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Bending and Compression Behaviour of Polyester Air-jet-textured and Cotton-yarn Fabrics

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Abstract: Air-jet-textured polyester yarns were produced using two feed yarns differing in filament fineness and number of filaments. By varying the yarn overfeed, filament fineness and air pressure, four textured yarns were produced. Woven fabrics were prepared using these textured yarns as weft and cotton yarns in warp. To study the effect of air-jet-texturing parameters on the bending and compression properties, the woven fabrics were tested for thickness, bending rigidity, hysteresis of bending moment, linearity of compression, compression energy and compression resilience. Statistical significance test was carried out at 99% confidence level to trace out the specific trend followed by the fabrics. Statistical analysis is based on the assumption of normal distribution of dataset. Axial orientation of filaments influences the bending properties and loop density and disposition of loops influences the compression properties. Frictional resistance mostly influences the hysteresis of bending moment. Increase in air pressure during texturing creates turbulence to disturb the axial orientation of the filaments; results in changes in fabric thickness, bending and compressional properties. Fabrics with coarser filament have higher bending rigidity due to higher moment of inertia. Fabrics with fine filaments offer higher compression energy due to the ease of loop formation of finer filaments.

Keywords: Air pressure, air-jet textured fabric, bending, compression, core and sheath over feed, filament denier.

1. INTRODUCTION

The comfort characteristics like fabric aesthetic property, thermal comfort and physical comfort like handle of clothing material are getting more priority in the quality evaluation of fabric. The fabric handle mainly depends on its low-stress mechanical properties. The low stress mechanical property of fabric such as shear, bending and tensile together with compression and surface friction have, therefore become essential facets of fabric and clothing objective measurement technology [1]. Fabric properties, especially bending and compression properties exert a major influence on the handle and draping behaviour of apparel fabrics [2]. The bending behaviour of the material is expressed in terms of bending rigidity. Bending rigidity is a measure of ease with which the fabric bends. The fabrics bending rigidity basically depends on the constituent fibres and yarns from which the fabric is manufactured, the fabric construction, and most importantly, the nature of the chemical treatment given to the fabric. Inter-yarn and intra-yarn friction plays important role in deciding the bending behaviour and the type of chemical treatment given to the material, mainly controls this frictional restraint. Bending at low stress is more important because it has a direct relationship and greater association with fabric handle. The higher the rigidity, the lower the fabric handle value [3]. The bending rigidity of a woven fabric is slightly greater than the sum of the bending resistance of the component yarns [4]. More recent work done by Thierron has shown a high correlation between the flexural rigidities of ring, rotor, air-jet spun yarns and the bending lengths of their corresponding knitted fabrics. Thierron and later, Subramaniam *et al.* concluded that yarn structure as it relates to fibre arrangement within the yarn has an important influence on the bending behaviour of yarns and fabrics [5, 6]. One of the most important geometrical aspects of the textile structures is the dimension normal to the plane of the fabric, or the fabric thickness [7, 8], which manifests the compressional properties. The compressibility of a fabric mainly depends on yarn packing density and yarn spacing in the fabric. Compressibility provides a feeling of bulkiness and spongy in the fabric. Compressibility has some correlation with the thickness of the fabric; the higher the thickness, the higher the compressibility [3]. Postle indicated that bulk density or compressional properties of knitted structures are related to the effective diameter of the yarn inside of the fabric and also to the curvature of the loops out of the fabric plane [7, 8]. Ajayi and Elder investigated the effect of fabric compression on frictional properties of woven, knitted and nonwoven fabrics. It is shown that as the fabric compression increases, the difference between the static and kinetic friction forces increases [9].

Improvement in the bulk of continuous-filament yarns is generally achieved by ‘texturing’, a process that introduces crimps, coils, loops and wrinkles to modify the geometry of the constituent filaments to make the yarn more voluminous [10]. Apart from the improvements in the bulk characteristics of fabrics made from textured yarns, there are other added advantages like improved pill resistance, crease resistance, dimensional stability, durability, flexibility, cover and appearance. The textured-yarn fabrics are easy to wash and dry. They also retain strength, abrasion resistance and toughness of the continuous-filament yarn [11]. Air-jet-textured yarns partially simulate the spun yarns, because of their surface loops. The structure of an air-jet-textured yarn depends on the texturing parameters: air pressure, overfeeds of core and effect components, filament denier, number of

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filaments and positioning of coarse and fine filaments in core or sheath and *vice versa*. Fabrics produced from these yarns are affected by their structures and fabric construction parameters. In this article, we discuss on the effect of air pressure, differential change in core and sheath overfeed, and filament fineness on the bending properties; bending rigidity and hysterisis of bending moment and compression properties; linearity of compression curve, compression energy and com-pression resilience and thickness of fabrics.

2. MATERIALS AND METHODS

Polyester yarns of 50 denier (5.5 tex)/48 filaments and 75 denier (8.33 tex)/36 filaments were used as feed yarns for air-jet texturing. The details of feeder yarns are given in Table **1**.

Table 1. Details of Feed Yarns used for Air-jet Texturing

Yarn Code	Yarn Tex	No. of Filaments	Filament Fineness (dtex)
A1	5.55	48	1.156
A2	8.33	36	2.313

2.1 Air-jet Texturing

Texturing was done on Eltex AT-HS air-jet texturing machine at a speed of 400 m/min and air pressure of 9 kgf/cm^2, using a nozzle 'HemaJet Core S325'. After tex-turing, yarns were stretched by 4.7%, heat set at 200 ^{o}C and wound with a stretch of 0.9%. During heat setting, yarns were overfed by 2.9% to the heater. The core and sheath overfeeds were varied to get textured yarns of different structures. Core yarns were wetted using water jet, at a pressure of 2 kgf/cm^2 and flow rate of 0.5 L/jet/h, before feeding them into air nozzle. Textured yarns were produced using the combination of feed yarns A1 and A2. The count of the textured yarns was kept constant at 20 tex. Textured yarns with codes and details of process parameters are given in Table **2**.

2.2 Preparations of Fabrics

Woven fabrics were made from these seven yarns as weft on Saurer automatic loom at 200 picks/min. and cotton yarn of 15 tex was used as warp. Ends and pick density (per inch) were kept at 68 and 50 respectively. The fabric codes made from yarns S1… S4 are F1… F4 respectively.

2.3 Preparations of Fabric Samples

Fabrics were desized, scoured and bleached in comer-cial operations. During processing alkali concentration and operating temperature were kept to a minimum and weft way stretching of fabrics was avoided. Wet processing of fabrics is given in the flow chart below:

Fabric samples → Desizing (in Jigger at 2% NaOH and boiling temperature 80-90 ^{o}C) → hot washing→ Scouring (with caustic soda + hydrogen peroxide + detergent) → Hot washing→ Cold washing → Bleaching (sodium hypochlorite 0.5%) → Cold wash →Neutralization by HCL→ Cold wash →Hot wash with detergent → Cold wash.

2.4 Evaluation of Bending Properties

The bending properties of fabric were evaluated using KES (FB2) pure bending tester. The tester is used for pure bending tests of thin films materials such as fabrics, leather etc. A fixed chuck holds one edge of the sample, while moving chuck holds the other. The moving chuck follows a fixed orbit turning its head at an angle, so that a uniform curvature is maintained on the sample to find the relationship between the curvatures and bending moment. Clamp interval is 1 cm. and rate of bending is 0.5/cm.sec. Maximum curvature is +/- 2.5/cm. The bending parameters, their definitions and units are given in the Table **3**. The typical

Table 2. Yarns Textured with various Process Parameters

Sample Code	Air Pressure Kgf/cm^2	Overfeed of Components %		Feed Yarn Used		Wetting of End
		Core or Normal	Effect	Core or Normal	Effect	
S1	9	11	21.5	A1	2 × A1	core
S2	8	11	21.5	A1	2 × A1	core
S3	9	15	20	A2	A2	core
S4	9	15	19.5	A1	2 × A1	core

Table 3. Kawabata's Bending and Compression Parameters

Test Parameter	Definition of Parameters	Unit
Bending		
B	Bending rigidity	gf.cm^2/cm
2HB	Hysteresis of bending moment	gf.cm/cm
Compression		
LC	Linearity of compression curve	unit less
WC	Compressional energy at 5Kpa pressure	gf.cm/cm^2
RC	Resilience or energy loss due to compression hysteris	percentage (%)

bending moment-curvature curve is depicted in Fig. (**1**). Bending rigidity (B) and bending hysteresis (2HB) are calculated within the curvature of 0.5 and 1.5 and -1.5 and 1.5 respectively.

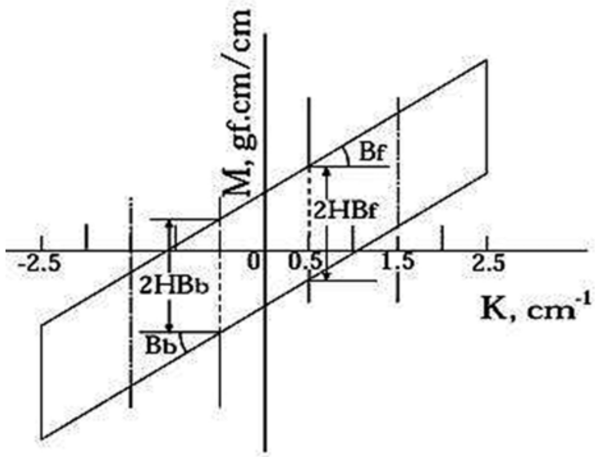

Fig. (1). KES bending measurement: Typical bending moment-curvature curve for fabric in forward and backward direction.

2.5 Evaluation of Compression Properties

The compression properties of fabrics samples were evaluated using KES (FB3) compression tester. This instrument is designed to measure the compressional deformation properties of fabric, rubber, film etc. with high accuracy and sensitivity. The first procedure in the instrument is the setting of the upper limit force. Fabric samples were put on the bottom flat surface. When the driving motor switched is turn on, a plunger (area 2 sq.cm.) starts to descend and compress the sample at a constant rate. When the compression reaches the upper limit force, which is preset, the motor automatically turns to recovery process. The maximum compressional force is 2500 gf. The compresssional parameters, their definitions and units are given in the Table **3**. A typical pressure-thickness curve is presented in Fig. (**2**). Curve BCD stands for the compression cycle and DEB for recovery. The area under the curve BCD indicates the compression energy (WC) and the ratio of the area under the curves DEB &BCD evaluates the compression resilience (RC). The linearity of compression is the ratio of area under the curve BCD and area under the right angle triangle BCD (if the point Band D will be connected by a straight line).

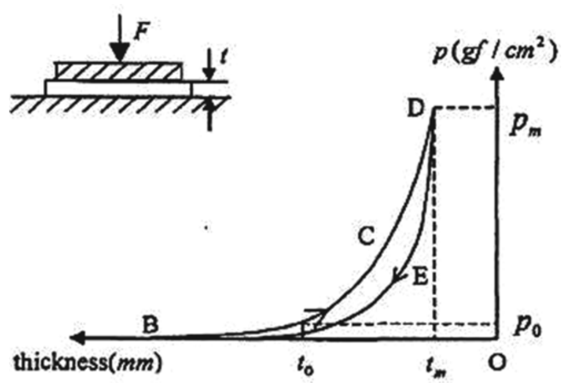

Fig. (2). KES compression measurement: Typical pressure-thickness curve for fabric in lateral compression.

3. RESULTS AND DISCUSSIONS

Fabric thickness, bending properties; bending rigidity, hysteresis of bending moment, and compression properties; linearity of compression curve, compressional energy and compressional resilience for fabrics are shown in Table **4** and Statistical analysis was carried out on the thickness, bending and compression properties at 99% confidence level and the inference drawn is presented in Table **5**.

3.1 Effect of Air Pressure on Bending and Compression

Yarns S1 and S2 are textured at 9 and 8 bar of air pressure respectively, while keeping the same core and sheath overfeed of filaments. The higher air pressure used during air-jet texturing of yarn S1 create more air turbulence and form more number of core and sheath loops, compared to yarn S2. Higher air turbulence also leads to disorientation of filament's core and loops, hence the yarn S1 is loose and bulky compared to yarn S2. Fabric F1 carrying loose and bulky textured yarn S1 display statistically higher thickness than fabric F2. The same cotton yarn is used in the warp direction of both the fabric F1 and F2, hence display almost similar value of bending rigidity (Bwp) in warp direction. The difference between the bending rigidity (Bwp) in warp direction is statistically insignificant, as shown in Table **5**. The value of bending rigidity (Bwt) in weft direction increases with decrease in air pressure from 9 bar to 8 bar. Higher air pressure during texturing creates turbulence to disturb the axial orientation of the filaments; hence the filament yarn S2 textured with lower air pressure carries filaments, which are comparatively flat and aligned to the yarn axis than the filaments of yarn S1. As the parallel filaments work together to resist bending moment, the fabric F2 carrying yarn S2 displays higher value of bending rigidity (Bwt) than fabric F1. It is observed that, there is statistically no difference between the value of hysteresis of bending moment (2HBwp and 2HBwt) in warp and weft direction of fabrics F1 and F2. Bending of fabric occurs with initial resistance offered by the yarn-yarn friction at the cross-over points, then inter-filament friction depending on the cohesiveness of filaments and finally, by bending of the yarns. The contribution of the yarn-yarn and inter-filament friction cannot recover, after the removal of bending moment. The hysteresis of the bending moment is mostly constituted of frictional resistance offered during bending. The yarn S1 carrying disorientated filaments with higher number of loops are less compacted than yarn S2, hence will offer higher yarn-yarn friction, because of shearing of more contacting areas. Yarn S2 carrying flat and orientated filaments than are more compacted and behave cohesively, hence offer higher inter-filament friction than yarn S1. The no difference between the hysteresis of bending moment values of fabrics could be ascribed to the similar resultant frictional resistance of yarn-yarn friction at cross-over points and inter-filament friction. The loosely compacted structure deform easily with normal force, hence the value of compression energy of fabric F1 is lower than fabric F2. Compression resilience is higher in fabric F2 than F1, which is due to more compact structure and less deviation of filaments from there original position, so the filaments can easily shift to their original position after the removal of normal forces. More parallel filaments in weft direction of

Table 4. Bending and Compression Properties of Fabrics

Sample Code		B gf.cm^2/cm	2HB gf.cm/cm	LC	WC gf.cm/cm^2	RC %	T (mm)
F1	Warp	0.094	0.050	0.505	0.039	41.39	0.31
	Weft	0.018	0.016				
F2	Warp	0.094	0.052	0.654	0.058	44.26	0.28
	Weft	0.022	0.016				
F3	Warp	0.091	0.051	0.435	0.036	47.09	0.27
	Weft	0.039	0.017				
F4	Warp	0.092	0.053	0.585	0.070	44.48	0.30
	Weft	0.021	0.016				

B-Bending rigidity, 2HB- Hysterisis of bending moment, LC-Linearity of compression curve, WC-Compression energy, RC- Compression resilience, T-Fabric thickness (mm).

Table 5. Statistical Significance Test; *t* Values and Inferences

Sets	Bwp	Bwt	2BHwp	2BHwt	LC	WC	RC	T
F1, F2	0 NS	4.12 S	1.29 NS	0 NS	4.15 S	4.27 S	2.86 S	2.94 S
F1, F4	0.87 NS	3.59 S	1.54 NS	0 NS	3.53 S	4.98 S	3.11 S	1.18 NS
F3, F4	0.63 NS	5.27 S	1.31 NS	0.42 NS	3.96 S	5.34 S	2.69 S	3.47 S

Bwp- Bending rigidity in warp direction, Bwt-Bending rigidity in weft direction, 2BHwp-Bending hysteresis in warp direction, 2BHwt-Bending hysteresis in weft direction, S- Significant, NS-Not significant.

fabric F2 than fabric F1, causes lower frictional restraint, hence increase the value of linearity of compression.

3.2 Effect of Differential Change in Core and Sheath Overfeed on Bending and Compression

The effect of differential changes in coreand sheath overfeeds on fabric thickness, bending and compressional properties are shown in Table **4**. It is observed that, there is statistically no difference between the thickness values of fabrics F1 and F4. The yarn S4 carries higher core loops and lower sheath loops, where as yarn S1 carries higher sheath loops and lower core loops. Though there is difference in the total density of core and sheath loops due to differential change in core and sheath overfeed, but it is insufficient to cause any difference in the textured yarn thickness. The fabrics F1 and F4 constituted of yarns S1 and S2 don’t refelect any difference in their values of thickness. It is statistically observed that, there is no difference between the values of bending rigidity (Bwp) in warp direction of fabric F1 and F4, which is due to similar cotton yarns used in the warp direction. Fabric F4 displays higher bending rigidity (Bwt) in weft direction than fabric F1, irrespective of no difference in the thickness values. The bending rigidity is mostly influenced by the axial orientation of the filaments in yarn; though the frictional resistance has some contributions. Yarn S4 carries filaments with lower loop density than yarn S1, due to differential change in overfeed rates, hence the axial orientation of filaments is higher in yarn S4 than S1; which could be the possible reason behind the higher bending rigidity (Bwt) of fabric F4 than F1. It is observed that, there is statistically no difference in the values of hysteresis of bending moments (2HBwp and 2HBwt) in warp and weft direction of fabrics F1 and F4, which could be due to the similar explanation, as mentioned in section 3.1. Here with increase in core overfeed, there is increase in compressional energy, linearity of compression and compression resilience. In yarn S4, with slightly lower overfeed of sheath; fine loops are formed on yarn surface, which are entangled with more loops of core filaments (higher core overfeed). These compacted textured yarns formed with fine sheath loops entangled with dense core loops favours the distribution compressive forces, which in turn also lead to higher values of LC and RC. Though there is direct correlation between the fabric thickness and compression properties; the distributions of compressive forces alter the compression properties of fabrics F1and F4, irrespective of equal value of thickness.

3.3 Effect of Filament Fineness on Bending and Compression

The effect of changes in feed yarns on thickness, bending and compressional properties are shown in Table **4**. It is statistically observed that, fabric F4 indicates higher value of thickness than fabric F3. The relationship between bending rigidity values of yarn and single filament’s diameter is shown in Equation 1 [12];

$$G_y = \frac{(n\pi r^4)}{4} \quad (1)$$

Where, G_y is the yarn bending rigidity; n is number of single filaments; E is initial tensile modulus of filament; r is filament radius. According to the equation, the coarser filament of yarn S3 will have higher bending rigidity than yarn S4. The size of loops formed during texturing, is influenced by the bending rigidity of filaments. Higher bending rigidity will lead to higher bending curvature, results in larger size loops and vice-versa. Yarn S3 carrying coarser filament will lead to formation of larger loops, where as yarn S3 will form smaller loops. The smaller loops are resilient and show higher stability to deformation than larger loops; hence fabric F4 indicates higher thickness than fabric F3. It is statistically observed that, there is no difference between the bending rigidity (Bwp) values of fabrics F3 and F4, which is due to the similar cotton yarns used in warp direction. Fabric F3 made from coarser filament textured yarn has higher values of bending rigidity (Bwt) than fabric F4 made from finer filaments. This is due to higher bending rigidity of yarn S3 than S4. There is statistically no difference between the values of hysteresis of bending moments (2BHwp and 2Hbwt) in warp and weft direction of fabrics F3 and F4; which could be due to the similar explaination, as mentioned in section 3.1. Fabrics F3 contain textured weft yarn made from few coarser filaments, where as weft yarn of fabric F4 consists of more number of finer filaments. Finer filaments are less rigid than coarser filaments under compression, but during texturing they form many smaller loops than coarser filaments, which have higher compressional stability than the bigger loops of coarser filaments. Further, finer filaments are more in number; hence this favours for higher linearity of compression and compression energy of fabric F4 than F3. The higher loop density and smaller loops of textured yarn S4 leads to more entanglements among themselves than the lower loop density and larger loops of yarn S3, hence the chances of retention of original filament position after the withdrawn of normal force is lower in yarn S4 than yarn S3; which causes fabric F4 to display lower value of compression resilience than fabric F3.

4. CONCLUSIONS

The bending rigidity (Bwp) of fabric in warp direction is mostly dependent on the type of warp yarns used and independent on the texturing process parameters employed to produce the textured weft yarns. There is statistically no effect of change in air-pressure, differential changes in core and sheath overfeeds and changes in feed yarns on the bending rigidity of fabrics in warp direction. The hysteresis of bending moment is constituted of yarn-yarn friction at the cross-over points and inter-filament friction. The hysteresis in bending moments in both the warp and weft direction is statistically found to independent of the texturing process parameters; change in air-pressure, differential changes in core and sheath overfeeds and changes in feed yarns. Increase in turbulence with increase in the air pressure decreases the axial orientation of the filaments, resulting in increase in fabric thickness and decrease in bending rigidity in weft direction, linearity of compression, compression energy and compression resilience. Differential change in core and sheath overfeed (higher increase in core overfeed than decrease in sheath overfeed) causes no change in fabric thickness, but increases bending rigidity in weft direction, linearity of compression, compression energy and compression resilience. Increase in filament fineness increases bending rigidity in weft direction and compression resilience and decreases thickness, linearity of compression and compression energy of fabrics.

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REFERENCES

[1] B. K. Behera, and D. B. Shakyawar, “Structure-property relationship of fibre, yarn and fabric with special reference to low-stress mechanical properties and hand value of fabric”, *Indian J. Fibre Text. Res*., vol. 25, pp. 232-237, 2000.

[2] P. Radhakrishnaiah, “Low stress mechanical behaviour of cotton/polyester yarns and fabrics in relation to fiber distribution within the yarn”, *Text. Res. J.*, vol. 66, pp. 99-103, 1996.

[3] B. K. Behera, “Comfort and handle behaviour of linen blended fabrics”, *Autex Res. J*., vol. 7, pp. 33-47, 2007.

[4] P. Grosberg, “The mechanical properties of woven fabrics, Part II: The bending of woven fabrics”, *Text. Res. J*., vol 36, pp. 205- 211, 1966.

[5] W. Thierron, “The flexural rigidity of polyester fibre-cotton yarns produced on the ring, rotor and friction spinning systems”, *J. Text. Inst*., vol. 76, pp. 454-458, 1985.

[6] V. Subramaniam, G. Nalankilli, V. Mathivanan, and K. Jagannathan, “Abrasion resistance of ring and rotor spun yams in relation to their coefficient of friction”, *Text. Res. J.*, vol. 57, pp. 369-370, 1987.

[7] R. Postle, “Structural mechanics of knitted fabrics for apparel and composite materials”, *J. Text. Inst.*, vol. 62, pp. 80-90, 2001.

[8] R. Postle, “A geometrical assessment of the thickness and bulk density of weft-knitted fabrics”, *J. Text. Inst.*, vol. 65, pp. 155-163, 1974.

[9] J. O. Ajayi, and H. M. Elder, “Fabric friction, handle, and compression”, *J. Text. Inst*., vol. 88, pp. 232-241, 1997.

[10] N. Eskin, “Analysis of a high temperature heater in a false twist texturing process”, *Energy Conver. Manag.*, vol. 44, pp. 2531-2547, 2003.

[11] I. C. Sharma, and V. Bhargava, “Influence of number of filaments of textured yarn on fabric characteristics”, *Indian Text. J.*, vol. 94, pp. 99-103, 1983.

[12] V. K. Kothari, *Quality control*. Development Commissioner for Handlooms: Ministry of Textiles, Government of India, 2000.

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