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Evaluation of the Bending Properties of Viscose/Polyester Woven Fabrics

Abstract
This work investigates the effect of warp and weft density on the bending properties of polyester viscose woven fabrics. 25 lightweight woven fabrics of different densities were produced and evaluated with three methods; KES, extraction, and a newly-suggested method. The test results of the three methods were compared. A correlation between the quantitative parameters of the three methods indicates that the concentrated loading method is better able to show the effect of warp and weft density increase. It is observed that as the density (warp and weft / cm) increases, so the buckling zone of the fabric under concentrated tensile loading moves up (the buckling phenomenon occurs late). In other words, the specification of the buckling zone of the fabric is dependent upon the changes in warp or weft density. It also shows that the post-buckling slope increases due to the increase in warp or weft density. In addition, the ending slope decreases as the fabric density increases.

Key words: *bending behaviour, extraction method, KES system, concentrated loading method .*

Introduction

The bending behaviour of the woven fabrics is important to fabric producers and clothing manufacturers. In practice, the tools which are used to measure this property are the KES-FB2 pure bending tester (which measures bending rigidity per unit width and the hysteresis of the bending movement) and the FAST-2 bending meter, which is based on Peirce's bending length [1] and measures a fabric's two bending properties, namely the fabric bending length which is related to the fabric's ability to drape, and the fabric bending rigidity which is related to the quality of stiffness when a fabric is handled [2].

It is claimed that the extraction of fabric through the ring could also be a method of evaluating mechanical properties including bending (due to the folding phenomenon which occurs during extraction) [3, 4].

It is also known that when tensile force (i.e. concentrated force) is applied to a very small portion of a plate or sheet-like material, the elements in the immediate vicinity of the points of application of load are subjected to very large stress, while other elements near to the ends are free from any stress [5]. This phenomenon causes the development of longitudinal stress in the direction of the applied load as well as lateral force in the opposite direction. In the case of flexible sheet materials, such as woven fabrics, the phenomenon results in buckling which includes 'in-plane' (tensile and shearing) and 'out-of-plane' (bending) deformations [6, 7] (Figure 1). To benefit from the buckling phenomenon, the tensile, shearing and bending properties of the woven fabrics can be evaluated [8].

The present work is aimed at comparing the ability of extraction and the concentrated loading method (200 cN tensile force applied over a small portion of the bias sample) to measure the low-stress bending behaviour of woven fabrics.

Materials

25 plain weave woven fabrics of different warp and weft densities with the specifications as shown in Table 1 were produced on the Sulzer-Rapier 6100 weaving machine under the same conditions.

Methods

The samples were tested on a KES F2 bending tester, and the bending quantitative values (B and 2HB, as shown in Figure 2) were set as bases for the compari-

Table 1. *Specifications of the fabrics.*

Fabric code	End/cm	pick/cm	Number of cross, points/cm	Weight, g/m^2
A1	24	20	480	91.00
A2		22	528	95.00
A3		24	576	99.10
A4		26	624	103.31
A5		28	672	107.50
B1	26	20	520	95.10
B2		22	572	99.12
B3		24	624	10.30
B4		26	676	107.33
B5		28	728	111.60
C1	28	20	560	99.00
C2		22	616	103.23
C3		24	672	107.39
C4		26	728	111.50
C5		28	784	115.70
D1	30	20	600	103.20
D2		22	660	107.25
D3		24	720	111.50
D4		26	780	115.55
D5		28	840	120.00
E1	32	20	640	107.30
E2		22	704	111.50
E3		24	768	115.62
E4		26	832	119.67
E5		28	896	123.92
fabric weave: plain	**warp yarn count:** 2/9.8s, tex		**weft yarn count:** 1/19.6s, tex	**materials:** 50/50 polyester/viscose

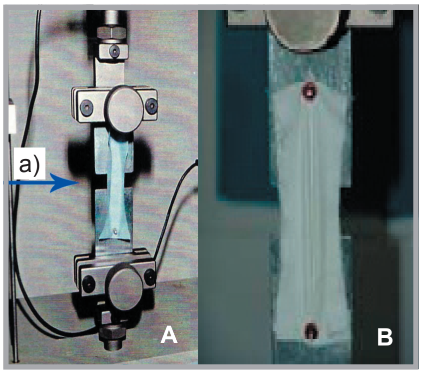


***Figure 1.** A. Measuring stand for behaviour determination of woven fabrics under concentrated force; a - special plates. B. Enlarged view of the specimen.*

***Figure 3.** Polished steel cylindrical ring.*

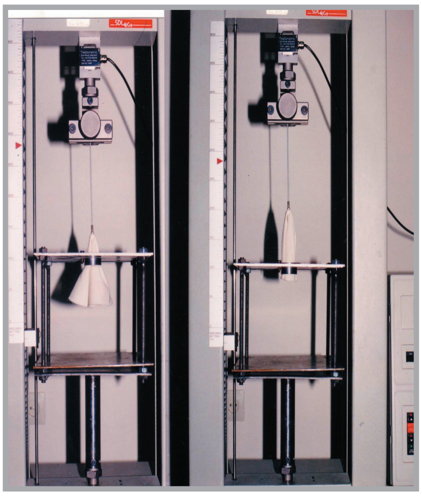


***Figure 4.** Specimen being withdrawn through the ring.*

son and evaluation of other methods. The values are the average result of 4 tests.

Sample preparation and test procedure

Extraction Method

This method is based on holding the sample at its centre and then pulling (extracting) it through a ring of appropriate diameter by using an Instron tensile tester. A circular specimen of 25 cm in diameter was cut from each fabric [9]. A highly polished metallic ring of 15 mm in diameter and 20 mm in height (Figure 3) was mounted on the jaws of a Shirley Testometric-Micro 350 apparatus (Figure 4).

The circular samples were drawn through the ring at the rate of 5 mm/min (Figure 4). The behaviour of the fabric during testing (folding, shearing, bending, compressing and rubbing against the interior wall of the ring) was recorded on the load-elongation chart of the tensile testing machine (Figure 5). Since the specimen is circular, the direction would not make any difference. Table 2 and Figure 6 show the parameters extracted from each withdrawal load-displacement curve.

Concentrated Method

The testing method is based on applying a 200 cN force over a small portion of the edge of the rectangular specimen (Figure 1).

Three rectangular specimens, each 24 cm long and 5 cm Wide, were cut from each sample fabric; one at an angle of 22.5° to the warp direction (which is 67.5° to the weft direction), one at 45° to the warp (which forms the same angle to the weft), and one 67.5° to the warp (which is 22.5° to the weft). The strip thus obtained was folded in half to form a double ply of face-to-face fabrics (12 cm long). The puncher inserts an eyelet 1 cm from the ply ends opposite to the fold, and the second eyelet was inserted 10 cm away from the first one after any possible slack is removed. The eyelets are used to prevent the distortion of the fabric (sample) at the points of the load insertion.

The length/width ratio of the sample was taken to be 2, due to the fact that the distribution of load at the distance equal to the width of the sample from the point of application of a concentrated force was very close to the condition of uniform loading [5]. It should be noted that doubling the strip frees the samples from any shear strain which could be developed under tensile stress.

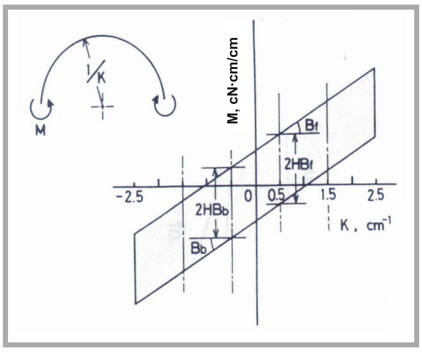


***Figure 2.** Kawabata evaluation system; B = Slope at K = 0.5 and 5, 2HB = Hysteresis at K = 0.5.*

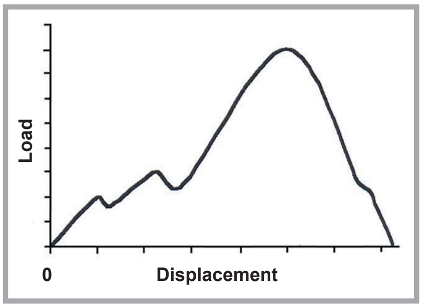


***Figure 5.** Typical withdrawn displacement curve.*

Figure 1 shows the highly polished plates, (5 cm × 7 cm with a pin for sample mounting) fixed on the jaws of the Shirley Testometric-Micro 350.

The ready samples were mounted on the pins by the operator, and were subjected to a single loading at a rate of 10 mm/min with 200 g maximum force by using a simple attachment to the jaws of the Testometric-Micro 350 made in the Shirley

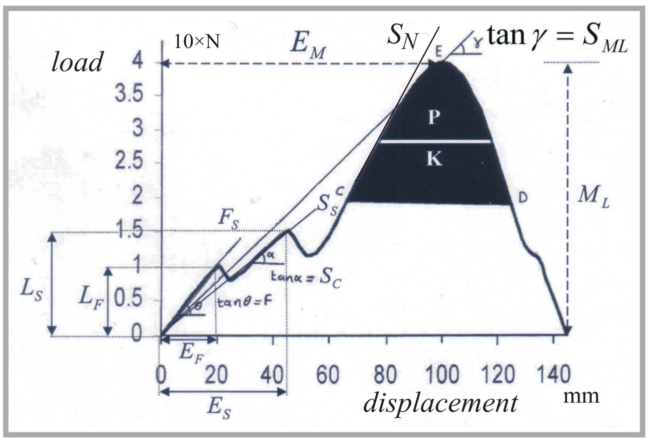
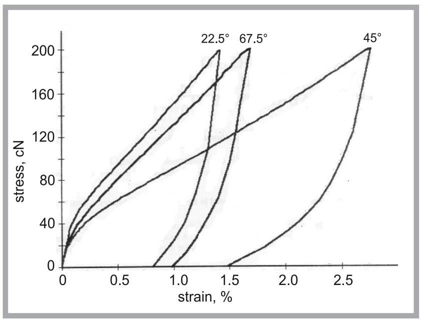


***Figure 6**. Parameters extracted from the withdrawal load-displacement curve of extraction method.*



Figures 7. *Typical concentrated loading curves.*

developments with a 2 kg-load cell. Figure 7 shows the typical load extension curves of the concentrated method.

Despite the fact that all the loading curves of the new method are not the same, they do all have a common zone among themselves. This zone specifies the limit of the 'in-plane' deformation, after which a sample shows 'out-of-plane' deformation.

The parameters extracted from the curves in respect to the buckling zones are shown in Table 3 and Figure 8.

Results and discussion

Table 4 shows the correlation coefficient between the KES bending parameters [bending rigidity (B) and bending hysteresis (2HB)], the parameters extracted from the curves of the extracted method, and the features extracted from the concentrated loading curves.

The features extracted from the curve of the concentrated loading method showed higher correlation to the KES bending parameters, as well as the changes in warp and weft density (Tables 4 and 5), indicating the ability of the method to show the effect of the changes on the bending properties.

Among the parameters extracted from the curves of the two methods, the highest correlation was found in the post-buckling slope (PBS) of the concentrated loading methods (where the out-of-plane deformation starts), as well as the load/elongation (*l/e*), where the maximum deformation occurs.

It is interesting that the post-buckling slope of the samples cut close to the warp direction ($PBS_{22.5°}$) shows a higher correlation to the bending rigidity of the weft direction (as well as the weft density

Table 2. *Features extracted from the load displacement withdrawal curve.*

Parameter	Symbol	Units	
		CGS	SI
Initial slope (from zero load up to the first jump). Behaviour up to the first folding	F_S	*kgf/mm*	*N/m*
The slope of the second jump (from zero load up to the second jump). Behaviour up to the second folding	S_S	*kgf/mm*	*N/m*
The nominal slope (slope of the CE line)	S_N	*kgf/mm*	*N/m*
Stress at the point of first jump (first folding)	L_F	*kgf*	*N*
Displacement at the point of first jump (first folding)	E_F	*mm*	*m*
Maximum load used to extract the fabric through the nozzle	M_L	*kgf*	*N*
Displacement at maximum load	E_M	*mm*	*m*
The slope from zero load up to the maximum load	S_{ML}	*kgf/mm*	*N/m*
Load used for the second folding phenomenon	L_S	*kgf*	*N*
Displacement at the second folding phenomenon	E_S	*mm*	*m*
Area under the curve (work done during the extraction)	A_R	*kgf mm*	*N m*
Bottom part of the summit area of the curve (where maximum deformation occurred)*	*K*	*kgf mm*	*N m*
Top part of the curve where maximum deformation occurred	*P*	*kgf mm*	*N m*

* Maximum height of the extraction curve is halved, and the top height is halved again to P and K, as shown in Figure 6.

Table 3. *Features extracted from the curves of the new method.*

Parameter	Symbol	Units	
		CGS	SI
Strain at 200 g load	EML	%	%
Initial slope (first 10 g loading). Initial behaviour of the fabric when load is applied	*IS*	*gf*	*N*
Post buckling slope (50 g load after buckling point).	*PBS*	*gf*	*N*
Ending slope	*ES*	*gf*	*N*

Table 4. *Correlation values between warp and weft KES bending properties and parameters from other methods.*

Method		Elements	Correlations			
			Bending hysteresis		Bending rigidity	
			warp	weft	warp	weft
Concentrated loading method	67.5°	Load/elongation at 200 cN force*	0.711	0.725	0.683	0.705
		Ending slope	0.742	0.621	0.652	0.579
		Initial slope	0.513	0.692	0.443	0.644
		Post buckling slope	0.854	0.716	0.839	0.633
	45.0°	Load/elongation at 200 cN force	0.792	0.811	0.787	0.795
		Ending slope	0.799	0.833	0.764	0.829
		Initial slope	0.614	0.695	0.571	0.664
		Post buckling slope	0.755	0.791	0.771	0.782
	22.5°	Load/elongation at 200 cN force	0.798	0.852	0.781	0.833
		Ending slope	0.705	0.862	0.691	0.801
		Initial slope	0.422	0.256	0.344	0.236
		Post buckling slope	0.776	0.911	0.732	0.876
Extraction	F_S	Initial slope (from zero load to the first jump)	0.355	0.491	0.371	0.463
	S_S	Initial slope (from zero to the second jump)	0.481	0.532	0.451	0.497
	S_n	Nominal slope (slope of the CE line)	0.591	0.563	0.562	0.554
	K	Bottom part of the summit area of the curve	0.793	0.801	0.722	0.764
	E_m	Displacement at maximum load	0.664	0.692	0.633	0.681
	L_F	Stress at first jump (first folding)	0.351	0.362	0.310	0.330
	E_F	Displacement at first jump (first folding)	0.310	0.360	0.241	0.244
	M_L	Maximum load used to extract the fabric through the nozzle	0.491	0.443	0.411	0.432
	S_{ml}	The slope from 0 load up to the maximum load	0.588	0.592	0.532	0.553
	L_S	Load used for the second folding phenomenon	0.605	0.594	0.592	0.544
	E_S	Displacement at the second folding phenomenon	0.190	0.211	0.140	0.195
	AR	Area under the curve (work done during the extraction)	0.792	0.721	0.711	0.686
	P	Top part of the curve where maximum deformation occurred	0.722	0.785	0.653	0.662

* The l/e parameter is the ratio of change in load inserted (cN) to change in strain (%) at the maximum point (which is 200 cN load). Its unit is therefore cN alone.

changes), while the post-buckling slope of the samples close to the weft direction ($PBS_{67.5°}$) shows a higher correlation to the bending rigidity of warp direction, as well as the warp density changes. This is due to the fact that when samples are under tensile load, the longitudinal threads are under tension (tensile load) and the crossing yarns are relatively free to bend.

Table 4 also shows that the value of *l/e* is highly correlated to the bending rigidity, as well as the changes in fabric density, indicating the fact that as the tightness of the yarns in fabric (warp or weft density) increases, so the fabric deformation to the prefixed load is decreased. So the stiffer the fabric, the higher the slope would be.

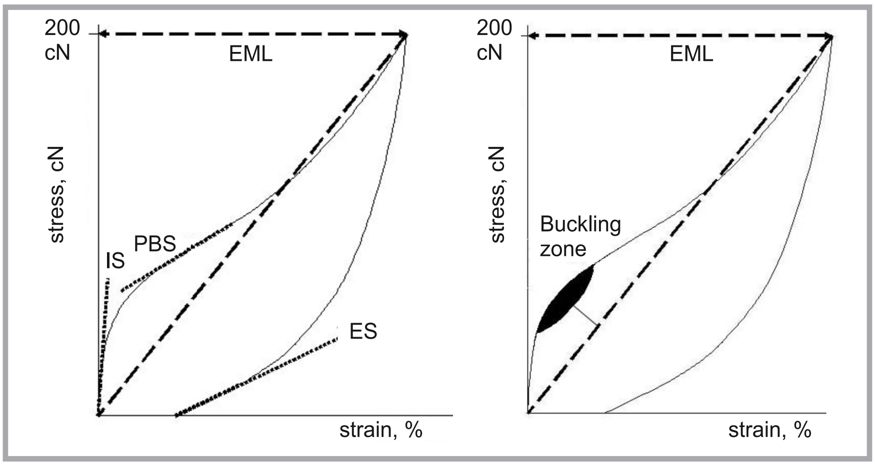


Figure 8. *Quantitative features extracted from the concentrated loading method.*

Table 5. *Correlation values between fabric density and bending parameters.*

Method		Elements	Correlation between number of the cross points	warps	wefts
KES		Bending rigidity in weft direction	0.841	0.424	0.722
		Bending rigidity in warp direction	0.803	0.762	0.402
		Bending hysteresis in weft direction	0.781	0.451	0.645
		Bending hysteresis in warp direction	0.742	0.795	0.305
Concentrated loading method	67.5°	Load/elongation at 200 cN force	0.861	0.671	0.561
		Ending slope	0.633	0.682	0.252
		Initial slope	0.720	0.547	0.502
		Post buckling slope	0.901	0.736	0.533
	45.0°	Load/elongation at 200 cN force	0.844	0.599	0.571
		Ending slope	0.703	0.511	0.461
		Initial slope	0.626	0.493	0.410
		Post buckling slope	0.872	0.684	0.553
	22.5°	Load/elongation at 200 cN force	0.851	0.591	0.580
		Ending slope	0.802	0.636	0.491
		Initial slope	0.294	0.485	0.071
		Post buckling slope	0.855	0.514	0.642
Extraction	F_S	Initial slope (from zero load to the first jump)	0.622	0.457	0.463
	S_S	Initial slope (from zero to the second jump)	0.703	0.426	0.496
	S_n	Nominal slope (slope of the CE line)	0.754	0.496	0.445
	K	Bottom part of the summit area of the curve	0.811	0.565	0.532
	E_m	Displacement at maximum load	0.723	0.452	0.411
	L_F	Stress at the point of first jump (first folding)	0.555	0.411	0.342
	E_F	Displacement at the point of first jump (first folding)	0.331	0.251	0.283
	M_L	Maximum load used to extract the fabric through the nozzle	0.510	0.341	0.399
	S_{ml}	The slope from zero load up to the maximum load	0.773	0.552	0.511
	L_S	Load used to have the second folding phenomenon	0.662	0.544	0.371
	E_S	Displacement at the second folding phenomenon	0.751	0.452	0.522
	AR	Area under the curve (work done during the extraction)	0.711	0.433	0.501
	P	Top part of the curve where maximum deformation occurred	0.772	0.485	0.453

Observation of the fabrics during testing showed that each fabric, depending upon its density, would have different types of deformation; so that as the fabric density increases, the buckled zone shape of the fabric goes toward the rounded curvature shape (Figure 9). Therefore the buckling configuration and specification gives objective and subjective information to the engineers about the properties of the woven fabric such as drape, handle and wrinkle.

The ending slope of the unloading curve of the concentrated loading method is highly correlated to the bending hysteresis. This portion of the curve shows how the fabric will revert to its original form. Naturally, if the slope is not the same as the initial slope, it means that some in-plane deformation has happened, which could obviously be related to the fabric bending hysteresis.

Figures 10 and 11 show the valuable comparison of the effect of warp and weft change on concentrated loading curves. This comparison gives textile engineers a practical guide to see how the change in warp and weft density will affect the properties of the fabric.

Nowadays technical communication between the apparel and textile engineers has become close, and as a result the relation between the objective data of the fabrics and the result of the tailoring is transmitted from apparel factories to textile engineers. So any tools which show the exact changes to the fabric properties are helpful to both groups, as well as improving the fabric quality. Thus, it seems that the concentrated loading method could be a valuable tool, due to its ability to offer objective and subjective evaluations of the effect of the changes on the properties.

It is worth mentioning that in a KES bending tester, 4 samples for each direction must be taken; the fabric sample is mounted in a vertical plane, which the operator must handle with great skill and dexterity. In contrast to the KES tester, the concentrated loading method requires no extra instruments for the textile manufacturers.

Conclusions

- The tensile concentrated loading of the bias sample can be used to evaluate the bending behaviour of the woven fabrics. The ability comes from the phenomenon of 'in-plane' and 'out-of-plane' deformation of the woven fabrics due to the buckling deformation of fabrics.

- Three parameters extracted from the loading curves of the new system (the post-buckling slope, strain at 200 cN force and the ending slope) are highly correlated to the KES bending parameters, and can be accepted as quantitative bending elements of the evaluation.

- The new method readily displays the effects of any change (such as fabric density) on the bending behaviour of the fabrics. The change is obvious by the movement of the buckling zone (change in the post-buckling slope and change in maximum strain). In practice, this capability is very helpful to quality engineering management.

- Samples cut close to the warp direction show the effect of weft changes, and samples cut close to weft direction show the warp changes to the bending properties.

- With regard to the fact that the cost of a KES pure bending tester is relatively high, the role of the operator in testing the fabrics by KES is vital. Although textile factories mostly do have the tensile tester, the new methodology can be readily used to measure the bending properties of the woven fabrics without any additional cost or complexities.

- The top portion of the extraction method curve (bottom part of the summit area of the curve) also show a good correlation to the bending properties of the woven fabrics, due to the folding phenomenon which occurs when passing the fabric through the nozzle. However, no effect of direction change (warp or weft density changes) is found by this method.

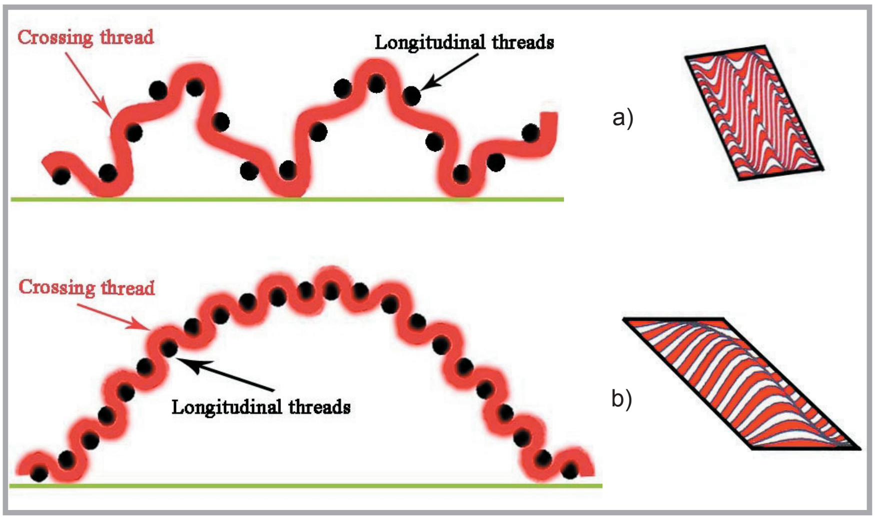


Figure 9. *Types of the buckling of the woven fabric due to tensile concentrated loading (the middle portion of the specimen); a) low density - **double curvature**, b) high density - **single rounded curvature**.*

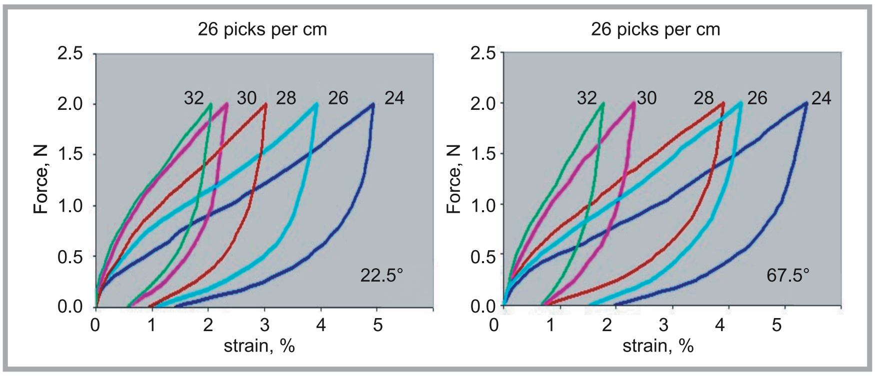


Figure 10. *Effect of warp increase (24, 26, 28, 30 & 32).*

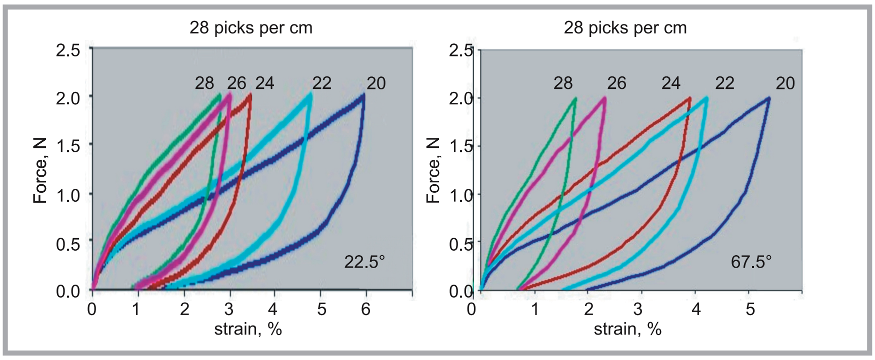


Figure 11. *Effect of weft increase (20, 22, 24, 26 & 28).*

Editorial note

In all figures and tables, 'cN' and 'N' are placed as the units of force in accordance with the SI-unit system. In reality, the Authors carried out their measurements by devices marked in 'gf' and 'kgf' and by those values have been marked the y-axis. Both units are similar, but to obtain exactly values it is necessary to use a corrected function.

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