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Mechanical Behavior of Knitted Fabrics under Bending and Shear Deformation

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Abstract

It is very important to understand the mechanical response of fabrics under deformation since their aesthetic properties and performance are directly related to their mechanical properties, such as tensile, bending and shear. During use, fabric is always stressed by these kinds of deformations. Fabric properties such as drape, handle, and bagging are also affected by the bending and shear characteristics of the fabric. Thus, this study was carried out to gain a better understanding of the bending and shear behavior of knitted fabric. The effects of several factors such as tightness factor, relaxation treatment and the direction of bending and shear on the response of fabric under deformation are discussed. The results indicate that the increase in the tightness factor and relaxation of the fabric generally lead to an increase in rigidity fabric against bending and shear deformation. It has also been seen that the response of fabric under deformation is affected by the direction of deformation applied.

Key words: Knitted fabric, Bending properties of fabric, Shear properties of fabric.

Introduction

To understand the behavior of knitted fabrics under bending and shear deformation is very important, since their functional properties are closely related to their mechanical properties, such as bending, shear and tensile. For example, the drape properties of fabrics are affected by both bending and shear properties. Drape is the aesthetic property of the fabrics. It is defined as deformation of the fabric produced by gravity when one part of the fabric is directly supported. An increase in bending and shear parameters, such as bending and shear rigidity, hysteresis of bending and shear, result in a decrease in the drape structure of the fabric, something undesirable in most cases (Gaucher and King, 1983). Another example of the importance of the bending and shear characteristics of fabrics involves their handle properties. Handle is the sum total sensations of the physical and mechanical properties of fabric when it is handled by touching, flexing by the fingers, smoothing, etc. In most cases, lower bending and shear parameters and lower roughness for knitted fabrics are necessary for the best handle (Chen *et al.,* 1992). Many examples exist showing the relationship between a fabric's functional properties and its bending and shear properties.

The bending behavior of woven fabrics was first studied by Pierce (1930). Hamilton and Postle (1974) analyzed the bending characteristics of plain knit fabrics. They assumed that each wale in the fabric behaved as a pair of double helices. Stewart and Postle (1974) analyzed the effect of felting on the bending and shear properties of wool knitted fabric. Gibson and Postle (1978) compared the bending and shear properties of woven and knitted fabrics. Alimaa *et al.* (2000) constructed a straight parallel yarns model in which the knitted structure is assumed to consist of a series of straight yarns to explain the bending behavior of several basic knit fabrics.

To date, most studies have shown that fabrics' bending and shear rigidity parameters increase with increases in relaxation, (i.e. with wash & dry treatment)(Hamilton and Postle, 1974; Stewart and Postle, 1974; Hamilton and Postle, 1976; Gibson and Postle, 1978). However, recently, one study on the mechanical properties of knitted fabrics yielded a different result, i.e. an increase in relaxation resulted in a decrease in bending and shear parameters (Mackay *et al.,* 1999).

Thus, this study has been carried out to determine the validity, and the reasons for these two contradictory results and to obtain some additional information.

Materials and Methods

Several plain knitted fabrics with different tightness factors were produced in the laboratory (see Table 1). The tightness factor is a measure of the tightness of the fabric. As the tightness increases (or as the slackness decreases), the tightness factor increases. As a yarn material, 100% cotton ring yarn with 20 Ne yarn count, $\propto_e$: 3.3 yarn twist coefficient was used. All fabrics were relaxed with two different relaxation procedures, i.e. dry relaxation and wash & dry relaxation. For dry relaxation, fabrics were placed on a flat surface in a standard atmosphere (25 °C at 65% RH) for 1 week. For wash & dry relaxation, after dry relaxation, fabrics were washed in a domestic washer at 60 °C for 30 min using commercial detergent and tumble dried at 70 °C for 15 min in an electrically heated dryer. This procedure was repeated four times. Before measurements were taken, the fabrics were conditioned for 24 h in a standard atmosphere.

The bending and shear properties of the fabrics were measured by a KES-FB system (Kawabata, 1980) and the tests were carried out on standard sized samples (20 cm x 20 cm). Bending moment and shear force were applied about axes parallel to the course and wale directions, respectively (see Figure 1). Each test was repeated five times for each direction, i.e., course direction and wale direction. Thus, a total of 80 measurements (observation) were obtained for all factors, i.e., for each relaxation, tightness factor and direction of deformation. Bending rigidity (B), hysteresis of bending (2HB), shear rigidity (G) and hysteresis of shear (2HG5) were obtained from the KES-FB test system. The data in Table 1 obtained from KES-FB are the mean values calculated from these five measurements. The relationships between variables are summarized in Figures 2-9. Bending rigidity (B) and shear rigidity (G) are measures of elastic resistance to the bending and shear of yarn, respectively. They are affected by the bending, torsion, tensile and compression properties of yarn during deformation. Hysteresis of bending (2HB) and hysteresis of shear (2HG5) are measures of interyarn and interfiber friction opposing yarn and fiber movement arising from bending and shear, respectively.

Analysis of variance was used to test the hypothesis that mean values of each level of each factor are equal. The F values obtained from the analyses of variance are shown in Table 2.

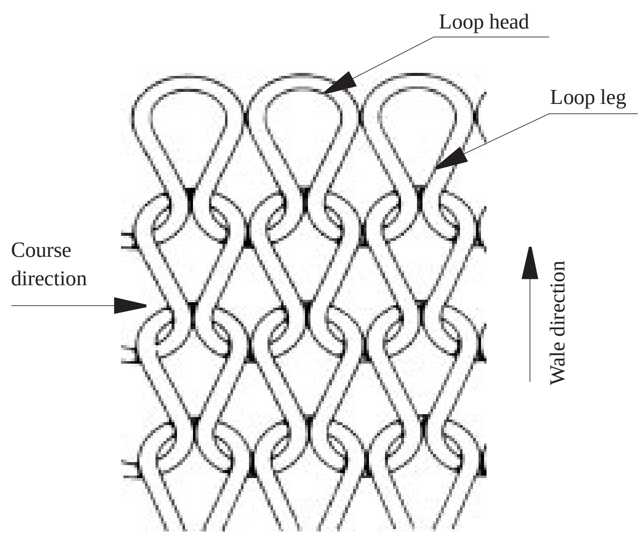

Figure 1. Bending moment and shear force are applied about axes parallel to the course and wale directions of plain knitted fabric.

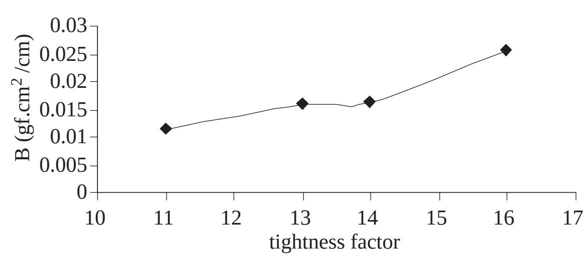

Figure 2. The effect of tightness factor on bending rigidity (B) for wale direction and wash & dry relaxation.

Table 1. Fabric properties.

Sample	Tightness Factor ($Tex^{1/2}$/cm)	Relaxation	Fabric weight (g/m^2)	Direction	B* gf.cm^2/cm	2HB* gf.cm/cm	G* gf/cm degree	2HG5* gf/cm
1	11	dry	152	course	0.0152	0.0405	0.368	0.968
				wale	0.0115	0.0310	0.300	0.634
		wash & dry	166	course	0.0312	0.0491	0.396	1.118
				wale	0.0114	0.0279	0.326	0.772
2	13	dry	165	course	0.0168	0.0478	0.488	1.270
				wale	0.0108	0.0267	0.356	0.810
		wash & dry	176	course	0.0325	0.0631	0.458	1.226
				wale	0.0157	0.0463	0.440	0.938
3	14	dry	177	course	0.0281	0.0487	0.506	1.198
				wale	0.0182	0.0389	0.448	0.978
		wash & dry	193	course	0.0443	0.0872	0.530	1.468
				wale	0.0162	0.0530	0.522	1.124
4	16	dry	191	course	0.0396	0.0886	0.678	1.644
				wale	0.0186	0.0476	0.628	1.352
		wash & dry	211	course	0.1656	0.1005	0.726	1.782
				wale	0.0255	0.0584	0.664	1.540

*B: bending rigidity, 2HB: hysteresis of bending, G: shear rigidity, 2HG5: hysteresis of shear force at 5 degrees, as measured using KES-FB instrument. Tightness factor is the $(Tex)^{1/2}/l$ where Tex is the yarn count, l is loop length in cm.

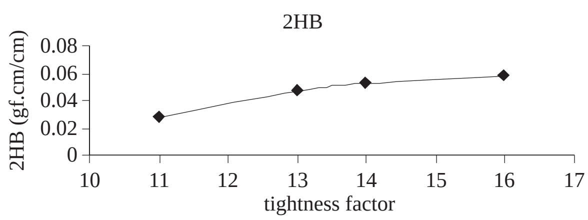

Figure 3. The effect of tightness factor on bending hysteresis (2HB) for wale direction and wash & dry relaxation.

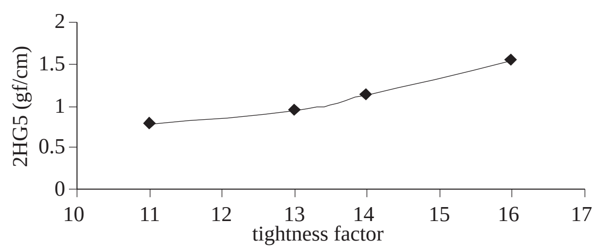

Figure 5. The effect of tightness factor on shear hysteresis (2HG5) for wale direction and wash & dry relaxation.

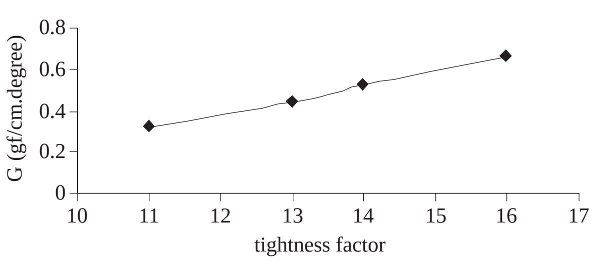

Figure 4. The effect of tightness factor on shear rigidity (G) for wale direction and wash & dry relaxation.

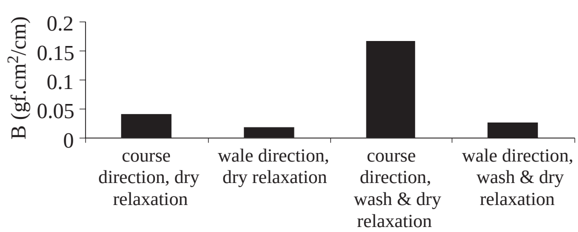

Figure 6. The effect of direction and relaxation on bending rigidity (B) for tightness factor 16.

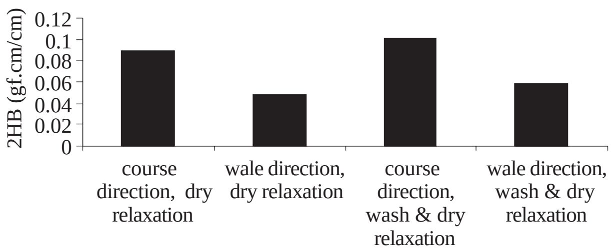

Figure 7. The effect of direction and relaxation on bending hysteresis (2HB) for tightness factor 16.

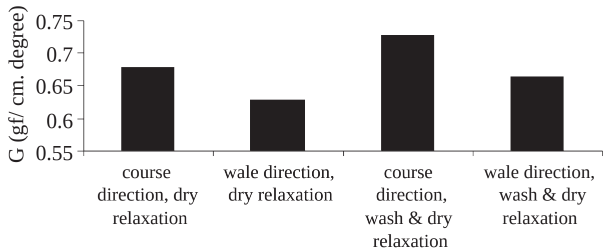

Figure 8. The effect of direction and relaxation on shear rigidity (G) for tightness factor 16.

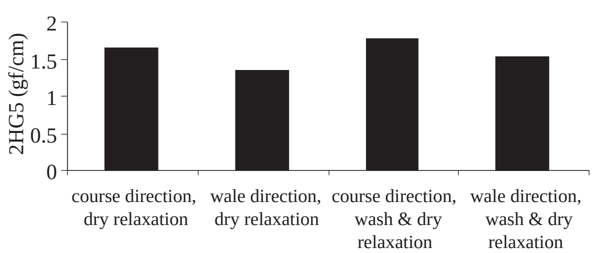

Figure 9. The effect of direction and relaxation on shear hysteresis (2HG5) for tightness factor 16.

Results and Discussion

As mentioned above, analysis of variance was used to test the hypothesis that the mean values of each level of each factor are equal (see Table 2). Here there are three factors, i.e., tightness factor, relaxation treatment and direction of bending. Tightness factor has four levels (11, 13, 14 and 16), relaxation treatment has two levels (dry and wash & dry relaxation), and direction of deformation for bending and shear has two levels (course and wale directions). As a result of analysis of variance, it was seen that the null hypothesis is rejected, i.e., mean values of each level of each factor are not equal to each other (significantly different from each other, 99% significance level), for each deformation parameter, i.e., B, 2HB, G and 2HG5. This is due to the fact that the F values in Table 2 are greater than the F critical values for the 99% significance level (F critical values are 4.1, 7.2 and 7.2 for the tightness factor, direction and relaxation, respectively) (Hamburg, 1970). Thus, according to the results of the analysis of variance, the tightness factor, relaxation treatment and direction of deformation have significant effects on the bending and shear parameters of knitted fabric (B, 2HB, G, 2HG5). This means that as the tightness factor, or relaxation treatment or direction of deformation changes, the mean values of bending parameters (B, 2HB) and shear parameters (G, 2HG5) change significantly.

Table 2. Results of analyses of variance.

Factor	Dependent Variable	F value
Tightness factor	G	393.11
	2HG5	232.43
	B	12.57
	2HB	19.82
Direction	G	69.88
	2HG5	259.3
	B	88.23
	2HB	47.58
Relaxation	G	27.06
	2HG5	50.43
	B	17.00
	2HB	16.62

Several results can be inferred from the data in Table 1 and Figures 2-9:

- There is a general trend that an increase in the tightness factor leads to an increase in bending and shear parameters (B, 2HB, G, 2HG5). An increase in the tightness factor (tightness of structure) results in an increase in inner friction and compression. Thus bending and shear parameters increase.

- Another general trend is that the improvement in relaxation with wash & dry treatment leads to an increase in bending and shear parameters. With wash & dry relaxation, relaxation of the fabric progresses and compactness of structure (loop number per area) increases. This leads to an increase in inner friction and compression. Thus bending and shear parameters increase.

- Bending and shear parameters in the course direction are greater than those in the wale direction. While two loop legs for each loop (i.e., two yarns) are forced to bend or shear in the course direction, one loop head (i.e., one yarn) is forced to deform in the wale direction (see Figure 1). Thus, bending and shear parameters in the course direction are greater than those in the wale direction.

Conclusions

Most studies in the literature have shown that the progress of relaxation (wash & dry treatment) leads to a decrease in bending and shear rigidity parameters, due to a decrease in frictional forces between fibers and between yarns. However, in this study, it has been noted that the progress of relaxation (wash & dry treatment) resulted in an increase in bending and shear rigidity parameters. This may be due to the fact that the wash & dry treatment increases the fabric density (number of loops per unit area or fabric weight), leading to an increase in inter fiber and yarn pressure. Of course, an increase in inter fiber and yarn pressure can cause an increase in fabric bending and shear parameters. The wash & dry treatment can also lead to an increase in bending and shear parameters due to fibrillation damage to the yarn. Thus, we cannot conclude with any certainty that the wash & dry treatment decreases the bending and shear parameters. This is dependent on which effect of relaxation is the predominant effect on the fabric. In this study, the second effect, i.e. an increase in bending and shear parameters due to an increase in inter fiber and yarn pressure was predominant.

There is a general trend that an increase in the tightness factor leads to an increase in bending and shear parameters. Bending and shear parameters in the course direction are greater than those in the wale direction.

Statistical analyses showed that the results are also significant statistically, i.e., both tightness factor and relaxation treatment, direction of deformation have significant effect on the bending parameters and shear parameters of knitted fabrics (B, 2HB, G, 2HG5)

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