Pakistan J. Sci. Ind. Res., Vol. 13, No. 4, December 1970

PLY EFFECT ON YARN SHRINKAGE DUE TO RELAXATION AND FELTING

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(Received December 26, 1969)

The relaxation shrinkage of worsted ply yarns increases with the single's ply number, twist factor and tex (yarn mass per unit length), but ply twist is unlikely to be a significant factor. Besides, the ply number has accounted for 99.9% variation of the relaxation. However, the yarn felting shrinkage usually decreases with the increase of ply number, especially, the even number. The general effect of ply number may correspond closely to that of twist factor rather than tex. Eventually, in harmony with observations on the worsted ply, a large difference of felting rates has been noted between 1- and 2- ply woollen yarns of 4 widely different wools.

Relaxation shrinkage also known as the crimp recovery of wool fibres,[1,2] occurs in the recently manufactured yarns and fabrics when they are left unstrained, especially in the wet state, due to the release of processing strains and hygral expansion. It may survive the finishing treatments to pose the problems of dimensional change during end-uses of wool fabrics.[3] Furthermore, the rigid requirements of garment-making behoove the weavers to produce definite fabric width. As a result, the relaxation shrinkage of various manufacturing lines of a raw wool are usually determined by independent trials of considerable cost. An apriori knowledge of the relaxation process is likely to reduce the number of these expensive trials, particularly, in the Pakistani mills where the Merino wool tops are imported for apparel manufacture.[4]

In addition to yarn geometry, the relaxation shrinkage may depend upon fibre length[5] diameter and crimp, probably, because the processing operations are normally adjusted according to fibre geometry. Although yarn relaxation may account for the major bulk of fabric relaxation shrinkage, the latter depends additionally on the weaving or knitting stress which, in turn, is highly influenced by yarn geometry such as tex, twist factor[6] and perhaps, ply number. These variables have, therefore, been studied by processing the same wool in order to minimise variations due to the differences of fibre attributes.

On the other hand, yarn felting shrinkage is mainly dependent on twist factor and tex. Whilst the twist shows highly significant negative correlation with yarn[7,8] and fabric[6] felting rates, the tex effect observed on fabric felting[9] is likely to be complicated by its association with fabric cover factor and the number of fibres in the yarn crosssection.[6] Moreover, literature does not appear to report any systematic study of ply number even though plying is frequently used in yarn manufacture and always it increases tex. Hence, a study of the effect of ply number on felting shrinkage seems desirable both as an end in itself and as a means of clarifying the following divergencies.[10–14]

Early works[10,11] generally demonstrated a higher felting rate of the worsted than that of the woollen fabrics produced from the same wool. This is because other studies[15–17] indicated greater fibre decrimping in the worsted than that in the woollen manufacture and the resulting uncrimping may accentuate felting rate.[8,18–20] But later works[12–14] showed a considerably higher felting rate of the single's woollen cloth than that of the comparable worsted fabric of 2-ply, and the reversal could not be cogently explained in terms of the reported differences of fibre and/or fabric attributes between them. This paradox, however, can be reconciled by assuming an effect of ply number which, therefore, deserves a thorough examination in juxtaposition with other significant parameters.

With a view to evade possible variations due to fabric structures, however, the present analysis has been restricted to the yarns. Although Mercer[12] pointed out that yarn linear shrinkage was more closely related to the typical felting behaviour of a wool than the change of fabric area or thickness, the point of view needs to be treated with certain reservations. Nevertheless, a knowledge of ply felting rates may be useful for quality control in some wet finishing operations such as back-washing, dyeing and shrink-proofing which are often convenient to execute at the yarn stage.

Experimental

A Merino wool of fibre fineness 20.4μ and length 9.0 cm was processed almost identically in the shortened Bradford system and spun in a Magnum Spinning Frame in which the doubling and draft were adjusted to produce singles of nominal tex/twist factor—90/2.5, 90/2.0, 90/1.7, 60/2.5, 60/20 and 60/1.7. They were aged for at least 1 year before ply-making. Each single was manually twisted into 2,3,4,5 and 6 strands of approximate length 3 metres. All plies were allowed to snarl for attaining a steady state of equilibrium.

Worsted Ply Relaxation.—Every ply was marked out into 10 specimens separated by knots at test lengths of about 15.0, 17.5, 20.0, 22.5, 25.0, 27.5, 30.0, 32.5, 35.0 and 37.5 cm. The test length graduation helped easy identification of the specimen. Satisfactory reproducibility of the results was obtained by measuring the specimen length under a tension of tex/5 against a vertical scale in a natural atmosphere. The specimens were all submerged in distilled water at about 27°C for 24 hr and then air-dried to estimate the relaxed length L'. The relaxation shrinkage, R of an initial length L was calculated as follows:

$$R = \frac{L - L'}{L} \times 100 \tag{1}$$

The Ply Twist.—The single's helical loops (H) were clearly visible on the ply surface and counted by visual inspection over the entire relaxed length of a specimen to estimate its ply twist per unit length, t as

$$t = \frac{H}{N.L'} \tag{2}$$

where N is the ply number. The ratio of single to ply twist in each of the 6 samples, varying in the range from 4.0 to 3.5, was considered fairly constant for most practical purposes.

Worsted Ply Felting.—The relaxed specimen was enclosed individually inside a 225 denier 45-filamen Terylene tube of diameter 2 cm and stitch length, 0.5 cm. The 50 specimens thus obtained for every sample, were washed together in a 0.2% soap-soda (50–50) solution using 1:20 (w/w) wool: liquor at a room temperature of about 26°C. Initially, the sample indicated as 90/2.0 was subject to 15-min washing by 300 hand-squeezing which produced a very low amount of felting shrinkage whereupon extraneous factors could overwhelm the variables under study. The other 5 samples were, therefore, washed individually for 1 hr by employing 1200 hand squeezes. The felted specimen was carefully cut out of the tube and air-dried to determine its length Lf as usual. The felting shrinkage; Y was then calculated as follows:

$$Y = \frac{L' - Lf}{L'} \times 100 \tag{3}$$

Besides, the single 60/2.5 was laid into 3-ply using 3.2 turns per cm. From both the single and 3-ply 30–15 cm test lengths were measured out separately after their usual relaxation. The specimens were enveloped individually by the Terylene tube and washed together. After 100 squeezes, 5 specimens were taken out from each of the 1-and 3-plies to estimate their felted length. But their enclosures were added to replenish the washing load. The operation was repeated after 200, 400, 800, 1600 and 3200 squeezes to observe any time-dependent ply felting behaviour.

Eventually, the influences of single's tex and twist factor were studied by a separate test in which even number plying was carried out but the twisted ply was always drawn twice from one end to the other by means of a cloth in order to redistribute the twist. The results obtained by the usual 1 hr washing are set out in Table 3.

Woollen Ply Felting.—An woollen ring spinning frame produced singles of nominal tex 200 and 2.4 turns per cm from Merino, Southdown, Border Leicester and Ryeland wools which were considered typical of the Fine, Down, Long and Carpet types. After 2 years, each yarn was laid into 2-ply with 79.8 turns per metre. At least 10 specimens were derived from each of the 1- and 2-plies, relaxed and separately enclosed by the tube as before. All specimens were felted together by 1600 hand squeezings at the then room temperature, 21°C.

Finally, the handwashing test has the advantage of reducing any error due to a cumulation of heat[22] which is likely to arise from a prolonged washing in domestic type machines. Thus a low error of the present measurement demonstrates satisfactory reproducibility of the results. The technique is not only simple but also inexpensive.

Results and Discussion

It is worthwhile to note that in commercial plying the variation of bobbin tension within a machine may be a source of error that has been controlled largely in the hand-plying. In addition, successive adjustments of the same machine and usual difference between machines could introduce considerable variations in ply shrinkages. Nevertheless, any generalisations abstracted from a set of observations, manifesting no significant interactions as indicated succeedingly, can be normally transferred from one plying situation to another, perhaps, from hand-plying to industrial conditions as well.

Relaxation Shrinkage.—The single's ply number, when adjusted for any possible effect due to ply twist by a convariance analysis,[23] shows significant influence on the relaxation shrinkage (Table 1). An examination of the mean sum of squares suggested that both the shrinkage and ply twist varied significantly with ply number even before the adjustment. Hence, the variation of relaxation is mainly attributable to the differences of ply number. Consequently, the coefficient of correlation between ply twist and the shrinkage, though always negative, is generally non-significant save in one sample, 90/2.5 which recorded the highest single's twist factor of 2.7[8] that is unlikely to be used in normal worsted spinning. The usual twist factor tends to distribute within the range from 2.5 to 1.5. Although the tex range, from 90 to 60 may comprise the coarse yarns only, the twist factor range, 2.5 to 1.7 would nearly represent the entire range of worsted spinning to which the present analysis is likely to appertain.

Table 1 further shows the mean relaxation of each ply together with standard error of the difference between any two ply means and coefficient of variation of grand mean shrinkage for individual sample. Thus the effect of ply number can be compared with those of single's tex and twist factor within their indicated ranges. Twist factor effect seems about 3/2 times greater than the tex effect in conformity with another observation on single's relaxation in a much wider range of variation encountered in practical situations.[8] Since the relaxation or crimp recovery is normally a direct measure of crimp removal; the ply number, twist factor and tex may decrimp wool fibres in descending order of their importance.

Figure 1 illustrates an excellent relation between ply number (N) and the shrinkage (R) when the effects of twist factor and tex are averaged over all the 6 samples. The equation 4 of the graph, derived empirically for the least square estimator ($\hat{R}$),

$$\hat{R}=2.694+4.424 \log N \tag{4}$$

accounts for 99.9% variations of the shrinkage ranging from 2.7 to 6.1%, in terms of the ply number varying from 1 to 6. This relation seems to be useful to the manufacturer who should take into account the fact that the indicated linear shrinkage may occur along the 2 dimensions of a cloth area.

Eventually, the observed tex effect could survive to affect fabric relaxation in the same sense although the twist factor effect may be reversed[6] due, possibly, to the relatively lower strain of knitting the stronger singles and/or greater restriction of fabric structure; both of them tend to increase with twist factor. Indeed, the restrictive influence of twist factor when coupled with fabric tightness could be highly effective means of inhibiting crimp recovery, particularly, because the fibres are

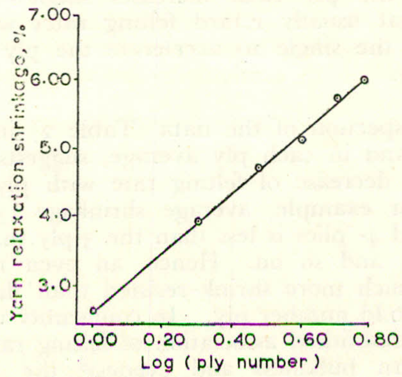

Fig. 1.—The influence of single's ply number on the relaxation shrinkage of the Merino worsted yarns.

TABLE 1.—VARIATION OF RELAXATION SHRINKAGE WITH SINGLE'S TEX, TWIST FACTOR, PLY NUMBER AND PLY TWIST.

Sample	Nominal tex/twist factor	Ply twist per metre	Geoff of corr. Bet. P. twist & rel. shrinkage	Var. ratio of P. shri. on adjusting p. twist, $F_{4, 44}$	Mean rel. shrinkage % in ply number 1	2	3	4	5	S.E. of diff. bet. 2 means, ±	CV % of grand mean shrinkage
1	90/2.5	90.6	—0.425**	8.4**	5.1	6.7	7.6	7.8	8.2	0.46	15.2
2	90/2.0	70.9	—0.170	2.8*	4.8	5.8	6.0	6.4	6.4	0.50	18.9
3	90/1.7	55.2	—0.093	6.1**	2.5	3.1	3.9	4.6	4.2	0.46	27.5
4	60/2.5	102.4	—0.139	10.3**	4.5	4.7	5.6	7.1	7.5	0.63	24.3
5	60/2.0	86.7	—0.122	7.6**	3.7	4.0	4.9	4.7	5.2	0.43	20.6
6	60/1.7	78.8	—0.127	2.8*	3.3	4.7	4.5	4.4	5.0	0.53	21.6
	90–60	Tex difference on averaging twist factor			0.3	2.2	2.5	2.6	1.1		
	2.5–1.7	Twist factor difference on averaging tex			1.9	1.8	2.4	2.9	3.2		

*and** Imply statistical significance at the 5% and 1% levels respectively.

constrained and set into artificial crimp on yarn surface under the influence of twist factor.[15] Thus the twist factor may exhibit dissimilar effects on the relaxation of yarn and fabric.

Worsted Ply Felting.—In order to ascertain the statistical significance of the small decrease of felting rates with ply number, an analysis of co-variance (Table 2) seems reasonable. The non-significant variance ratio of the sample 90/2.5 whose single had been twisted beyond the upper limit of normal worsted spinning, suggests the significance of ply twist rather than ply number. But a non-significant variance ratio (*F*) for the sample 60/1.7 is attributable to its largest error of measurement (*S.E*) as expected from handling thinner yarn of the lowest twist factor. These inferences are unlikely to negate the highly significant *F*-values registered by the other 4 samples since the coefficient of correlation between ply twist and felting rates is always non-significant too. Consequently, the difference in felting shrinkage is mainly due to the variation of ply number rather than ply twist. This is probably because the ply twist increases single's helical loops that usually retard felting rates whilst it untwists the single to accelerate the ply felting tendency.

An inspection of the data (Table 2) in every sample and in each ply average, suggests a differential decrease of felting rate with ply number. For example, average shrinkage (35.5%) of 2- and 4- plies is less than the 3-ply shrinkage (37.8%) and so on. Hence, an even number ply is much more shrink-resisted than the comparable odd number ply. In conformity with an almost established association of felting rate with both yarn bulkiness and eveness[8] the present outcome indicates that an even number ply tends to be rougher and bulkier than the odd number one.

Time-dependent Ply Felting.—The felting rates of 1- and 3- ply worsted yarns are illustrated in Fig. 2 at various washing levels ranging from 100 to 3200 hand-squeezing. In harmony with a previous finding[6] both plies exhibit 2 different felting rates with the washing time. In addition, the single always displays a higher felting tendency than that of the 3-ply and certainly, a much higher felting rate than the comparable 2-ply rate (Table 2). Although a maximum difference of shrinkage between the two plies (Fig. 2) is recorded around 400 squeezes, the difference falls off more rapidly at the initial stage of low washing than that at high washing level. This could be one of the reasons for elusive nature of the effect due to ply number since the woollens are normally washed by mild agitation in practical situations.

Ply Felting and Single's Geometry.—In agreement with the behaviour of fabrics[6] and a wide variety of singles[8] the results in Table 3 indicate a positive

TABLE 3.—EFFECTS OF SINGLE'S TEX AND TWIST FACTOR ON PLY FELTING RATES.

Ply number all even	Felting shrinkage (%) in the indicated samples			
	90/2.5	90/1.7	60/2.5	60/1.7
2	40.1	45.4	36.9	43.2
4	39.7	43.6	36.8	42.6
6	37.5	38.5	35.6	36.8

90—60 Tex Difference=2.2 units on averaging twist factor effect.

2.5—1.7 T.F. Diff.=3.9 units on averaging tex effect.

TABLE 2.—VARIATION OF YARN FELTING RATE WITH PLY NUMBER AND TWIST.

Sample no. as in Table	Coeff. of corr· bet. p. twist and felting rate	Variance ratio of P. felting (F4,44) on adjusting P. twist	Mean felting shrinkage, % in ply number					S.E. of difference bet. 2 means, ±	CV (%) of grand mean felting
			2	3	4	5	6		
1	0.204	2.2	42.0	40.3	40.3	42.2	38.0	1.44	7.9
2	0.223	21.5**	16.9	16.1	11.3	10.8	9.0	1.02	17.8
3	-0.063	5.2**	46.0	45.5	41.8	43.3	41.5	1.27	6.5
4	0.174	14.1**	39.7	40.8	35.9	34.6	32.7	1.29	7.8
5	0.051	18.5**	41.2	49.3	44.1	44.0	40.4	1.14	5.8
6	-0.136	1.9	31.5	34.9	35.1	32.7	35.4	1.73	11.3
	All average		36.2	37.8	34.6	34.8	32.8	—	—

**Significant at the 1% level.

TABLE 4.—DISTRIBUTION OF WOOLLEN YARN FELTING SHRINKAGE (%) WITH PLY NUMBER AMONG THE 4 DIFFERENT WOOLS.

Ply number	Merino			Ryeland			Border Leicester			Southdown		
	Mean±	S.E.	CV,%	Mean±	S.E.	CV,%	Mean±	S.E.	CV, %	Mean±	S.E.	CV, %
1	37.1	1.15	9.8	28.9	0.94	10.3	21.5	1.08	15.9	20.4	0.49	7.6
2	13.9	0.97	22.0	10.3	0.75	22.8	8.7	0.51	18.4	6.8	0.68	31.5
Difference	23.2			18.6			12.8			13.6		

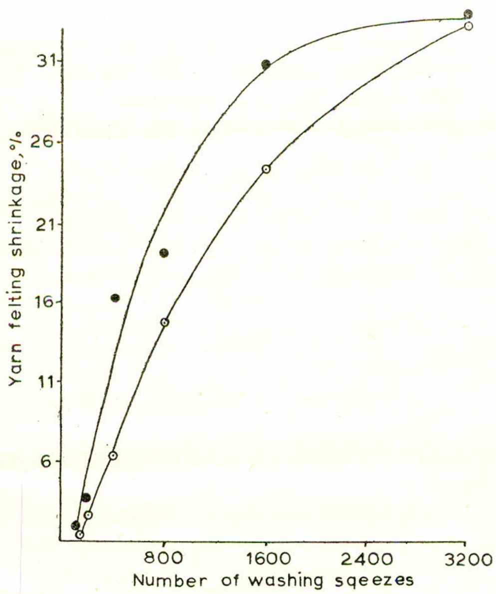

Fig. 2.—Relationship between number of washing squeeze and felting shrinkage in 1 (●) and 3 (◉) ply worsted yarns.

correlation of ply felting rate with single's tex and a negative correlation of the former with the twist factor. The comparison of felting rate differences produced by tex and twist factor within their present ranges shows the latter to be more important than the former.

Woollen Ply Felting.—The outstanding outcome of this analysis is the largest difference of ply felting shrinkage manifested between the woollen 1- and 2- ply (Table 4) as noted in the worsted plies. The difference of felting rates between the plies is positively correlated with the yarn felting propensity of the 4 different wools. These results appear to be transferable to similar industrial situations since a positive correlation between the actual felting rates exhibited by 1- and 2- ply yarns of the diverse wools, clearly demonstrates the lack of significant interaction effect of ply-making and breed type. The large reduction of the shrinkage from an average of 27.0% in the singles to 9.9% in 2-ply, appears to be more useful than a recent modification of fabric width shrinkage from 15.0% to 6.3% which was achieved by administering chemical additives to sheep's diet[24] that could be poisonous to the animal and detrimental to the growth and quality of wools.

Conclusions

Ply relaxation generally increases with the single's ply number, twist factor and tex, perhaps, implying a diminishing order of their importance in fibre decrimping. The ply twist, which untwists a single during constraining it into helical shape, is unlikely to be significant factor in governing either relaxation or felting shrinkage. Similar to the single's felting behaviour[8] ply felting rate varies inversely with the single's twist factor and directly with its tex. Furthermore, the felting shrinkage tends to diminish with the increase of ply number, particularly, the even number. This tendency seems to disappear at extremely low and high levels of washing. But both in the worsted and woollen manufactures, 2-ply shows remarkably lower felting rate than that of the corresponding single. This may not only provide a means of further understanding the previous results[12,14] but is also a guide to the manufacturer.

Acknowledgements.—The author is thankful to Messrs Sydney Woollen Mills Ltd for assistance in single yarn manufacture and to Mr. F.K. Khan, PCSIR Laboratories, Rajshahi for his help in the experimental works. Also, the wise encouragements of Dr. N. A. Khan, Director of these laboratories, is highly appreciated by the author.

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