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Effect of alkaline hydrolysis on low-stress mechanical properties of polyester/cotton blended weft knitted fabrics

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Polyester/cotton blended weft knitted fabrics produced from ring-spun yarn have been treated with alkaline hydrolysis to study their low-stress mechanical and thermal properties. The major changes in the low-stress mechanical properties of the treated fabrics have been noticed. The most affected properties are tensile, shear, bending, and compression. Surprisingly, alkaline hydrolysis treatment increases surface roughness. The thermal properties are also found to exhibit good handling by the alkaline hydrolysis treatment. The 35/65 polyester/cotton blended fabrics exhibit an increase in thermal insulation property. It is apparent that the 65/35 polyester/cotton blended knitted fabric exhibits an exceptionally good handle following alkaline hydrolysis.

Keywords: Alkaline hydrolysis, Mechanical properties, Polyester/cotton fabric, Surface roughness, Tensile properties, Weft knitted fabrics

1 Introduction

Today, everyone needs low-cost and high-quality fabrics, which possess good handle and comfort. As per the consumers' experience, the polyester/cotton fabrics are harsher in feel in comparison with polyester/viscose blended fabrics. The work undertaken is concerned with the modification of polyester/cotton and polyester fabrics by alkaline hydrolysis.

Polyester/cotton fabrics have become very popular, as they provide better serviceability and comfort to the wearer. An alkaline hydrolysis treatment is given to polyester fabrics in order to impart a soft feel to them. A knitted fabric with a linen-like handle has been claimed for a material formed from polyester bicomponent fibres and given ethylamine treatment[1]. If the alkaline hydrolysis treatment is applied to polyester/cotton fabric, not only the polyester is affected but the cotton component is also affected and as a result, the whole fabric undergoes considerable changes.

Jeddi and Otaghsara[2] investigated the correct relaxation treatment of 100% cotton, blended cotton/polyester, and 100% polyester knitted fabrics. They concluded that, while the correct relaxation state for cotton fabrics to have maximum shrinkage was achieved by full mechanical relaxation, that for blended cotton-polyester and 100% polyester fabrics was achieved by chemical relaxation treatment. Their empirical results show that the effect of mechanical relaxation is decreased as the percentage of polyester is increased. Besides studying the relaxation treatment, they did not investigate any other properties of knitted fabrics.

Shet *et al.*[3] carried out considerable work on the alkaline treatment of polyester and cotton woven fabrics and reported only some results. Their work was carried out on 65/35 polyester/cotton and 100% cotton fabrics. The authors studied the properties of blended fabrics in terms of weight loss, shrinkage, moisture absorbency, drop absorbability, and tensile properties.

It is to be understood that the increased use of various fibre blends is for cost advantage and that the process of differential alkaline hydrolysis on the low-stress mechanical properties will be of use to the textile industry. The work carried out by researchers[2,3] did not deal with the low-stress mechanical properties of polyester knitted fabrics treated with sodium hydroxide, but they were concerned with other aspects, such as weight loss, moisture absorption, and dimensional stability.

Research work on alkaline hydrolysis of polyester[4] led to a revolutionary new finding that the surface of the polyester fibres becomes rough instead of becoming smooth. The goals of the work are, therefore, to define the level of changes in mechanical and surface properties, translate the property differences

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into handle quality differences, ascertain the statistical significance of the resulting changes, relate them to thermal comfort performance, and define the influence of the treatment.

However, from the research carried out so far, we find that there is a lack of information on the effect of blend composition on the properties of weft-knitted fabrics subjected to alkaline hydrolysis for changing their handle and comfort. Therefore, in this study, the effect of the blend composition of polyester and cotton on the characteristics of knitted fabrics has been examined following alkaline hydrolysis treatment. The Kawabata Evaluation System was used to test the changes that occurred in the materials after treatment.

The primary objective of this research is to establish a technique which could be routinely used to determine the handle of fabrics on fabric specimens. The investigation carried out on various polyester/cotton blends subjected to alkaline hydrolysis shows that the measurement technique is a powerful sensitive aid to characterize different fabric samples. It is found that there are major changes in the low-stress mechanical properties of treated fabrics. Surprisingly, alkaline hydrolysis shows an increase in friction and surface roughness, which is in agreement with the findings of Tavanai[4].

2 Materials and Methods

2.1 Materials

Polyester/cotton blended yarns of 65/35, 50/50 and 35/65 blend composition of 40 Ne (14.76 tex) were used for knitting the fabrics. They were produced by the ring spinning method. The characteristics of fibre and yarn used in this work are given in Tables 1 and 2, which were tested as per ISO 2062:1993. It is apparent that as the polyester content is increased, the tenacity increased, accompanied by higher elongation. An improvement in evenness and imperfection is noticed with an increase in hydrolysis content. Hairiness shows a significant reduction with the increasing polyester content.

2.2 Fabric Production

The knitted fabrics were produced on a weft knitting machine having the following specification: gauge 28, diameter 17 inches, and the number of feeders 34.

In all three types of yarn combinations, knitted fabric samples were produced. The geometrical properties of knitted fabrics are given in Table 3.

2.3 Sodium Hydroxide Treatment of Fabrics

The fabric of dimension 30cm × 30cm in tubular form (conditioned at 65% RH and 25ºC) was weighed accurately. It was immersed in 25% aqueous sodium hydroxide for 2 min at 27ºC and then padded twice to obtain a uniform distribution of alkali in the fabric. This concentration was chosen, because it was normally used in the industry. The padded sample held between two ceramic frames was heated in an oven fitted with a blower at 60ºC for 15 min. At the end of the treatment, the fabric was carefully washed with tap water to remove hydrolyzed products as well as untreated alkali. Washing was continued with distilled water. The residual alkali in the fabric was removed by immersion in 1% aqueous hydrochloric acid for 5 min. This was followed by thorough rinsing with distilled water. Samples were left overnight in distilled water to ensure the complete removal of the acid, and washings continued if necessary until the rinsed water was neutral to litmus. The samples were air-dried, conditioned for 48 h at 65% RH & 25ºC, and weighed again. Each treatment was done in duplicate. Control samples were treated similarly for

Table 1 — Fibre characteristics

Fibre properties	Polyester	Cotton
Fibre fineness, tex	0.086	3.8
Fibre length, mm	32	29
Tenacity, cN/tex	51.52	21
Elongation, %	21.6	—
Cross section	Circular	—

Table 2 — Yarn characteristics

Blend	P/C 35/65	P/C 50/50	P/C 65/35
Tenacity, cN/tex (Uster Tensojet 4)	19.11	23.06	25.77
Tenacity, CV%	7.7	8.5	9.6
Elongation, %	5.81	7.85	8.88
Elongation, CV%	7.9	9.9	9
U, %	12.43	12.42	11.72
Thin places/km	30	29	15
Thick places/km	215	195	118
Neps/km	319	239	157
Total imperfections/km	564	463	290
Hairiness (Uster)	6.52	5.7	5.26
S3 (Zweigle G566)	2258	2130	807

Table 3 — Geometrical properties of knitted fabrics

Fabric	Wales/ cm	Courses/ cm	Stitch density, cm^2	GSM	Thickness mm
35/65 P/C	21	22	462	142	0.43
50/50 P/C	20	21	420	139	0.44
65/35 P/C	19	23	437	135	0.42

15 min, except that water instead of sodium hydroxide was used as padding liquor.

2.4 Fabric Tests

Relaxation Treatments

After knitted fabrics had been produced on the machine as detailed above and treated with sodium hydroxide, they were relaxed following "Starfish" knitting recommendations.

Low-stress Mechanical Properties

The Kawabata evaluation system for fabrics (KES-F) was used for measuring the low-stress mechanical properties of treated and untreated fabrics. The parameters obtained from the system are:

- Tensile properties — Elongation (EM), %; linearity (LT); energy (WT), g.cm/cm^2; resilience (RT), %
- Shear properties — Shear rigidity (G), g/cm.deg; hysteresis at 0.5° (2HG), g/cm; hysteresis at 0.3°(2HG3), g/cm
- Bending properties — Bending rigidity (B), g.cm$^{2/}$cm; bending moment (2HB), g.cm/cm
- Compression properties: Linearity (LC); energy (WC), g.cm/cm/cm^2; resilience (RC), %; actual thickness of the fabric (T$_0$), mm
- Surface properties — Geometrical roughness (SMD), µm; co-efficient of friction (MIU); mean deviation of co-efficient of friction (MMD); Weight of actually-tested fabric (W), mg/cm^2

Handle

The fabrics were tested for handle by an attachment fixed to the Instron tensile tester. A sample of 30cm in diameter was passed through a highly polished stainless-steel bush of 2cm in diameter and the withdrawal force was measured. The mean of five readings was taken.

Thermal Property

The thermal insulation values (TIV) and the heat keeping ratio of samples were measured by the KES-F7 Thermolabo II Thermal Insulation Tester by the dry contact method. Ten readings were taken for each sample, and the mean was calculated. This is given by the following formula:

$$\text{TIV} = \frac{\text{Heat loss without specimen - Heat loss with specimen}}{\text{Heat loss without specimen}}$$

3 Results and Discussion

3.1 Moisture Absorption

Table 4 shows the moisture regain and moisture content values of control and treated samples. It is also interesting to note that the values agree with those reported for the woven fabrics by Shet *et al.*[3]. A cotton-rich (35/65 P/C) blend had a high moisture content and regain value, due to the swelling of cotton fibres.

3.2 Weight Loss

It is interesting to note that the weight loss shows an increase with the increase in polyester content in the fabrics as observed in Table 4. This is due to

Table 4 — Moisture, weight loss and tensile properties of polyester/cotton (P/C) fabric

Parameters	P/C 35/65		P/C 50/50		P/C 65/35	
	Untreated	Treated	Untreated	Treated	Untreated	Treated
Moisture content, %	3.72	4.1*	3.11	3.47*	2.07	2.56*
Moisture regain, %	3.83	4.28*	3.19	3.59*	2.1	2.63*
Weight loss, %	—	1	—	1.97	—	5.97
LT-1	0.48	0.65*	0.64	0.42*	0.72	0.65*
LT-2	0.44	0.35	0.67	0.69	0.72	0.44*
Mean LT	0.46	0.50	0.65	0.55*	0.72	0.55*
WT-1, g.cm/cm^2	6.96	9.21*	12.35	7.55*	15.53	12.10*
WT-2, g.cm/cm^2	10.33	8.57*	23.77	22.19*	28.76	16.90*
Mean WT	8.65	8.89	18.06	14.87*	22.15	14.50*
RT-1, %	33.80	34.57	36.50	50.65*	34.70	26.32*
RT-2, %	70.14	69.71	41.65	36.20*	25.21	40.19*
Mean RT	51.97	52.14	39.07	43.43*	29.96	33.30*
EM-1, %	11.56	11.27	15.48	14.50	17.15	14.79
EM-2, %	18.62	19.79	28.32	25.57*	31.75	30.38
Mean EM	15.09	15.53	21.90	20.04	24.45	22.58*

*Significant at 95% level; 1 — wale way; 2 — course way.

hydrolysis, which is in line with the earlier reported findings[3].

3.3 Tensile Properties

The tensile properties measured are tensile energy (WT), tensile resilience (RT), and extensibility (EM). The different tensile properties of the weft-knitted fabrics controlled and treated with alkali as measured by the KES-F systems are presented in Table 4.

Tensile energy (WT) is defined as the energy required for extending the fabric, which reflects its ability to withstand external stresses during extension. It is apparent that following alkaline treatment, WT values show a decrease in all cases. The course way's WT values are higher than those of the wale way. It is interesting to note that as the polyester content increases, the extensibility also increases progressively. This may be due to the inherent yarn properties of the blend, as shown in Table 4.

EM follows the same trend as WT, and both are interrelated; WT is also closely related to the fabric's flexibility, softness, gentleness, smoothness, and compactness. Similar research findings[5-9] have characterized the quality of polyester fabrics and silk fabrics using their tensile properties.

RT is defined as the ability of a fabric to recover after applying tensile stress. A lower value of RT implies that the fabric is not recovering after the removal of applied tensile stress. It shows that the alkali treatment has improved recovery. With the reduction of polyester, while the values of RT show an increase, the LT values show a decrease in treated fabrics. This may be due to a lower cohesive force between yarns. The differences in RT between the control and treated samples in respect of 35/65 polyester/cotton blends are less as compared to the 65/35 and 50/50 polyester/cotton blended fabrics. This shows that the recovery of 35/65 polyester/cotton blended fabric is good in comparison with other fabrics. Fabric extension is greatest in a 65/35 P/C blend and least in a 35/65 P/C blend.

3.4 Bending Properties

The bending properties of the fabric have a significant effect on both the handle and tailoring performance. It is apparent from Table 5, that the wales-way bending rigidity is higher than that of the course-way, and the alkaline hydrolysis treatment has lowered the bending rigidity in 35/65 and 65/35 P/C blends.

With the increase in polyester content, the bending rigidity values show a significant decrease after treatment, suggesting that the fabrics have become more flexible. A greater decrease is observed in the 65/35 P/C blend, which accounted for 31.25%, which is due to the hydrolysis of polyester fibre. Bending hysteresis (2HB), unlike bending rigidity, shows an increase following alkaline hydrolysis treatment, which is due to higher frictional restraint.

Values of 2HB/B for treated fabrics are found higher as compared to the control. The higher the value of 2HB/B, the poorer is the recovery, and on this basis, the 65/35 P/C blend shows the highest value.

Thus, although bending rigidity values show a drop, bending hysteresis shows an increase following

Table 5 — Bending and compression properties

Parameters	P/C 35/65		P/C 50/50		P/C 65/35	
	Untreated	Treated	Untreated	Treated	Untreated	Treated
B -1, g.cm^2/cm	0.017	0.015	0.016	0.014	0.016	0.011*
B -2, g.cm^2/cm	0.008	0.006	0.006	0.007	0.006	0.004
Mean B	0.012	0.010	0.011	0.010	0.011	0.007*
2HB -1, g.cm/cm	0.022	0.026	0.025	0.025	0.021	0.023
2HB -2, g.cm/cm	0.015	0.012	0.016	0.014	0.014	0.014
Mean 2HB	0.018	0.019	0.020	0.019	0.018	0.019
2HB1/B1	1.29	1.73	1.56	1.78	1.31	2.09
2HB2/B2	1.88	2.0	2.6	2	2.3	3.5
2HB-M/B-M	1.50	1.9	1.8	1.9	1.6	2.7
LC	0.38	0.35*	0.38	0.38	0.344	0.34
WC, g.cm/cm^2	0.32	0.26*	0.37	0.31*	0.284	0.33*
RC %	46.0	43.9*	43.3	45.7*	46.556	46.30
T, mm	0.84	0.76	0.91	0.83	0.795	0.85*
W, mg/cm^2	13.9	13.9	14.3	14.10	14.24	13.39

*Significant at 95% level; 1 — wale way; 2 — course way.

alkaline hydroxyl treatment. The course-way values of 2HB or B are higher, implying that the recovery is poorer. This may be due to the larger number of threads as compared to that in wales. The larger the number of threads and the larger the number of contacts, the higher is the frictional restraint. The significance of 2HB/B has been discussed by Grosberg and Swani[10], stating that the length in that frictional restraint is directly related to residual stresses in a fabric. Alkaline hydrolysis treatment has increased 2HB, and this may be due to the increased clustering of fibres as a result of the treatment.

3.5 Compression Properties

Only a single parameter is obtained for the compression properties. With the exception of 65/35 polyester/cotton blended knitted fabrics, WC values show a decrease in treated fabrics. An increase in WC (compression energy) implies that the fabric has become fluffy and shows improvement in the handle, and thus the alkaline hydrolysis treatment for the 65/35 P/C blend has led to a better handle. Except for the 35/65 blend, no significant changes are noticed for compressional linearity, LC (linearity of fabric compression), thickness curve and compression properties (Table 5).

It may be noted that the compressibility is higher for untreated fabric and lower for treated fabric. As expected, an increase in the thickness caused by alkaline hydrolysis treatment is accompanied by a significant change in compressional energy (WC). In fact, WC increases in the 65/35 P/C blend, which shows a fluffier fabric. This may be due to a higher degree of treatment.

It is interesting to note that the fabric thickness increases in a significant manner for the 65/35 P/C blend after the alkaline hydrolysis treatment; this reflects the fact that the alkali-treated fabric becomes fuller than that of the untreated fabric. The increase in thickness could be due to a decrease in inner strains of the yarns that results in relaxation of the fabric structure, and as a consequence of this, the fabric swells. The 50/50 blend shows the highest compressibility when untreated. While 35/65 and 50/50 P/C blends show a change in RC (a percentage energy loss due to compressive hysteresis), the 65/35 P/C blend does not show any significant change and similar kind of results have been obtained in the earlier research reports[11,12].

3.6 Shear Properties

The shear rigidity (G) reflects the ability of the fabric to resist shear stress. Shear is an important property that determines the handle and drape of fabrics. As observed in Table 6, apart from the 65/35 P/C blend, it is apparent that shear rigidity shows a slight increase in other blends.

Unlike bending, it is interesting to note that the course-way values are higher than those of the wale-way. This is principally due to greater contacts made. The treated fabrics show higher values for shear rigidity and shear hysteresis. Shear hysteresis values show an increase following alkaline hydrolysis which may be due to increases in contact. Values of 2HG/G and 2HG3/G, which represent residual shear strain, show an increase in all the cases, implying that the recovery has decreased. The greatest increase has occurred in the 65/35 P/C blend, which is an indication of greater frictional restraint and shear characteristic trends.

3.7 Surface Properties

MIU reflects the fabric smoothness, roughness, and crispness, and SMD constitutes the geometric smoothness. Lower values of these parameters are favourable. From Table 6, it is apparent that, with the exception of the 50/50 P/C blend, there is a reduction in MIU. In all the cases, SMD values show an increase, implying that the fabrics have become rougher. The surface of the treated fabric becomes harsher after treatment with alkaline hydrolysis. A work on alkaline hydrolysis of polyester, using an atomic microscope demonstrates that the polyester fibre becomes rough following weight reduction, and the experimental results obtained are in line with the earlier published works[4].

3.8 Total Hand Value

Kawabata's primary hand characteristics for women's dress materials to evaluate the different tactile qualities of the experimental fabrics have been used. The primary and total hand values of the untreated and alkali-treated knitted fabrics are illustrated in Table 7. It is interesting to note that THV shows a progressive increase with the increase in polyester content. Alkaline hydrolysis treatment has led to an improvement in the handle of all the treated fabrics. The results obtained reveal that alkaline hydrolysis treatment makes the fabrics smoother (Numeri), fuller, softer (Fukurami), and less stiff.

The knitted fabrics containing a 65/35 P/C blend exhibit an exceptionally good handle in comparison with 35/65 and 50/50 P/C blends. The greater the value of the

Table 6 — Shear and Surface properties

Parameters	P/C 35/65		P/C 50/50		P/C 65/35	
	Untreated	Treated	Untreated	Treated	Untreated	Treated
G-1, g/cm.deg	0.81	0.82	0.85	0.87	0.91	0.83*
G-2, g/cm.deg	0.87	0.87	0.88	0.94	1.07	1.00*
Mean G	0.84	0.85	0.87	0.90*	0.99	0.92*
2HG -1, g/cm	2.75	3.02*	3.00	3.58*	3.04	3.59*
2HG -2, g/cm	3.04	3.82*	3.31	4.54*	3.78	4.91*
Mean 2HG	2.89	3.42*	3.15	4.06*	3.41	4.25*
2HG3-1, g/cm	2.88	3.26*	3.22	3.85*	3.24	3.79*
2HG3-2, g/cm	3.40	4.17*	3.61	4.83*	4.32	5.23*
Mean2HG3	3.14	3.71*	3.42	4.34*	3.78	4.51*
2HG/G	3.4	4.02*	3.63	4.48*	3.45	3.33
2HG3/G	3.7	4.37*	3.93	4.78*	3.82	4.90*
2HG1/G1	3.4	3.67*	3.40	4.10	3.3	4.30*
2HG2/G2	3.4	4.35	3.74	4.83	3.54	4.89*
Mean 2HG	3.4	4.03*	3.63	4.48*	3.44	4.62
2HG3.1/G1	3.5	3.9*	3.80	4.40*	3.6	4.54*
2HG3.2/G2	3.9	4.76*	4.08	5.14*	4.04	5.2*
Mean 2HG3	3.7	4.37*	3.93	4.78*	3.82	4.9*
MIU-1	0.19	0.21	0.23	0.23	0.22	0.20
MIU-2	0.20	0.18	0.22	0.22	0.22	0.20
Mean MIU	0.20	0.20*	0.22	0.22	0.22	0.20*
MMD-1	0.01	0.01	0.01	0.01	0.00	0.01
MMD-2	0.01	0.00	0.01	0.00	0.01	0.01
Mean MMD	0.01	0.01	0.01	0.01	0.00	0.01
SMD-1, µm	2.62	3.48	4.06	4.81	2.80	2.85
SMD-2, µm	2.23	1.74	2.49	2.29	2.09	2.64
Mean SMD	2.42	2.61*	3.28	3.55*	2.45	2.75*

* Significant at 95% level; 1 — wale way; 2 — course way.

Table 7 — Handle values, handle force and thermal insulation values

Sample	Primary handle values			Total hand value	Withdrawal force, N	Heat keeping ratio	Tog value
	Koshi	Numeri	Fukurami				
Without specimen	—	—	—	—	—	—	0.83
PC 65/35 normal	0.52	9.27	2.03	3.29	1.53	20.00	1.04
PC 65/35 alkali treated	0.24	8.83	2.92	3.46	0.616	20.00	1.03
PC 35/65 normal	-1.19	7.81	3.04	1.67	2.606	19.17	1.02
PC 35/65 alkali treated	-0.48	8.29	1.69	1.95	0.976	18.32	1.01
PC 50/50 normal	-0.62	7.28	2.80	1.62	2.83	19.17	1.02
PC 50/50 alkali treated	0.02	7.89	2.60	2.35	1.457	19.17	1.02

primary hand quality within the 0–10 range, the greater is the intensity of the particular hand tactile feeling. Residual strain and shear strain show a drop in alkaline hydrolysis treatments which implies better recovery. It is pointed out that this improvement is due to geometrical changes which occurred in the polyester fabric.

3.9 Handle Force

Table 7 gives the value of the handle force of the fabric samples from which it is evident that following alkaline hydrolysis, the handle has improved. It is interesting to note that the 65/35 P/C blend shows a drop of 60% in handle force, which is quite encouraging.

3.10 Thermal Insulation Value or Heat Keeping Ratio α

Table 7 shows that the Tog value increases in treated fabrics. Fabric made out of 35/65 polyester/cotton and treated with alkaline shows a lower value of thermal insulation. Tog is a unit of thermal insulation of garments and is expressed in square metres of Kelvin per watt (m^2.K/W). A unit of tog is equivalent to 0.1 m^2 K/W. It is apparent from Table 7 that there is not much variation in the tog values of specifications. A similar kind of trend in results has been discussed in the earlier reports also[13,14].

4 Conclusion

In this experimental research, three polyester/cotton blend weft knitted fabrics have been subjected to alkaline hydrolysis treatment, and they are evaluated using KES-F and other testing instruments for their properties. It is found that the major changes occur in the low-stress mechanical behaviour of the treated fabrics. The properties most affected by alkaline hydrolysis treatment are tensile elongation (EM%), tensile resilience (RT%), shear rigidity (G), shear hysteresis (2HG), compression resilience (RC%), the linearity of the compression curve (LC), surface friction (MIU) and surface roughness (SMD). Some of these properties change by as much as 30% after the alkaline hydrolysis treatment. The 35/65 P/C blended fabrics exhibit an increase in thermal insulation property. The results provide evidence to conclude that alkaline hydrolysis treatment affects the low-stress mechanical properties significantly. It is apparent that the 65/35 polyester/cotton blended knitted fabric exhibits an exceptionally good handle following alkaline hydrolysis.

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