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EFFECT OF LAUNDERING ON THE DIMENSIONAL STABILITY AND DISTORTION OF KNITTED FABRICS

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Abstract

Three popular 100% cotton knitted fabrics, (plain single-jersey, 1x1 rib and interlock) were subjected to five cycles of four different washing and drying regimes. This was in order to investigate the effect of laundering with detergent as opposed to water, and tumble drying against line drying. The main aim of this work was to systematically investigate the effect of the principal washing and drying variables on the dimensional stability and distortion of knitted fabrics. The work demonstrated that changes occurring after laundering were largely due to alterations in the loop shape, rather than yarn or loop length shrinkage. The fabrics had taken up their fully relaxed dimensions after five wash and dry cycles and appropriate conditions for laundering had been applied, as no significant yarn stitch length or linear density changes occurred.

Further research work was conducted to investigate and thus isolate the area of the laundering cycle causing the most dimensional changes and distortion in knitted fabrics. Three 100% cotton knitted fabrics, plain single-jersey, lacoste and interlock, were investigated during this stage of research. These fabrics were subjected to five cycles of different washing and drying regimes which isolated the wash, rinse, spin, agitation during drying and the effect of heat during drying. The work demonstrated that changes occurring after laundering were largely caused due to the agitation during tumble drying. The agitation was found to have caused 34% of the changes during laundering, followed by the spin cycle during washing, which caused 24% of the dimensional changes and distortion.

Introduction

It is well known that weft knitted fabrics tend to undergo large changes in dimensions and are often prone to distortion upon repeated laundering. A large number of factors are responsible for causing these undesirable effects in knitted structures; these are all associated with the yarn, knitting, finishing and making-up of the fabrics. It is also a fact that consumers are becoming increasingly concerned and aware of fabric quality and expect higher standards of performance than ever before, even after a number of wash and dry cycles.

Knitted cotton fabrics possess certain qualities to allow garments to fit closely and snugly, making them ideal for next-to-skin wear (1). However, knitted fabrics are prone to stretching and mechanical deformations (2); this is due to the fact that the yarns are put under a high stress factor whilst the fabric is being produced and finished. These torsion forces within the yarns are present when the fabric is taken off the machine and the fabric is left in a highly distorted state (3). Knitted fabrics often never fully recover from these strains and have to withstand the considerable wear and tear due to everyday use and laundering processes (4).

To meet the demands of an increasingly discerning market, knitters have called for increased research into the dimensional stability of knitted cotton goods (4). With the rising popularity of cotton, greater demands in terms of quality were required as the customer became more aware of the negative properties, e.g. shrinkage from laundering (4). The properties of cotton are limited due to its natural origins (5), therefore, if the consumer continues to expect higher quality and dimensionally stable garments, the actual construction of the fabric needs to be investigated.

Another problem manufacturers have to contend with is the factors affecting variability in customer washing processes. Munshi et al. (4) compiled the following list:

1) No two persons wash identically.

2) Different detergents are invariably used.
3) No two localities have identical water.
4) Water temperature often varies.
5) No two washing machines are identical.
6) No two loads are the same.

The prediction of washing performance is therefore an enormous task. It requires an in-depth knowledge of the geometry, stability and forces held within the fabric. Knitted fabrics are inherently difficult to stabilise, as the construction allows for contraction of up to 40%. The commercial knitter will therefore benefit from any research into the dimensional behaviour and techniques of predicting stable dimensions (4).

The major aims of the research were, therefore, firstly to systematically study the effect of principal variables on the dimensional stability and distortion of knitted fabrics; and secondly, to study the mechanism of shrinkage and distortion both empirically and theoretically of knitted fabrics upon repeated laundering. From this, a preliminary investigation into the effect of home laundering was devised by initially looking at the main variables contributing to fabric shrinkage and distortion.

The variables included firstly testing with detergent against water alone, and secondly tumble drying against line drying. Plain single-jersey, 1x1 rib and interlock cotton fabrics were subjected to systematically controlled laundry regimes in order to quantify the relative contribution, if any, of each of the variables. The regimes and codes are described in Tables 1 and 2.

Table 1: Laundry regimes - stage 1

REGIME	CODE
0) Fully finished parameters	**FF**
1) Water wash with line drying	**WL**
2) Detergent wash with line drying	**DL**
3) Water wash with tumble drying	**WT**
4) Detergent wash with tumble drying	**DT**

Table 2: Fabric coding system

CODE	STRUCTURE	WASH	DRY	CYCLE NO.
PWL0	*Plain*	Water wash	line	0
RDT4	Rib	Detergent wash	tumble	4
IWT2	Interlock	Water wash	tumble	2

Birkett (6) has stated that “up to about five cycles, there are relatively large differences between different fabrics; beyond five cycles the changes in dimensions are small and for most practical purposes can be ignored”. Therefore, each fabric type was subjected to five cycles of each regime (labelled as 0-5). For accuracy, specimens were duplicated and analysed after being fully conditioned for 48 hours.

The second stage of the research project was concerned with the isolation of the wash, rinse, spin, agitation during drying and the heat applied during drying into five separate stages of the full laundering process. The different regimes studied in order to enable each stage of laundering to be isolated are given in Table 3. Again, each fabric type was subjected to each given regime five times.

The ultimate aim of the ongoing research project is to formulate a generalised model to predict, determine and control fabric stability upon washing and drying. This will enable recommendations to be made to the sponsoring company as regards possible modifications to the design and programming of their washing and drying equipment. This paper reports and discusses the results of a part of the work carried out to date.

Experimental methodology

Materials and machinery

Commercially finished fabrics used by a leading high street store were obtained from an outside source. The three fabrics investigated during the first stage of the work were 100% cotton plain single-jersey, 1x1rib and interlock structures. In the second stage of the research plain single-jersey, lacoste single-jersey and 1x1 interlock fabrics were used. In the second stage of the research, the 1x1 rib fabric was replaced by lacoste single-jersey as the results from the latter structure were thought to be more critical for laundering because of its complex single-jersey construction. The fabrics were fully analysed after 48 hours' conditioning to obtain the fully finished constructional parameters (FF). The results are given in the Appendix.

Table 3: Laundry regimes – stage 2

1) wash, rinse, spin, tumble dry- to confirm the combined effect of the full cycle
Regime (1)
2) wash, rinse, spin, flat dry- to determine the effect of the rinse cycle
Regime (3) minus (6)
3) rinse, spin, flat dry - to determine the effect of the wash cycle
Regime (2) minus (3)
4) rinse, spin, tumble dry-to determine the effect of the agitation during tumbling
Regime (4) minus (3)
5) rinse, spin, flat hot dry-to determine the effect of the heat during tumble drying
Regime (5) minus (3)
6) fill, spin, flat dry - to determine the effect of the spin mechanism
Regime (6)

The laundering equipment used included an AATCC approved Kenmore Super Capacity washer and a Kenmore Super Capacity Plus dryer. When washed, the fabrics were washed on a normal fabric setting (as opposed to heavy-duty or delicate) on a warm setting, averaging 42°C. When rinsed the fabrics were rinsed in cold water. In stage 1, the fabrics were either tumble-dried for 60 minutes on the cotton setting averaging 75°C, or line dried for 24 hours. In stage 2 the fabrics, if dried, were either tumbled or placed flat on a rack in the tumble dryer for 60 minutes. The wash load was kept constant at a 3.6kg load. To ensure that accurate results were obtained, it was also necessary to establish that the level of water hardness used to wash the fabric samples was of a uniform standard. This was achieved by adding the appropriate amount water hardness stock solution, to bring the water hardness up to a consistent level of 155 parts per million.

In stage 1 the wash load consisted of 30 samples, 10 of each fabric structure. The mass of the load was made up to 3.6kg by a ballast of similar-sized knitted cotton squares. As specimens were removed after each wash cycle, more squares were added to maintain the load mass. Detergent suitable for the washing machine type (top-loader) was obtained from the USA; this was the commercially available Tide with Bleach.

Specimen preparation and test methods

Fabrics were fully conditioned for 48 hours in a standard atmosphere of 20 ± 2^{o}C and 65 ± 2% relative humidity. The specimens to be tested for dimensional stability and skewness were prepared as recommended in the AATCC Test Method 150-1995 'Dimensional Changes in Automatic Home

Laundering"’and 179-1996 ’Skewness Change in Fabrics and Garment Twist Resulting From Automatic Home Laundering‘. The specimens were also prepared so that a test for spirality could be carried out. This involved using the ’open pillowcase‘ construction, which enabled seam overlap to be measured and hence the angle of spirality to be determined.

Evaluation techniques

Once the various laundering regimes had been carried out, the fabrics were again conditioned for a period of 48 hours before any analysis took place. Full fabric analysis of the fabric specimens was carried out, following 48 hours’ conditioning, after each regime in stage 1. This involved determining the parameters shown in Table 4. By plotting each of the variables against the number of washes, the different regimes could be compared against each other on the same graph. This was to distinguish which of the regimes caused the most changes from the original finished state figures.

In stage 2, the fabric specimens were all analysed and evaluated for dimensional stability (length and width direction), skewness, spirality and loop shape factor changes. The percentage changes occurring for each of the properties were then calculated. A multivariate analysis technique was used to determine the overall change caused after five cycles due to each individual stage of the laundering programme.

Table 4: Determination of fabric dimensions and properties; denotations and units

1. Courses per cm	c, cm^{-1}
2. Wales per cm	w, cm^{-1}
3. Stitch density	s, cm^{-2}
4. Stitch length	l, mm
5. Yarn linear density	tex
6. Fabric tightness factor	K, tex$^{1/2}$l^{-1}
7. Actual fabric area density	gm^{-2}
8. Theoretical fabric area density	gm^{-2}
9. Percentage difference between 7 and 8.	%
10. Dimensional stability	length %
11. Dimensional stability	width %
12. Skewness	%
13. Spirality angle	degree ^{o}
14. kc (constant)	c x l
15. kw (constant)	w x l
16. ks (constant)	s x l^{2}
17. Loop shape factor (Poisson’s ratio)	c/w or kc/kw

Results and Discussion – Stage 1

Stitch length

Stitch length remained more or less constant after the fabrics were subjected to the four different washing and drying regimes as shown in Figure 1. This was the case in all three structures. This confirmed that the fabrics were washed according to the conditions appropriate to the fibre type used in these fabrics. Therefore, the changes in fabrics’ dimensions and properties were largely caused due to changes in loop shape rather than loop length. The distortion was a result of distortion in the loops themselves and not in yarn structure. This also confirmed that the classical geometrical relationships applied, even after washing and drying treatments. The mean stitch lengths together with 95% confidence limits are shown in Table 5 for all three structures.

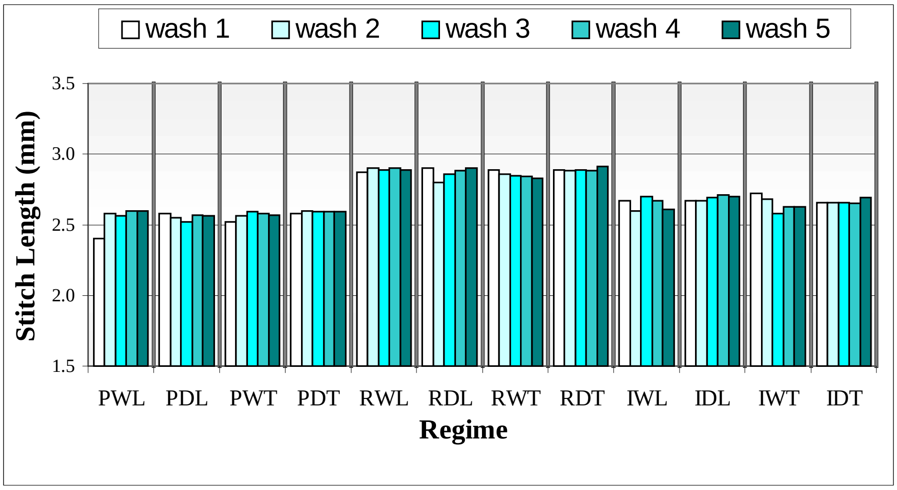

Figure 1: Effect of laundering (five cycles) on stitch length

Table 5: Stitch Length Values After Five Cycles (mm)

	FF	WL	DL	WT	DT	STANDARD ERROR OF MEAN	MEAN ± 95% CL
Plain	2.65	2.60	2.56	2.57	2.59	0.01	2.58 +/- 0.02
% change	-	-1.90	-3.40	-3.00	-2.30		
Rib	2.90	2.89	2.90	2.83	2.91	0.02	2.88 +/- 0.04
% change	-	-0.30	0.00	-2.40	0.30		
Interlock	2.70	2.61	2.70	2.63	2.69	0.02	2.66 +/- 0.04
% change	-	-3.30	0.00	-2.60	-0.40		

Linear density

Changes in yarn linear density after five washing and drying cycles were also insignificant in all three structures. This also confirmed once more that the majority of dimensional changes in the fabric samples must have been caused due to changes occurring in the loop shape rather than loop length as shown in Figure 2. It is well known that the loop shape alters significantly upon repeated washing and drying treatments, due to the loop distorting and bending out in the third dimension. This occurs as the loops attempt to take up their minimum internal energy state or stable state (1). Again, the mean yarn linear densities obtained together with 95% confidence limits are shown for the three structures in Table 6.

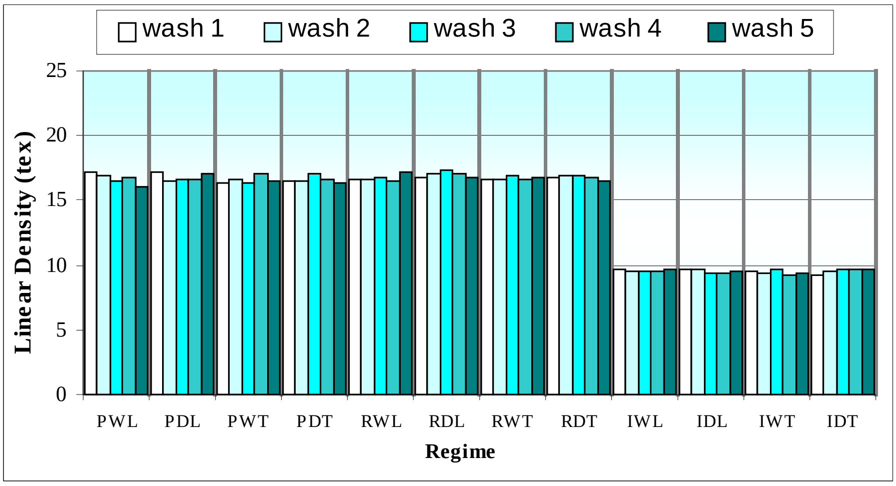

Figure 2: Effect of laundering (five cycles) on linear density

Table 6: Linear density values after five cycles (tex)

	FF	WL	DL	WT	DT	STANDARD ERROR OF MEAN	MEAN ± 95% CL
Plain	17.00	16.04	17.00	16.51	16.37	0.20	16.48 +/- 0.40
% change	-	-5.60	0.00	-2.90	-3.70		
Rib	16.60	17.17	16.77	16.76	16.52	0.14	16.81 +/- 0.28
% change	-	3.40	1.00	0.90	-0.50		
Interlock	9.50	9.60	9.53	9.33	9.64	0.07	9.53 +/- 0.14
% change	-	1.10	0.30	-1.80	1.50		

Loop shape factor

Table 7 illustrates the changes brought about by the different wash regimes on the loop shape factor or Poisson's ratio in the three different structures. In plain single-jersey, the effect of tumble drying was evident because the loop shape factor changed from 1.24 to 1.36 for the water wash-tumble and 1.26 to 1.35 for the detergent wash-tumble. This also indicated that that the detergent had virtually no effect upon the loop shape.

Table 7: Loop shape factor values after five cycles

	FF	WL	DL	WT	DT	STANDARD ERROR OF MEAN	MEAN ± 95% CL
Plain	1.40	1.24	1.26	1.36	1.35	0.03	1.30 +/- 0.06
% change	-	-11.43	-10.00	-2.86	-3.57		
Rib	1.45	1.65	1.65	1.62	1.66	0.01	1.65 +/- 0.02
% change	-	13.10	13.10	11.72	14.48		
Interlock	1.16	1.16	1.15	1.16	1.15	0.01	1.16 +/- 0.09
% change	-	0.00	-0.86	0.00	-0.86		

In both 1x1 rib and 1x1 interlock structures, the loop shape was almost constant for all four washing and drying regimes. This indicated that the loops had taken their least energy state or stable state in each wash and dry regime. The most important and significant conclusion drawn from Table 7, is that plain single-jersey, 1x1 rib and 1x1 interlock structures have attained their fully relaxed state after five wash and dry cycles. This is because the values achieved are extremely close to those reported by a number of other researchers, as shown in Table 8.

Table 8: Previously reported shape factor values

Plain **Single-Jersey**	**Present Work** **1.3 +/- 0.06**	Sharma(7) 1.32 +/- 0.07	Postle(8) 1.3	Anand (9) 1.3
1x1 Rib	**Present Work** **1.65 +/- 0.02**	Natkanski (10) 1.69	Knapton(11) 1.76	Smirfitt(12) 1.68
Interlock	**Present work** **1.16 +/- 0.09**	Anand (9) 1.15		

Dimensional stability (length)

It was expected that the results obtained for the dimensional stability tests carried out would be significantly different for the three fabric structures, due to the distinct nature of each structure. A positive dimensional stability test result indicates an increase in length, which represents length extension. A negative value represents a decrease and hence shrinkage.

The results obtained for the plain fabric specimens in Table 9 indicated that there was a significant difference between line drying and tumble drying for plain single-jersey. The tumble-dried specimens produced shrinkage in the length direction, whereas the line dried samples displayed extension in length. The water/line-drying regime caused more extension than the detergent/line regime, whereas detergent/tumble drying tended to produce higher shrinkage results than the water/tumble dried regime. It would therefore appear that washing with detergent caused higher shrinkage in the fabric length than with water alone.

Table 9: Percentage Length Shrinkage After Five Cycles

	FF	WL	DL	WT	DT	COEFFICIENT OF VARIATION (%)
Plain	0	1.90Ex	1.30Ex	-4.80	-6.40	67.00
Rib	0	-4.30	-7.90	-8.80	-11.50	36.53
Interlock	0	-4.00	-4.40	-8.60	-10.30	45.53

Higher length shrinkage values obtained for tumble-dried specimens in all three structures illustrated the severity of the tumble drying process. The loops were slowly agitated during drying, which resulted in their taking up a minimum energy state configuration, otherwise known as a fully relaxed, stable or reference state.

Dimensional stability (width)

The dimensional stability tests carried out in the width direction for the plain fabric samples showed similar trends for all four regimes. The maximum shrinkage took place after the first wash cycle, and thereafter virtually no change in width dimensions occurred upon further washing treatments. The overall dimensional stability results shown for the width direction indicated that there was a significant difference between regimes and structures, and are therefore very important to this investigation (see Table 10). The elastic nature of 1x1 rib was evident here, as the figures in Table 10 for line drying show extension rather than shrinkage; therefore the coefficients of variation show significant differences between the three structures.

Table 10: Percentage width shrinkage after five cycles

	FF	**WL**	**DL**	**WT**	**DT**	**COEFFICIENT OF VARIATION (%)**
Plain	0	-8.30	-9.90	-10.40	-9.90	9.45
Rib	0	8.00Ex	9.80Ex	-2.00	-3.00	66.49
Interlock	0	-11.50	-9.30	-14.40	-11.30	18.06

Skewness

The results obtained for the skewness tests after five cycles are given in Table 11 and Figure 3. The results indicated that there were significant differences between the three structures investigated. Plain single-jersey specimens produced large percentages of distortion; the average final value of percentage skewness was 8.1%. The main reason for this is because the structure is highly unbalanced. The forces created by interlacing loops are substantially different on the technical face and technical back due to the fact that loops are continuously formed in one direction only. This creates different forms and levels of forces on the two fabric faces. The main reason for achieving lower values of distortion in both 1x1 rib and interlock fabrics was that both structures are perfectly balanced.

The rib fabrics exhibited lower skewness values than the plain single-jersey fabrics, with an average value of 2.8%, whereas the interlock specimens appeared to be most stable as they achieved the smallest percentage skewness of 2.2% on average. These results demonstrated that both the double-jersey structures used were perfectly balanced, and hence produced low values of skewness after laundering.

Table 11: Percentage skewness values after five cycles

	FF	**WL**	**DL**	**WT**	**DT**	**COEFFICIENT OF VARIATION (%)**
Plain	0	9.70	5.30	8.60	8.80	23.83
Rib	0	5.20	3.50	2.70	0.00	76.14
Interlock	0	0.90	4.20	0.50	3.10	81.19

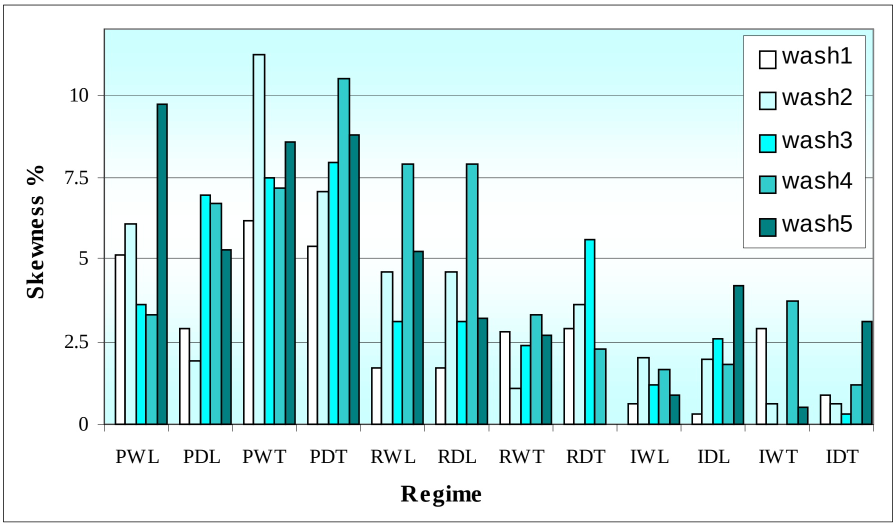

Figure 3: Effect of laundering (five cycles) on skewness

Spirality

The spirality angle results shown in Table 12 and Figure 4 demonstrated similar trends to the skewness distortion results already discussed in Section 3.6. The plain single-jersey specimens showed higher angles of spirality, the average angle being 5.75°, with no clear trend among the regimes. The rib structure proved to be more stable in this aspect as it displayed extremely low degrees of spirality. The interlock structure showed slightly higher spirality angles due mainly to the water/tumble-dried regime. Again for detergent/tumble-dried specimens, no spirality angles were recorded, showing no wale distortion at all for interlock samples. Again, this phenomenon is largely due to the balanced configuration of the interlock structure. These results confirm that distortions (skewness as well as spirality) are mainly prevalent in single-jersey structures.

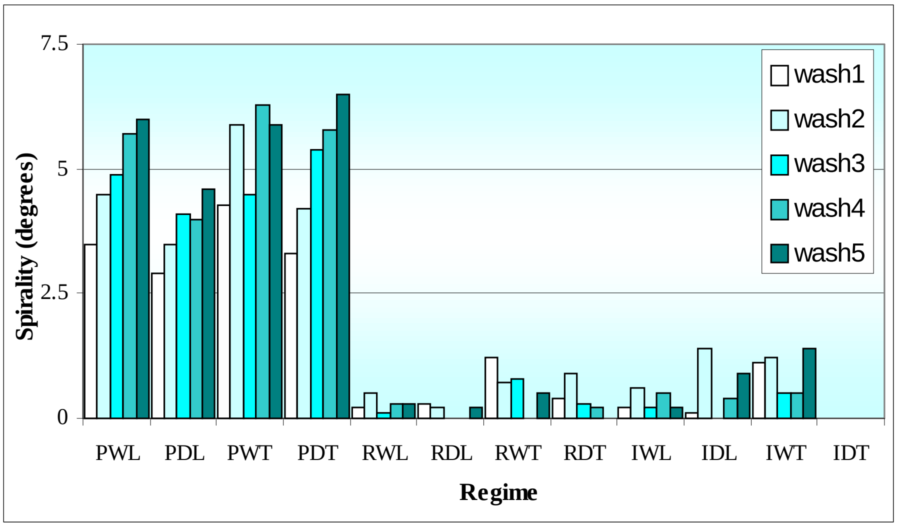

Figure 4: Effect of laundering (five cycles) on spirality

Table 12: Spirality angles (degrees) after five cycles

	FF	WL	DL	WT	DT	COEFFICIENT OF VARIATION (%)
Plain	0	6.0	4.6	5.9	6.5	0.22
Rib	0	0.3	0.2	0.5	0.00	0.12
Interlock	0	0.2	0.9	1.4	0.00	0.06

Results and Discussion – Stage 2

This part of the investigation enabled the following five stages of laundering to be examined individually:

1. initial wash,
2. rinse,
3. spin,
4. heat in the tumble dryer, an,
5. agitation in the tumble dryer.

The overall objective was to quantitatively ascertain the influence of each major part of the laundering cycle on fabric dimensional properties and distortion.

Loop shape factor

The results shown in Figure 5 indicated that the wash cycle only caused a significant change in the loop shape factor in the case of interlock structure. The highest percentage change during the whole laundering process occurred here in the interlock structure, indicating that the wash cycle played the most significant part in relaxing the interlock structure. The rinse cycle caused an average change of +2.6% in the three fabrics tested; however, the spin cycle caused the opposite effect to this with an average change of -4.6%. This suggested that the spin cycle left the fabrics in the most unbalanced state. The heat applied during drying tended to cause a negative percentage change in the single-jersey fabrics, more so in lacoste than in plain single-jersey. The interlock structure displayed a slight increase in loop shape factor due to the heat of the dryer, perhaps suggesting that the heat tends to relax the more balanced structures whilst disturbing the relaxation of the more unbalanced structures. Both the single-jersey fabrics appeared to relax the most, due to the agitation during tumble-drying.

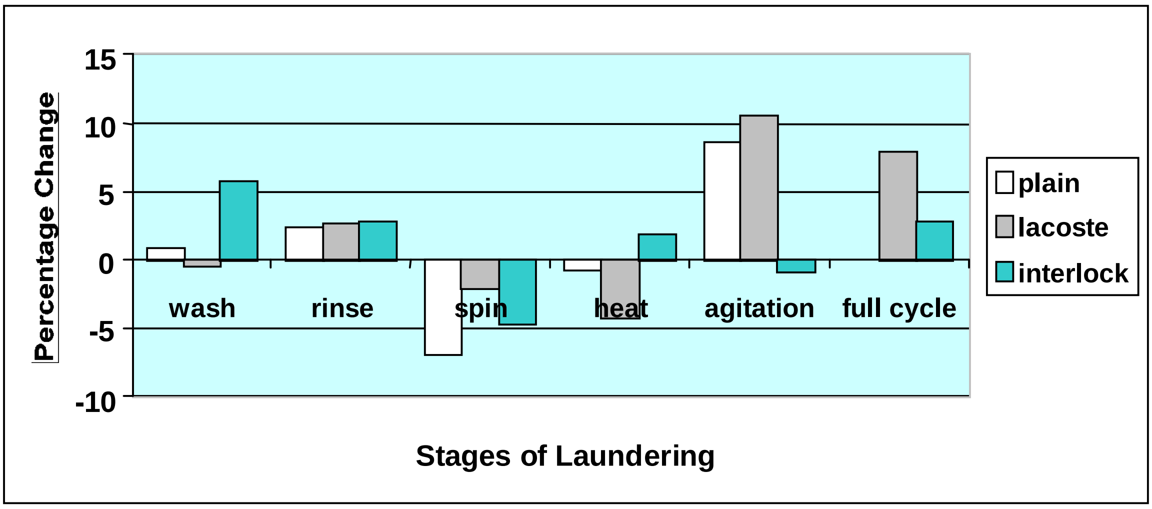

Figure 5: Changes in loop shape factor after five cycles

The three-dimensional movement of the fabrics during drying appeared to allow the single-jersey structures to relax to their minimum internal energy state. This was not true for the interlock structure where the agitation of the dryer actually caused a slight negative percentage change in loop shape factor. The percentage changes occurring in the full cycle suggested that overall loop shape factor changes occurred significantly in the lacoste fabric, whilst minimal changes occurred in the interlock structure. The changes that were observed for the plain single-jersey fabrics must have cancelled each other out. No changes were observed in the loop shape factor after five full wash and dry cycles.

Dimensional stability (length)

Firstly it must be stated that the positive percentage changes recorded were due to length extension, whilst the negative values were caused by length shrinkage. Negligible percentage changes were recorded for the wash, rinse, spin and heat applied during tumble drying for all three fabrics tested. This was except for the figure of -5.3% in the interlock structure caused by the spin cycle, showing that the single-jersey fabrics appeared to be more stable during this cycle.

The largest percentage changes were observed lengthways, due to the agitation during tumble-drying, where all three fabrics shrank by an average of 8.5%. Again, the three-dimensional movement of the fabric during drying caused a considerable amount of change within the structure. The results shown in Figure 6 for the dimensional changes in the length direction indicated that there were significant variations in the lengthways-dimensional stability in the three different structures after five full laundering cycles.

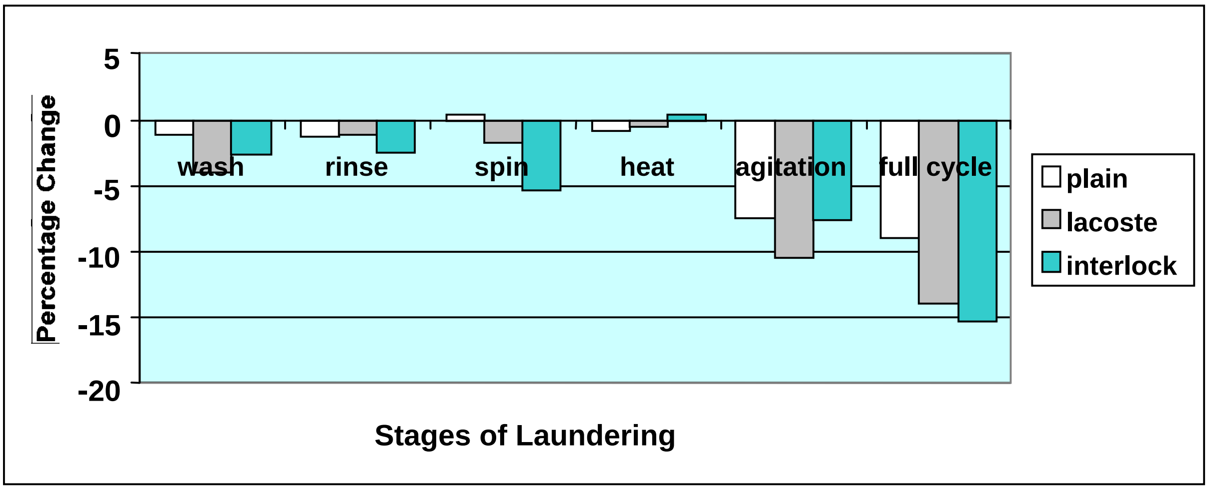

Figure 6: Change in length shrinkage after five cycles

Dimensional stability (width)

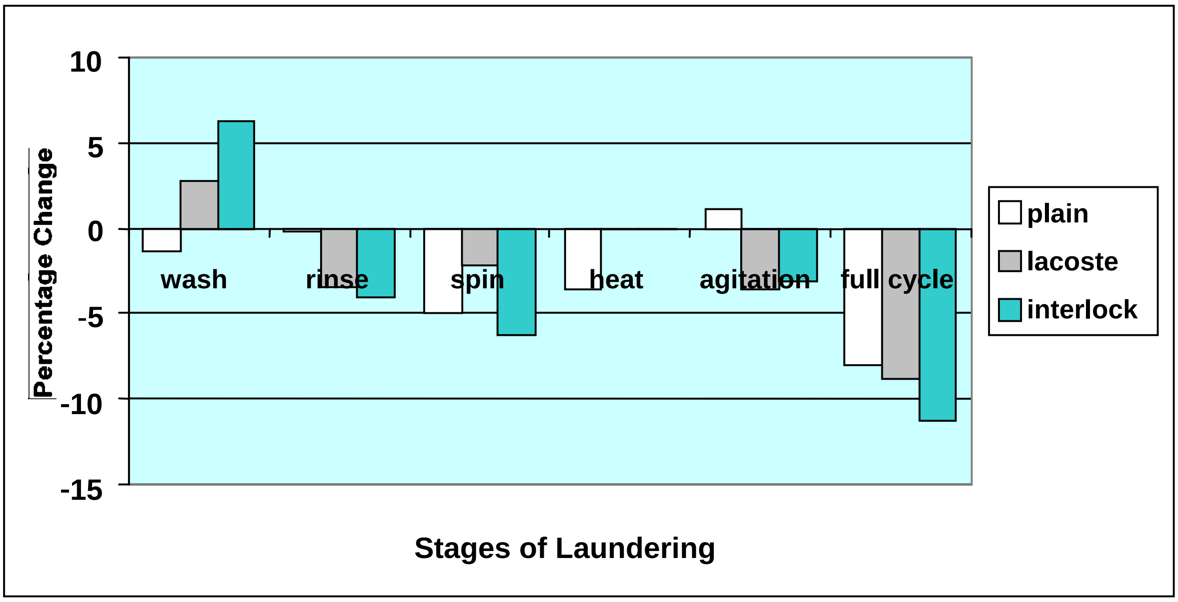

Figure 7: Change in width shrinkage after five cycles

The results of the wash and spin cycles illustrated in Figure 7 show that the interlock structure displayed excessive percentage changes in the width direction during these particular cycles. Overall, the interlock structure underwent the most significant amount of dimensional change in the width direction, as shown by the full cycle results in Figure 7. The plain single-jersey and lacoste fabrics displayed lower changes in the width direction.

Skewness

The percentage changes in skewness after five cycles of different regimes indicated that the wash, spin, heat and agitation had minimal effect on the fabrics investigated, with percentage changes in all cases being under 3%.

Only the rinse cycle exhibited high skewness in the plain single-jersey fabric, with a figure of 3.6%. The lacoste and interlock fabrics displayed no skewness during the rinse cycle, confirming the greater instability of the plain single-jersey structure. However, after five full cycles had been carried out on the fabrics, the interlock as well as the plain single-jersey structure underwent significant changes in fabric skewness (see Figure 8).

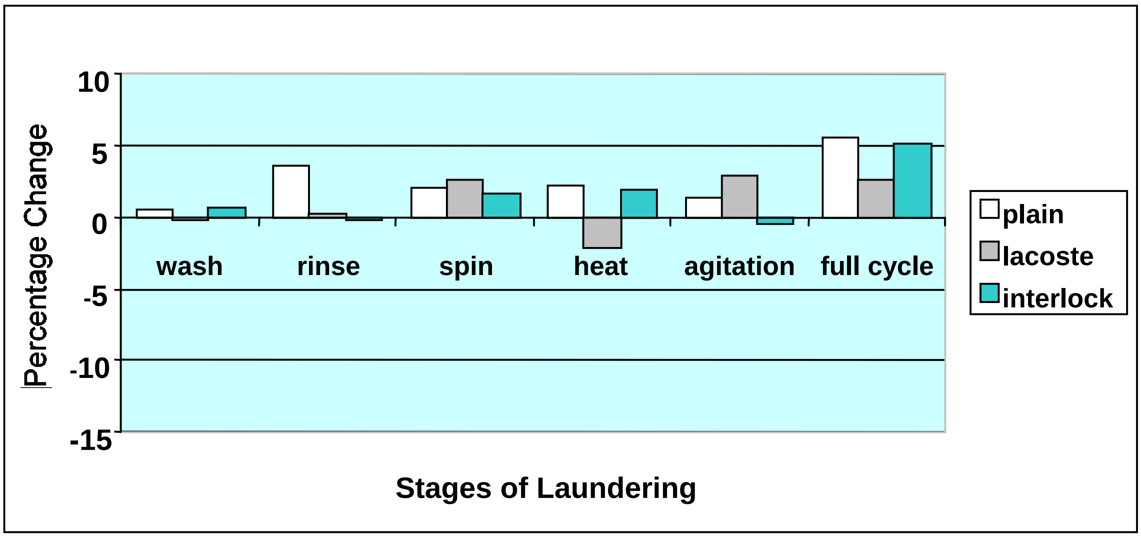

Figure 8: Change in skewness after five cycles

Spirality

The spirality results in Figure 9 indicated that all the significant changes in spirality, regardless of the wash regime, occurred in the plain single-jersey fabric. It has already been established in previous work that plain single-jersey is highly susceptible to spirality (7). The full cycle programme again confirmed this and demonstrated that the largest spirality change occurred in plain single-jersey structure. Interestingly, a negative value was obtained for the plain single-jersey fabric due to agitation during tumble-drying.

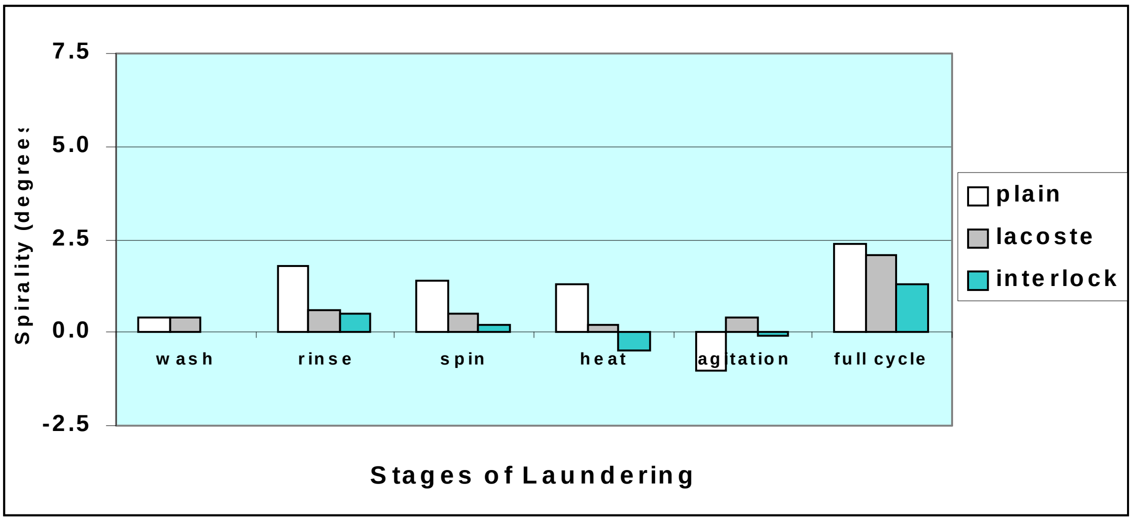

Figure 9: Changes in spirality after five cycles

Overall mean changes observed from the laundering cycle

The average results obtained for different properties, as well as different parts of the wash and dry cycle, were analysed by using an analysis of variance statistical technique. This enabled the determination of an overall mean change to be calculated for each individual part of the laundering cycle as shown in Figure 10. The results confirmed that the agitation during tumble-drying was the major contributor to changes within the fabrics, causing 34% of the changes observed. This was followed by the spin cycle, which again involved the use of agitation causing 24% of the changes. Agitation was also involved in the rinse cycle, which caused 15% of the changes, equal to the wash cycle.

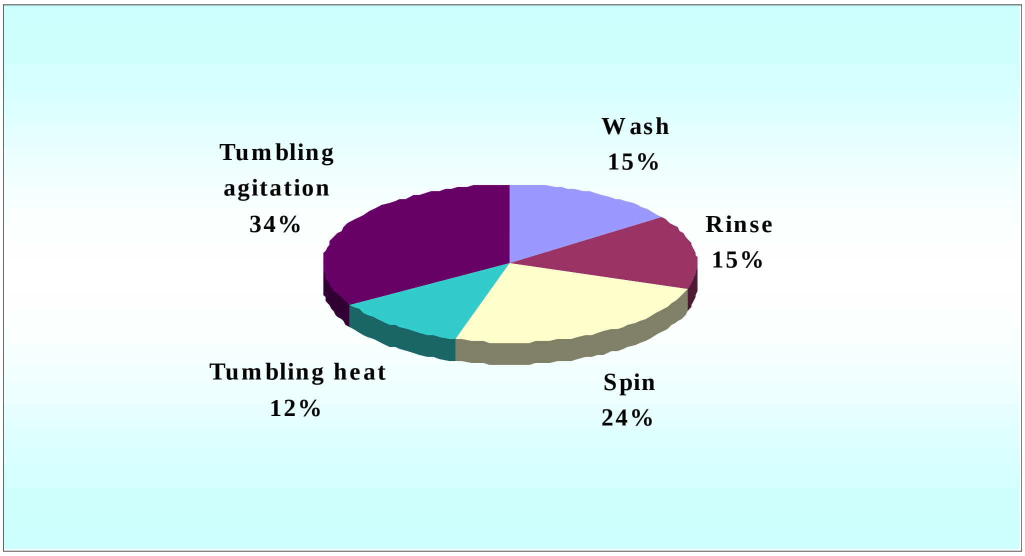

Figure 10: Mean percentage change after five laundering cycles

Conclusions – Stage 1

The results obtained during this part of the research indicated that the stitch length and yarn linear density of the fabrics examined did not alter significantly upon repeated laundering. This therefore confirms that any dimensional changes that occurred during the washing and drying treatments must have been caused due to changes in loop shape rather than yarn or loop length shrinkage. This conclusion also confirmed that the correct conditions appropriate to the cotton fibre type were used during laundering. Hence, no real modifications to the washing or drying conditions appear necessary.

The loop shape factor values obtained were very similar to the classical values reported by a number of previous researchers for fully relaxed fabrics. This confirmed that in all three structures, the loops had taken up their fully relaxed dimensions after five wash/dry cycles.

Length stability results for the three structures indicated that there was a significant difference between tumble and line drying. The tumble-dried specimens were found to shrink to a greater extent, confirming the severity of the tumbling action on fabric stability. Line drying caused actual length extension in plain single-jersey fabrics due to the mass of the fabric causing the fabric to be drawn downwards.

All three structures displayed similar trends for the dimensional stability tests in the length direction; therefore it would appear that all three fabrics were susceptible to length shrinkage. The 1x1 rib structure results for dimensional stability in width indicated more variation due to the higher potential relaxation possible in the width direction. The detergent-tumble regime caused the most shrinkage, whereas the water-line regime caused extension in the width.

Percentage skewness results obtained indicated that there was a significant difference between the three structures. As expected, the plain single-jersey showed the highest percentage skewness due to the unbalanced nature of the structure. Yet again, the regime that caused the highest degree of distortion was the detergent-tumble regime.

Spirality angles obtained during this investigation demonstrated the same trends as the skewness values; again most of these were related to the structural differences between the three fabrics. Plain single-jersey fabrics were found to be slightly more susceptible to distortions due to spirality. The average angle of spirality obtained was 5.75 degrees, an amount slightly above the commercially acceptable limit.

Overall, it can be concluded that the plain single-jersey requires more attention when laundering. It would appear that because the structure is so unbalanced, it would be unwise to launder the fabric under the same conditions as those applied to the 1x1 rib and interlock structures. It would therefore seem necessary to investigate the conditions under which single-jersey fabrics can be laundered so that the dimensional changes and distortion are kept to a minimum.

The effect of tumble-drying was evident throughout the investigation. It would appear that this method of fabric drying tends to cause the most dimensional changes in the fabric, due to a combination of constant slow agitation and temperature. This amalgamation forces the structures to take up their minimum energy state, which causes the most dimensional changes in the loop shape. In all three structures, the loops distort and bend in the third dimension. In fact a close examination of different fabric structures revealed that the loops in fact overlap similar to the ‘domino effect’.

Conclusions –- Stage 2

The single-jersey structures relaxed substantially during the agitation of the dryer, as indicated by the results for the loop shape factor in Figure 5. The three-dimensional movement of the fabric during drying caused this. The minimum internal energy states were obviously reached during this part of the laundering cycle. This is generally indicated by the loops becoming wider and shorter, and they even overlap as the loops distort into the third dimension.

Interlock has a more balanced structure, and so a negative loop shape factor change occurred when the fabric was subjected to agitation during drying. This effect caused the loops within the fabric to increase in height and become thinner. Overall, the lacoste structure altered the most after a full laundering cycle. This indicated that the complex structure of knit and tuck stitches had the most potential to alter; further research to determine more appropriate laundering conditions for this structure would therefore be beneficial.

The results of the dimensional stability tests in the length direction indicated that, overall, only the agitation during drying caused major changes. The spin cycle also caused slight problems in the interlock structure, because the spin cycle also agitated the fabrics. It would appear that it is essential to examine the agitation during drying more carefully in order to minimise the large length shrinkage results obtained in the fabrics investigated.

The widthways changes observed gave no clear indication as to which of the stages of laundering caused shrinkage or extension. However, the largest amount of damage appeared to be caused during the spin cycle. In order to eliminate the large dimensional changes it would again, therefore, appear necessary to investigate the effects of spin during washing and agitation during drying to ascertain the optimum conditions for spin and tumble drying regimes.

The skewness results did not indicate which specific stage of the laundering cycle caused the changes observed. However, it was found that the wash cycle caused minimal changes and played no significant part in any distortion observed. After a full cycle had been carried out, the plain single-jersey specimens did appear to distort the most. Although most distortion occurred during the rinse cycle for the plain single-jersey fabric, the spin cycle actually caused distortion in all three fabrics, suggesting that it would be beneficial to minimise distortion during the spin cycle.

The plain single-jersey fabric appeared to spiral significantly during each part of the laundering cycle. The unbalanced nature of the structure causes the fabric to be more susceptible to distortion, as found in the earlier investigations. The lacoste single-jersey and interlock fabrics displayed minimal distortion due to spirality. None of the individual cycles caused significant effects in the interlock and lacoste fabrics, yet overall after a full laundering cycle, lacoste and interlock structures did display significant spirality distortion. This indicated that the level of spirality determined after the full cycle was due to a cumulative effect of water agitation and heat during the laundering process, rather than any one specific stage during laundering.

The results obtained from the mean change pie chart in Figure 10 indicated that it is essential to investigate further the effects of the agitation during drying and spinning. These areas caused nearly two-thirds of all alterations obtained within the fabrics investigated, from both the dimensional stability and distortion aspects. The results for spirality and skewness indicated that the heat during drying might have had a negative effect on the fabric alterations. It may therefore be important to quantify this, perhaps to enable the use of heat to counteract the dimensional changes and distortion caused by agitation.

From the results of the dimensional stability tests, we can concluded that it is essential for agitation during drying to be further investigated, to ultimately limit the amount of shrinkage which occurs during this cycle. This area of the laundering cycle was also the culprit of the most changes in loop shape factor. This suggests that it was in that part of the laundering process where the fabrics were most likely to relax and hence take up their near stable states.

The cause of the distortion found during this investigation was harder to pinpoint, but it appeared that changes in the rinse, spin and agitation during drying may minimise the final distortion achieved after a full cycle.

Appendix – Fabric Specifications

Parameter	Plain Single Jersey	Interlock	1 x 1 Rib	Lacoste
Courses (cm^{-1})	20.8	18.7	15.8	16.8 (as seen) 22.4 (actual)
Wales (cm^{-1})	14.9	16.1	10.9	9.2
Stitch density (cm^{-2})	309.9	301.1	172.2	154.6 (as seen) 206.1 (actual)
Stitch length (mm)	2.65	2.70	2.90	3.26
Yarn linear density (Tex)	17.0	9.5	16.6	31.7
Tightness factor (K)	1.56	1.14	1.40	1.73
Actual area density (gm^{-2})	137.9	148.8	162.85	219.11
Theoretical area density (gm^{-2})	139.6	154.4	165.81	212.99
difference (%)	1.23	3.76	1.79	2.79

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