the ordered assemblies derived from slightly untwisted singles. These relations could be useful for quality control of silk-wool fabrics which, however, exhibit desirable softness, warmth and bulkiness suitable for both the summer and winter dresses.

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