Indian Journal of Fibre & Textile Research
Vol. 39, September 2014, pp. 221-229

Seam slippage and seam strength behavior of elastic woven fabrics under static loading

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Received 25 September 2013; revised received and accepted 1 January 2014

Effects of fabric extensibility and stitch density on seam slippage and strength behavior of elastic woven fabrics have been studied. Six fabric samples with different values of elasticity have been woven by changing the number of elastic core-spun cotton yarns and normal ring cotton yarns in the weft direction and then finished for sewing process. The samples are sewn with three stitch density levels (4, 5 and 6 stitches/cm) in warp direction and one stitch density level (5 stitches/cm) in weft direction. Fabric tensile properties, seam slippage load and seam strength have been measured and analyzed both in warp and weft directions. The results show that seam slippage and strength properties can be well explained in terms of fabric tensile properties. In general, increase in fabric extensibility leads to decrease in seam slippage load and seam strength in weft direction. In warp direction, seam slippage load also decreases with increase in fabric weft extensibility, whereas seam strength remains invariant. The results also reveal that the increase in stitch density results in a higher seam slippage load and strength value.

Keywords: Elastic woven fabrics, Fabric extensibility, Seam slippage, Seam strength, Static loading

1 Introduction

Seams are widely used in clothing industry for joining different pieces of fabrics to construct the garment with desired properties according to costumers' needs. The characteristics of a properly constructed seam are its strength, elasticity, durability, stability and appearance, which depend on the seam type and the stitches per unit length of the seam, the thread tension and the seam efficiency of the fabric[1].

Garments and consequently seams are constantly under different kinds of stresses, normally in different directions, according to body movement which is covered by garment. When the seam is under some transverse strain, then displacement (called seam slippage) of the stitch relative to fabric layers can occur[2]. In severe cases, applied load may lead to rupture but before seam failure occurs, enough yarn slippage (filling yarns shifting over warp yarns or vice versa) develops to render the garment unusable, because such failure is not readily repairable by seaming. Therefore, measuring resistance to slippage of yarns in woven fabrics is of great importance in quality control of garment[3].

Different aspects of seam slippage have been investigated. Galuszynski[2] developed a model mainly based on fabric geometry and related parameters to calculate the amount of seam slippage. It was observed that the amount of seam slippage increases with increasing yarn-to-yarn friction, contact angle between threads (fabric geometry), the number of weft yarn in fabric, stitch density and yarn flexural rigidity. Miguel *et al.*[4] performed seam slippage test in both warp and weft directions in a wide range of woolen and worsted fabrics. They found that the conventional variables that impact seam slippage most seriously are opacity, polyamide content, finish type and cover factor. Yildirim[5] constructed a system based on a non-linear regression mathematical model to predict the seam opening properties of woven seat fabrics. The author found that fabric physical properties especially weft density play a more important role in the seam opening behavior than the stitch density for these especial kinds of fabrics. Malciauskiene *et al.*[6] investigated the effect of weave type on seam slippage of unbalanced fabrics. It was found that seam slippage is influenced significantly by the weave type. In another work, they also studied the influence of weave, warp density and weft density on seam slippage of wool fabrics[7]. They concluded that the fabric weave and weft setting parameters have a substantial influence on the slippage resistance of yarns at a seam in woven fabrics, which can be predicted by a two-factor polynomial second order

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equation. Pasayev *et al.*[8] studied the techniques for decreasing the seam slippage in chenille fabrics. They found that fabric weft density, the number of interlaced chenille yarns over warp and stitch density are significantly affected by the seam slippage of these fabrics as well as sewing direction. They also supported their experimental results by developing a theoretical model discussing distribution of energies applied to sewn structure under tensile loads[9]. It was revealed that the increase in the fabric layers sewn together would lead to decrease in seam slippage.

Seam strength as a consequence of seam slippage growth is another important parameter of sewn structure performance from quality control point of view. Brain[10] tried to relate stitch strength properties to that of threads by imposing some corrections in minimum loop strength theory previously introduced by Burtonwood and Chamberlain[11]. It was concluded that although the corrected model had a relative good agreement with experimental measurements; further studies of the fabric contribution to seam strength need to be done. Tsui *et al.*[12,13] published a generalized mathematical and physical model particularly considering the effect of angle of bias (where the yarns in the fabric run at an angle to the seam line) to explain the relations between seam strength and parameters such as angle of bias, gauge length, width of seam, fabric type and fabric construction. Amirbayat[14] investigated the seam strength of a wider range of orientations, 66 different seams at 10° intervals including the 45° bias, i.e. (0-0), (0-10)…, (10-10)…, (10-45)…, and so on by two different methods, namely a simple tensile test and a grab test. The results revealed that seams sewn with similar plies, except at 45° which has the least strength among all samples, have higher grab strengths than seams of different ply properties. He also showed that incompatibility of ply strength has a negative effect on seam strength in both cases of seam failure.

Nowadays there is an increasing trend of using elastic fabrics, known as 'stretch fabrics' to produce garment not only with specific applications such as swimwear, sportswear, and lace but also for everyday clothing. With stretch fabric, comfort is achieved by reducing garment resistance imposed on the body, through increased fabric 'give'. This also means that the garments can be cut more neatly and will conform better to the body[3].

In recent years, there have been limited research studies on the seam slippage behavior of elastic woven fabrics. In particular, Gurarda[1] investigated the seam performance of PET/Nylon-elastane woven fabrics considering weft density, weave type and sewing thread as the variables. The results revealed that the increase in sewing thread size enhances the seam strength and seam efficiency. It was also shown that using elastane in the weft direction of the fabrics promotes seam performance comparing with the warp direction, while using elastic yarns in weft direction prevented the differences. In a further study, Gurarda and Meric[15] investigated the slippage and grinning behavior of lockstitch seams on elastic woven fabrics under cycling loading. Two different fabric weave types (twill and plain), two different weft densities (26 and 29 weft/cm) and two different elastane yarns (PET/elastane air-covered and twisted yarn) were taken as samples for the experiments. The results showed that seam slippage and grinning increase with the decrease in weft density and increase in fabric extensibility.

It can be seen that there are a few studies about different aspects of seam performance properties of elastic woven fabrics[1,15]. It can also be concluded from previous researches that there is no systematic research available on the seam slippage and strength of elastic woven fabrics produced with a predetermined elasticity values at a wide range of levels. Therefore, a need was felt to investigate more deeply about seam behavior of these kinds of fabrics sewn with different stitch densities under tensile loads. The present paper was aimed at studying the effects of fabric extensibility and also stitch density on seam slippage and strength of elastic woven fabrics.

2 Materials and Methods

2.1 Sample Preparation

Woven fabrics with different elasticity along weft direction were used for the study. Warp yarns were cotton ring-spun yarns with linear density of 15 tex (40 Ne) and twist factor of 3560 (α_{tex}). Two different yarns were used in fabric weft direction, namely normal cotton ring-spun yarns and elastic core-spun yarns with the same linear density of 20 tex (30 Ne) and twist factor of 4160 (α_{tex}). Elastic core-spun yarns were produced on a ring frame machine by using spandex filament of 44.4 dtex as the core and cotton as the sheath of yarns. Draw ratio value of spandex filament (ratio of front roller linear speed to that of filament feed roller) was kept constant at 3.5 during spinning process for all yarn samples. All of fabric samples were woven with plain weave type on Sulzer G6100 rapier weaving loom with six different weft layouts (Table 1).

To quantify the fabric elasticity in weft direction, elastane percentage ($E.P$) was calculated for each samples using the following equation and the results are given in Table 1:

$$E.P=(\frac{a}{a+b}).(\frac{Tex_e}{Tex_t})\times 100 \quad \dots (2)$$

where a is the number of core-spun yarns in weft direction layout; b, the number of normal spun yarns in weft direction layout; Tex_e, the linear density (tex) of elastane filament (44.4 dtex); and Tex_t, the linear density (tex) of weft yarns (20 tex). Schematic views of fabric structures are shown in Fig. 1.

Fabric samples were processed using the same dyeing and finishing procedures. The tension in weaving and finishing processes were adjusted in such a way to produce fabric samples with identical densities along weft and warp directions. Thus, final finished fabric samples were obtained with 27 cm^{-1} and 47 cm^{-1} density values in weft and warp directions respectively. In this way, the final fabric sample thickness and weight were measured as 0.28 mm and 124 g/m^2 respectively.

Table 1—Fabric samples characteristics

Sample coding	Yarn layouts in weft direction	Elastane percentage
C	Elastic ring core-spun yarns	22.20
3C1N	3 elastic ring core-spun yarns +1 ring normal spun yarn	16.65
2C1N	2 elastic ring core-spun yarns +1 ring normal spun yarn	14.80
1C1N	1 elastic ring core-spun yarn +1 ring normal spun yarn	11.10
1C2N	1 elastic ring core-spun yarn +2 ring normal spun yarns	7.40
N	Ring normal spun yarns	0

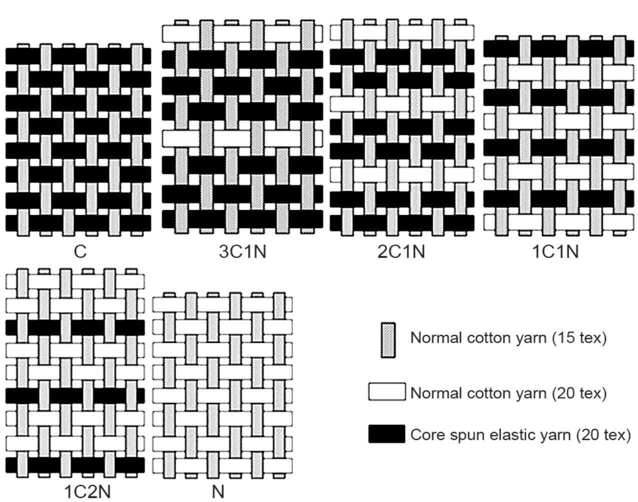

Fig. 1—Schematic views of woven fabric structures

To investigate the effect of stitch density together with fabric elasticity on seam slippage and strength behavior, fabric samples were sewn with three different stitch densities (4, 5 and 6 stitches/cm) parallel to warp direction. Samples were sewn only with the stitch density of 5 parallel to fabric weft direction. For this purpose, JUKI sewing machine (DDL-8700-7) with three-ply Gütermann M403 sewing thread of 45 tex (100% polyester) and twist of 550 T/m was used to sew samples with SSa-1 seam and 301 stitch types.

The sewing speed was set at 2000 stitches/min for all samples. Also to obtain balance stitches, some test samples were sewn and the lengths of both needle and bobbin threads extracted from 4 inches of fabric were measured and by changing the thread tensions both lengths of needle and bobbin threads were kept equal[10]. The needle number was 90/14 and for sewing each sample group, a new needle was used to avoid any periodic defects due to needle point damage.

2.2 Fabric Tensile Testing

In this study, the hypothesis of seam tensile behavior analysis for a specific stitch density is based on fabric tensile properties. So, fabric tensile behavior was measured firstly for all samples in weft and warp directions in terms of Young's modulus, breaking elongation percentage and tensile strength. Young's modulus of fabrics was measured as the slope of the steepest linear region of fabric load-elongation curves from the start point of tensile test up to the end of test procedure[16]. Also to quantify fabric elasticity, a similar factor to FAST index (E100[17]), here named as fabric extensibility, was defined as the fabric extension at the load of 100 N/m in the weft direction.

For fabric tensile testing, a universal tensile machine (Instron 5500R) was used. Tensile properties of fabrics were measured according to ASTM D 5034(2001) standard. Test speed was set in such a way that fabric failure occurs within 20±3 s. Average values of fabric tensile properties are listed in Table 2. Figure 2 shows average fabric stress-elongation curves for fabric samples in weft and warp directions.

2.3 Seam Slippage and Strength Testing

Seam slippage of samples was evaluated as the required load for a specific amount of slippage using

Table 2—Tensile properties of fabrics in warp and weft directions

Sample	Fabric extensibility, %	Tensile strength N		Breaking elongation %		Young's modulus N/mm	
		Warp	Weft	Warp	Weft	Warp	Weft
C	16.45 (0.23)	325.94 (10.44)	212.73 (14.19)	11.27 (0.14)	42.62 (1.44)	47.75 (2.42)	18.64 (1.14)
3C1N	15.84 (0.50)	343.34 (11.50)	228.49 (8.46)	9.73 (0.23)	41.32 (0.96)	48.58 (2.20)	20.28 (0.60)
2C1N	14.91 (0.18)	336.14 (9.95)	230.55 (11.13)	8.97 (0.33)	40.72 (0.61)	51.90 (2.06)	20.40 (0.52)
1C1N	14.19 (0.44)	341.00 (9.77)	226.63 (6.76)	9.62 (0.53)	39.16 (0.73)	54.35 (1.59)	20.72 (0.72)
1C2N	13.59 (0.24)	347.50 (5.26)	248.39 (11.63)	9.17 (0.1)	38.71 (0.85)	53.47 (0.58)	22.43 (0.72)
N	10.52 (0.29)	336.70 (5.01)	254.61 (13.43)	10.03 (0.25)	32.38 (0.75)	55.03 (0.88)	25.78 (0.94)

Values in parentheses are standard deviation of measurements.

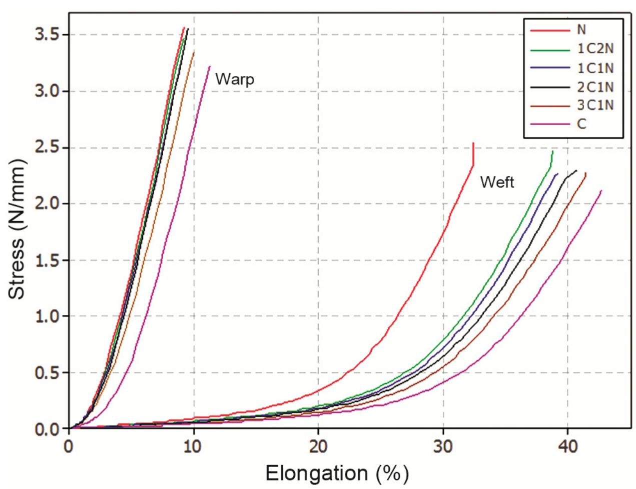

Fig. 2—Average diagrams of stress-elongation curves for fabric samples in weft and warp directions

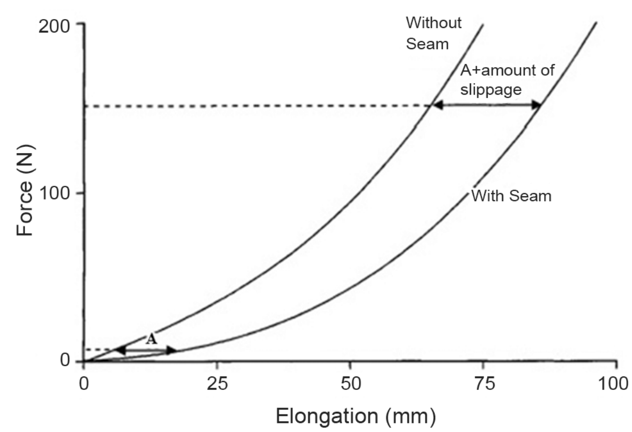

Fig. 3—Calculation of seam slippage load

fixed seam opening method. Sample dimensions and tensile apparatus setting were set exactly according to British Standard [BS EN ISO 13936-1(2004)].

Sewn samples were cut into two pieces, with and without seam. Both pieces were tested on the tensile testing machine and their load-elongation diagrams were plotted on the same coordinates. To calculate seam slippage load, the distance between two diagrams (A) was measured at a load of 5N (Fig. 3).

Value of A was added to pre-defined amount of slippage and the corresponding load to this distance was reported as the seam slippage load. Here, due to elastic nature of most fabric samples, the amount of slippage was adjusted at 2 mm value. The value of seam slippage load was calculated directly on Instron 5500R, universal tensile machine. All the tests were done at the speed of 50 mm/min. Also the values of seam strength were recorded as the required load for failure of sewing zone according to ASTM D 1683 (2004). Test speed was set as 50 mm/min. All the tests were conducted under the standard conditions at 22±2°C and 65±2 % R.H. The average values of seam slippage and seam strength in warp direction are shown in Table 3. Also, the average values of seam slippage and strength loads in weft direction for different values of stitch densities are listed in Table 4.

3 Results and Discussion

IBM SPSS Statistics software (Ver.19) was used for statistical analysis. One-way ANOVA and LSD tests were applied to results of fabric tensile

Table 3—Average values of seam slippage force and strength in warp direction

Sample	Seam slippage force, N	Seam strength, N
C	115.40 (23.87)	231.34 (20.31)
3C1N	152.75 (12.79)	231.72 (12.74)
2C1N	145.80 (7.41)	236.58 (10.72)
1C1N	155.10 (6.12)	225.84 (6.54)
1C2N	158.24 (7.60)	238.32 (6.66)
N	175.11 (5.17)	215.18 (4.90)

Values in parentheses are standard deviation of measurements.

Table 4—Seam slippage force and strength for different values of stitch densities in weft direction

Sample	Seam slippage force, N			Seam strength, N		
	4 cm^{-1}	5 cm^{-1}	6 cm^{-1}	4 cm^{-1}	5 cm^{-1}	6 cm^{-1}
C	51.03 (15.73)	79.55 (22.98)	93.32 (22.02)	174.00 (4.50)	194.80 (7.92)	190.06 (12.01)
3C1N	63.87 (13.44)	73.46 (17.01)	122.59 (29.09)	189.34 (6.06)	197.45 (9.76)	204.60 (7.15)
2C1N	67.91 (18.19)	92.99 (14.60)	123.22 (21.39)	192.68 (8.47)	201.74 (4.01)	210.02 (8.01)
1C1N	87.48 (8.90)	113.48 (15.25)	150.37 (20.32)	191.72 (14.64)	205.64 (4.74)	210.04 (11.94)
1C2N	108.55 (21.88)	126.57 (17.63)	142.41 (19.72)	192.68 (8.47)	223.74 (9.88)	221.48 (9.84)
N	90.11 (13.74)	105.18 (8.75)	125.61 (26.85)	199.66 (3.87)	212.92 (4.43)	227.06 (10.92)

Values in parentheses are standard deviation of measurements.

properties and sewn samples. All statistical procedures were performed at a significance level of 0.05. Statistical results are briefly summarized in Tables 5 and 6. Also a non-linear least square method was applied to illustrate the trends of different tensile properties of fabric and sewn samples using MINITAB software.

3.1 Fabric Tensile Properties

Trends of different fabric tensile properties are shown in Fig. 4. Various tensile properties such as fabric breaking elongation, Young's modulus and tensile strength are discussed hereunder.

3.1.1 Fabric Breaking Elongation

Figure 4(a) exhibits the values of fabric breaking elongation versus fabric weft extensibility. As it may be expected, fabric elongation in weft direction is

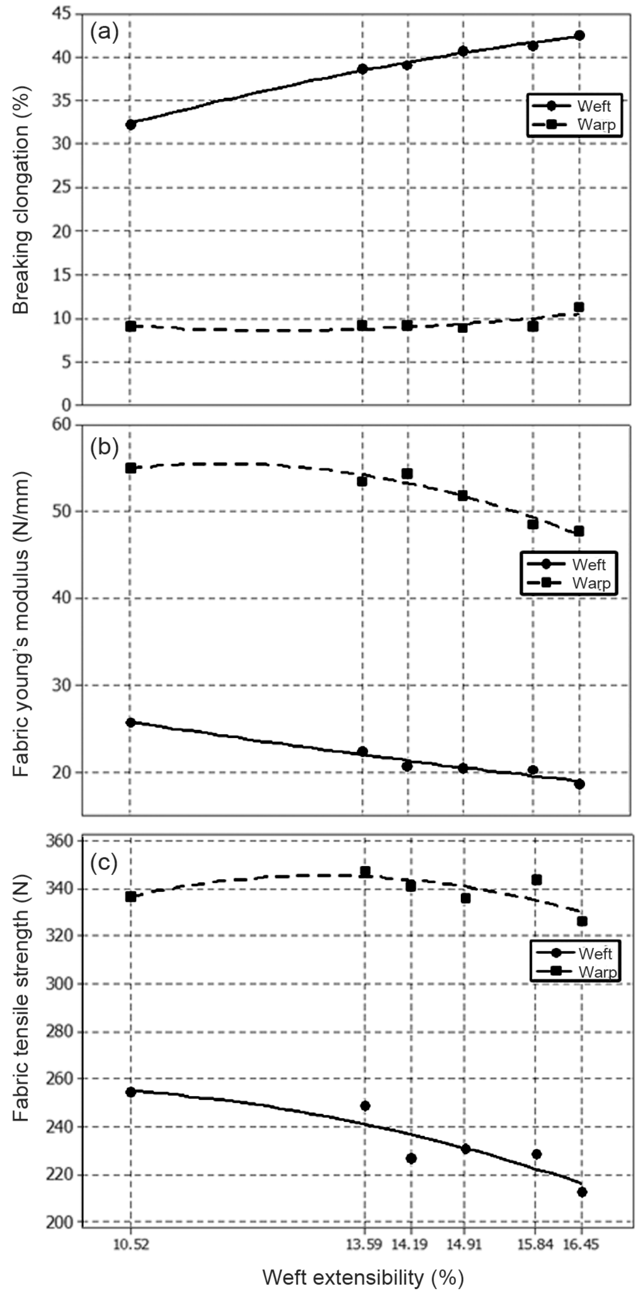

Fig. 4—Tensile properties of fabric samples versus weft extensibility in weft and warp directions [a—fabric breaking elongation, b—fabric Young's modulus, and c—fabric tensile strength]

significantly higher than in warp direction due to existence of elastic core-spun yarns in weft direction. The results also show that the increase in fabric weft extensibility leads to increase in fabric breaking elongation in the weft direction. However, fabric breaking elongation in the warp direction is invariant with fabric weft extensibility except for sample C which has the maximum value (Table 5).

Table 5—Statistical analysis results for fabrics tensile testing

Fabric layout		Weft				Warp		
(I) Weft	(J) Weft	Fabric extensibility	Tensile strength	Breaking elongation percentage	Young's modulus	Tensile strength	Breaking elongation percentage	Young's modulus
N	1C2N	0.000*	0.100	.000*	0.000*	0.209	0.000*	0.195
	1C1N	0.000*	0.000*	.000*	0.000*	0.612	0.038*	0.565
	2C1N	0.000*	0.000*	.000*	0.000*	0.947	0.000*	0.013*
	3C1N	0.000*	0.000*	.000*	0.000*	0.436	0.129	0.000*
	C	0.000*	0.000*	.000*	0.000*	0.211	0.000*	0.000*
1C2N	N	0.000*	0.100	0.000*	0.000*	0.209	0.000*	0.195
	1C1N	0.004*	0.000*	0.155	0.000*	0.445	0.026*	0.461
	2C1N	0.000*	0.000*	0.000*	0.000*	0.188	0.303	0.193
	3C1N	0.000*	0.000*	0.000*	0.000*	0.624	0.006*	0.000*
	C	0.000*	0.000*	0.000*	0.000*	0.017*	0.000*	0.000*
1C1N	N	0.000*	0.000*	0.000*	0.000*	0.612	0.038*	0.565
	1C2N	0.004*	0.000*	0.155	0.000*	0.445	0.026*	0.461
	2C1N	0.001*	0.298	0.000*	0.235	0.567	0.002*	0.048*
	3C1N	0.000*	0.619	0.000*	0.105	0.782	0.543	0.000*
	C	0.000*	0.000*	0.000*	0.000*	0.085	0.000*	0.000*
2C1N	N	0.000*	0.000*	0.000*	0.000*	0.947	0.000*	0.013*
	1C2N	0.000*	0.000*	0.000*	0.000*	0.188	0.303	0.193
	1C1N	0.001*	0.298	0.000*	0.235	0.567	0.002*	0.048*
	3C1N	0.000*	0.584	0.054	0.660	0.398	0.000*	0.009*
	C	0.000*	0.000*	0.000*	0.000*	0.235	0.000*	0.002*
3C1N	N	0.000*	0.000*	0.000*	0.000*	0.436	0.129	0.000*
	1C2N	0.000*	0.000*	0.000*	0.000*	0.624	0.006*	0.000*
	1C1N	0.000*	0.619	0.000*	0.105	0.782	0.543	0.000*
	2C1N	0.000*	0.584	0.054	0.660	0.398	0.000*	0.009*
	C	0.003*	0.000*	0.000*	0.000*	0.049*	0.000*	0.487
C	N	0.000*	0.000*	0.000*	0.000*	0.211	0.000*	0.000*
	1C2N	0.000*	0.000*	0.000*	0.000*	0.017*	0.000*	0.000*
	1C1N	0.000*	0.000*	0.000*	0.000*	0.085	0.000*	0.000*
	2C1N	0.000*	0.000*	0.000*	0.000*	0.235	0.000*	0.002*
	3C1N	0.003*	0.000*	0.000*	0.000*	0.049*	0.000*	0.487
Sig. value**		0.000	0.000	0.000	0.000	0.203	0.000	0.000

* Mean difference is significant at 0.05 level.
** ANOVA significant value.

3.1.2 Fabric Young's Modulus

Figure 4(b) shows the measured values of Young's modulus for different fabric samples in both weft and warp directions which decrease with increase in the weft extensibility. However, Young's modulus in warp direction is much higher than in weft direction due to the fact that there is no elastic yarn in fabric warp direction. Therefore, fabric samples would be extended easily in weft direction. There are decreasing trends of modulus in both warp and weft directions with increasing the number of core-spun yarns in weft direction (Table 5). Hence, under a constant load, fabrics with higher number of elastic core-spun yarns show greater value of elongation in both warp and weft directions.

3.1.3 Fabric Tensile Strength

The effects of fabric weft extensibility on fabric tensile strength are shown in Fig. 4(c) for both weft and warp directions. Using elastic core-spun yarns in fabric structure, tensile strength of fabric samples is found lower along the weft than warp direction and

Table 6—Statistical analysis results for sewn sample tests

Fabric layout		Seam slippage load				Seam strength load			
(I) Weft	(J) Weft	Weft			Warp	Weft			Warp
		4 cm^{-1}	5 cm^{-1}	6 cm^{-1}		4 cm^{-1}	5 cm^{-1}	6 cm^{-1}	
N	1C2N	0.078	0.053	0.410	0.038*	0.916	0.209	0.950	0.100
	1C1N	0.795	0.437	0.228	0.016*	0.171	0.613	0.123	0.438
	2C1N	0.036*	0.257	0.906	0.001*	0.227	0.182	0.122	0.126
	3C1N	0.015*	0.006*	0.881	0.008*	0.079	0.027*	0.020*	0.233
	C	0.001*	0.022*	0.120	0.000*	0.000*	0.007*	0.000*	0.243
1C2N	N	0.078	0.053	0.410	0.038*	0.916	0.209	0.950	0.100
	1C1N	0.046*	0.224	0.694	0.686	0.142	0.007*	0.495	0.365
	2C1N	0.000*	0.004*	0.348	0.118	0.190	0.001*	0.493	0.899
	3C1N	0.000*	0.000*	0.332	0.481	0.064	0.000*	0.128	0.629
	C	0.000*	0.000*	0.022*	0.000*	0.000*	0.000*	0.001*	0.610
1C1N	N	0.795	0.437	0.228	0.016*	0.171	0.613	0.123	0.438
	1C2N	0.046*	0.224	0.694	0.686	0.142	0.007*	0.495	0.365
	2C1N	0.062	0.063	0.188	0.238	0.866	0.954	1.000	0.434
	3C1N	0.027*	0.001*	0.178	0.762	0.676	0.491	0.955	0.667
	C	0.001*	0.004*	0.009*	0.000*	0.004*	0.207	0.048*	0.687
2C1N	N	0.036*	0.257	0.906	0.001*	0.227	0.182	0.122	0.126
	1C2N	0.000*	0.004*	0.348	0.118	0.190	0.001*	0.493	0.899
	1C1N	0.062	0.063	0.188	0.238	0.866	0.954	1.000	0.434
	3C1N	0.690	0.075	0.975	0.375	0.558	0.933	0.956	0.722
	C	0.105	0.212	0.149	0.001*	0.003*	0.658	0.048*	.701
3C1N	N	0.015*	0.006*	0.881	0.008*	0.079	0.027*	0.020*	0.233
	1C2N	0.000*	0.000*	0.332	0.481	0.064	0.000*	0.128	0.629
	1C1N	0.027*	0.001*	0.178	0.762	0.676	0.491	0.955	0.667
	2C1N	0.690	0.075	0.975	0.375	0.558	0.933	0.956	0.722
	C	0.212	0.567	0.157	0.000*	0.012*	0.992	0.247	0.978
C	N	0.001*	0.022*	0.120	0.000*	0.000*	0.007*	0.000*	0.243
	1C2N	0.000*	0.000*	0.022*	0.000*	0.000*	0.000*	0.001*	0.610
	1C1N	0.001*	0.004*	0.009*	.000*	0.004*	0.207	0.048*	0.687
	2C1N	0.105	0.212	0.149	0.001*	0.003*	0.658	0.048*	0.701
	3C1N	0.212	0.567	0.157	0.000*	0.012*	0.992	0.247	0.978
Sig. value**		0.000	0.000	0.124	0.000	0.001	0.000	0.000	0.576

* The mean difference is significant at the 0.05 level.
** ANOVA significant value.

also decreases with increasing the number of elastic core-spun yarns, whereas it has no significant effect in warp direction (Table 5). Decreasing trend of fabric tensile strength in weft direction is in agreement with decreasing trend of fabric Young's modulus [Fig. 4(b)].

3.2 Seam Slippage and Seam Strength

3.2.1 Seam Slippage

Figure 5 shows the values of seam slippage force for different fabric samples with different stitch densities in weft and warp directions. ANOVA statistical analysis results (Table 6) show that stitch density and fabric extensibility significantly affect seam slippage load. In samples which are sewn along fabric warp direction, seam slippage force increases significantly with the increase of stitch density. In stitch density levels of 4 and 5, seam slippage force decreases with increasing the numbers of core-spun yarns in weft direction. However, by adding one elastic core-spun yarns to weft layout together with

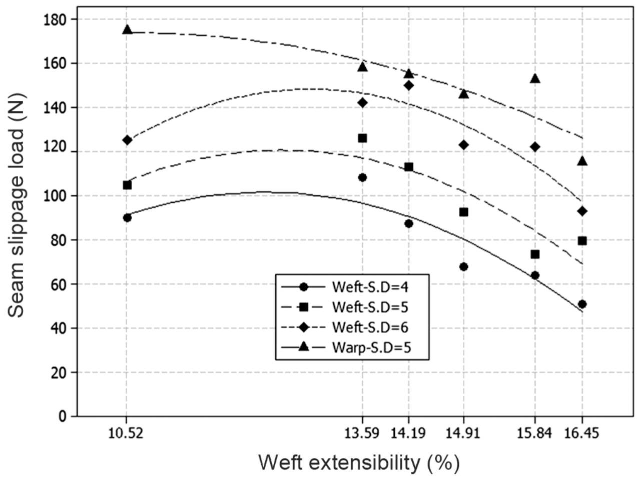

Fig. 5—Seam slippage load versus weft extensibility for different levels of stitch densities in weft and warp directions

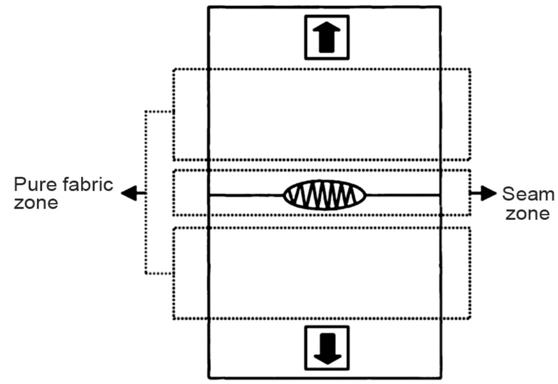

Fig. 6—Schematic view of a seamed structure imposed to tensile load

two normal yarns in one weft layout repeat (sample 1C2N), despite of the considerable increase of fabric weft extensibility as compared to normal sample (N), there is a slight increase in weft seam slippage load for all stitch densities which is not statistically significant (Table 6).

To explain the obtained results, the resistance of a sewn fabric structure can be divided into two regions, namely 'pure fabric zone' and 'seam zone', based on work done by Shimizaki and Lloyd [18] (Fig. 6).

An increase in stitch density value for a specific fabric sample leads to increase in seam zone resistance which is the weakest zone in a sewn structure sample against tensile loads.

Decreasing trends of seam slippage load with increase in fabric weft extensibility in stitch density levels of 4 and 5 can be interpreted considering fabric tensile behavior (Fig. 4) as discussed in previous section. As shown in Fig. 4(b), with the increase in fabric extensibility, fabric Young's modulus significantly decreases, which, in turn, causes fabric sample to be easily deformed under tensile loads. As a consequence, there will be lower amount of fabric contribution (in pure fabric zone) to sewn sample resistance against tensile loads and hence a larger amount of force would be imposed to seam zone, so seam slippage would easily occur.

Moreover, as shown in Figs 4(a) and (c), with the increase in fabric extensibility, fabric breaking elongation percentage increases and fabric tensile strength decreases that confirms decreasing trends of seam slippage load with increase in fabric weft extensibility especially in the cases where seam slippage occurs near fabric plastic deformation zone.

On the other hand, a high stitch density level (stitch density 6) prevents the pure fabric zone to play its role as it does in stitch densities of 4 and 5. Thus, there is not a clear decreasing trend of seam slippage load with fabric extensibility. However, as listed in Table 6, the seam slippage load of sample C (highly extensible fabric) is significantly lower than those of samples 1C2N and 1C1N.

Figure 5 also reveals that the seam slippage load is higher in warp direction with stitch density of 5 than those in weft direction for all levels of stitch densities. Similar reasoning as discussed before can be stated here. According to fabric tensile properties in related directions (Fig. 4), this result can be explained because of higher values of fabric Young's modulus and tensile strength and also lower breaking elongation in warp comparing with the weft direction.

Seam slippage load in warp direction decreases with increase in fabric weft extensibility that can be interpreted with decrease of Young's modulus [Fig. 4(b)] and also with increase in breaking elongation percentage [Fig. 4(a)] in warp direction as the numbers of elastic core spun yarns increases in weft direction.

3.2.2 Seam Strength

The results of seam strength for different values of stitch density in weft and warp directions are illustrated in Fig. 7. Similar trends have been found here. It has been illustrated that seam strength load decreases significantly with increase of weft extensibility for each stitch density level along weft direction. However, as shown in Table 6 and Fig. 7, the seam strength along warp direction is invariant with fabric extensibility. Similar to seam slippage results, the seam strength values along warp direction are higher than weft direction.

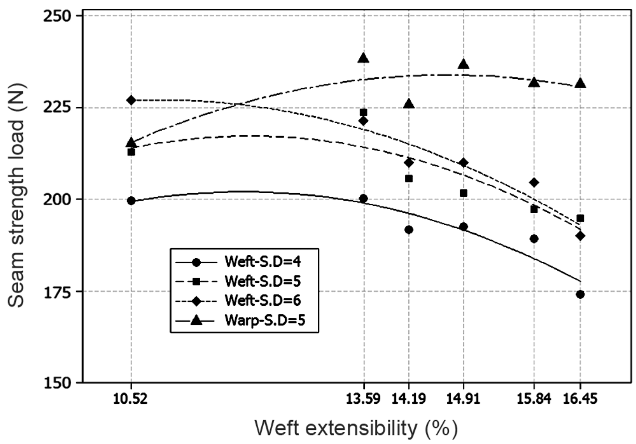

Fig. 7—Seam strength load versus weft extensibility for different levels of stitch densities in weft and warp directions

The obtained results for seam strength in warp direction can be interpreted similarly as it was discussed for seam slippage load. Because of higher value of seam strength than seam slippage load, fabric breaking elongation may be considered as a more effective parameter rather than fabric Young's modulus.

4 Conclusion

Fabric tensile test results reveal that the increase in fabric extensibility leads to increase in fabric elongation and decrease in Young's modulus both in warp and weft directions and also decrease in fabric tensile strength only in the weft direction.

The results also show that seam slippage load of sewn fabric samples decreases both in weft and warp directions with increase in the weft extensibility. However, at high values of stitch density (6 stitches/cm), the role of fabric extensibility diminishes and the seam slippage force remains invariant with increase in fabric extensibility. The results also indicate that the samples sewn with a higher stitch density exhibit a higher slippage load along weft direction. Nevertheless, the seam slippage load along warp direction is still higher than that along weft direction. Similar results are obtained for seam strength in which seam strength decreases with increase in fabric weft extensibility in weft direction. However, the seam strength remains invariant in warp direction. It is also found that the increase in stitch density leads to a higher amount of seam strength.

The findings suggest that the seam slippage and strength properties of elastic woven fabrics can be well interpreted from the fabric tensile properties point of view, particularly in weft direction. Further studies are needed to investigate the seam slippage and strength behavior of elastic woven fabrics under cycling loadings.

Acknowledgement

Authors are thankful to Mrs. Merce Mercader Maeztu and her team, Technical School of Mundet, Barcelona to help us sewing the samples and to head of iQAC, CSIC for providing laboratory test equipment. Thanks are also due to Mr. Sarsharzadeh for finishing our fabric samples in Harir-Semnan factory.

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