THE EFFECT OF DIMENSION AND LOOP LENGTH OF FABRIC SAMPLE ON THE BEHAVIOR OF SHEAR BUCKLING OF PLAIN WEFT-KNITTED FABRICS

Neda RABIEE[1], Saeed SHAIKHZADEH NAJAR[2], Ali A. JEDDI[2]
[1] *Islamic Azad University, Science & Research Branch, Department of Textile Engineering, Tehran, Iran*
[2] *Amirkabir University of Technology, Department of Textile Engineering, Tehran, Iran*
saeed@aut.ac.ir

Abstract

This study is focused on the effect of dimension and loop length of shear buckling behavior of plain weft-knitted fabrics. For creating buckling on fabric, shear method was used. To achieve this purpose, an apparatus was designed and constructed in order to apply shear on the fabric sample. Then the buckling waves caused by shearing were studied. Also by mounting shearing apparatus on tensile tester, shear-hysteresis curves were obtained. Some shear parameters obtained from diagrams, were studied. In this research, plain knitted fabric (35% cotton – polyester 65%) in two loop lengths was used. Three dimensions for fabric samples with different (*w/l*) width to length ratio were considered. Also shearing in two wale and course directions was applied.

The experimental results of shear buckling parameters were statistically analyzed using ANOVA. It was found that with increasing width to length ratio of fabric samples, and with enlarging loop length, buckle and shear parameters (content of shear stress and strain at start and maximum of buckling, and hysteresis) are increased. The results also showed that the number of buckling waves along two wale and course directions is different. However for two different loop lengths, buckling waves are almost similar.

Key word: buckling, shear, plain weft-knitted fabric, dimension, loop length

1. Introduction

Buckling is a very common phenomenon during the use of fabrics in garments. It might be noted, for example, that the bending of sleeve, trouser leg and even the natural folding of a garment, often involves buckling [1]. The purpose of buckling analysis is evaluation the formability of fabrics which determines the amount of compressibility related to certain compression force [2]. In the process of tailoring of fabric into a three-dimensional surface, shearing would be occurred. This ability of fabric to deform within its plane is important not only to tailoring, but also to the handle of fabric. As the shear stress increases, however, a critical stage is reached where the fabric starts to deform out of its plane, i.e., it buckles [3].

Until now, experimental work on fabric shear has involved primarily woven [4-9] and, to a less extent non-woven and knitted fabrics. The study of shear properties of knitted fabrics should be increased because of their extensive applications. In studying the shear fabric properties, Treloar [10] has dealt in a general way with various experimental parameters and has focused on several fundamental difficulties involved in making shearing measurements of textile structures. Carnaby and Postle [11] compared the shear properties of various structures of fabric such as woven, knitting and non-woven. It may be noted that almost in all previous works related to fabric shearing, the shear strain until appearance of buckling waves was considered. Thus, a tensile stress during the shear tests was applied on specimens to prevent buckling. In this research, by removing the tensile stress, shear buckling of fabrics as well as the number and depth of buckling waves reached to their maximum value were studied.

2. Experimental

2.1. Material

In this research, plain weft-knitted fabric (35% cotton-65% polyester) in two different loop lengths was used. The fabric samples were washed in domestic washing machine then, flatten on a smooth surface and dried. General fabric specifications are shown in Table 1.

Table 1. General fabric specifications

Stitch density	Course/cm (C.P.C)	Wale/cm (W.P.C)	Weight (g/m^2)	thickness mm) (	Loop length mm))	Fabric code
248.37 (0.035)	20.16 (0.025)	12.32 (0.013)	148.87)0.021(	0.53 (0.024)	2.7 (0.01)	Ps
223.23 (0.029)	18.48 (0.021)	12.08 (0.014)	135.92 (0.014)	0.56 (0.029)	3.11 (0.17)	Pl

Note: The data in brackets are SD values.; Ps: plain fabric with small loop length, Pl: plain fabric with large loop length.

2.2. Shear buckling tester

To create shear buckling on fabric, an apparatus was designed and constructed. It can be mounted on tensile tester in order to record shear-hysteresis curves. A photograph of the shear buckling tester mounted on a tensile tester is shown in Fig. 1. A schematic diagram of shear buckling tester is also shown in Fig. 2.

The apparatus consists of a rectangular main frame which two fabric clamps are placed on it. Right clamp is fixed on the frame and left clamp is placed on a rail which can move up and down. The values of shear elongation could be measured by a scale attached to the movable clamp. The bottom and upper sides of shear apparatus can be placed between two jaws of tensile tester. Upper jaw connects to the load-cell. The length of the fabric sample can be changed. The different size of samples and related elongation, are shown in Table 2.

Table 2. Dimension of fabric samples and their elongation

Elongation)(mm	Width)(mm	Length)(mm	Fabric sample
13	100	50	1
19	100	70	2
27	100	100	3

Figure 1. A typical image of shear buckling tester

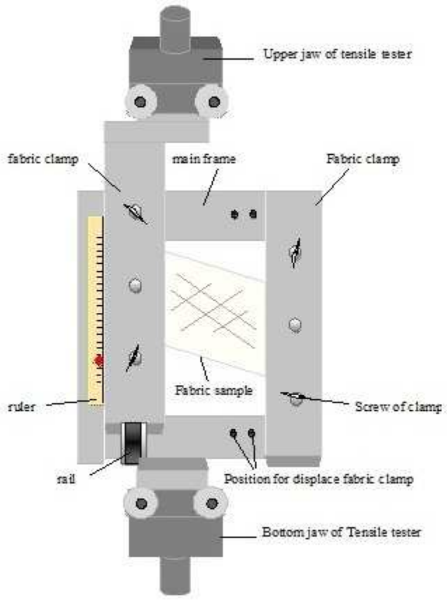

Figure 2. A schematic diagram of shear buckling tester

For evaluating the shear elongation, first several shear tests were performed until buckling waves achieved to maximum number and depth. So shear angle (θ), according to Eq. (1) and Fig. 3. was calculated. By averaging between obtained θ, ultimately $\theta = 15°$ for weft-knitted fabric (until receiving to maximum buckling) was considered Although, Kawabata had considered $\theta = 8^\circ$ (until receiving to start buckling) for woven fabric.

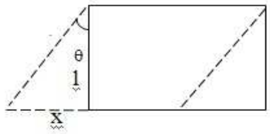

Figure 3. The geometry of fabric in shear

$$\tan\theta = \frac{X}{l} \tag{1}$$

By substituting $\theta = 15^\circ$ and the length of fabric sample (*l*), in Eq. (1), the shear elongation (*X*) was obtained.

2.3. Fabric Shear Tests

The fabric samples were ironed at low temperature in order to remove fabric curls. So, the fabric samples were relaxed for 24 hours under the standard conditions ($22 \pm 2^\circ c$ and $65\% \pm 2$ r.h.). All of fabric samples were positioned by a pre-tension of 52.83 gf between two fabric clamps. In order to obtain shear-hysteresis curve, tensile tester is adjusted at a cyclic movement corresponding to the fabric sample elongation and $5\, {cm}/{\min}$ speed. For each sample, tests were repeated three times along wale and course directions and obtained the average diagram. A typical shear hysteresis diagram is shown in Fig. 4. Some shear parameters according to Table. 4 are obtained.

Since, the movable clamp of the shear tester has friction in the rail, so the shear test was investigated without fabric sample and then the friction hysteresis diagram was obtained as shown in Fig. 5. Therefore, by subtracting corresponding friction value from shear parameter, the actual value was calculated.

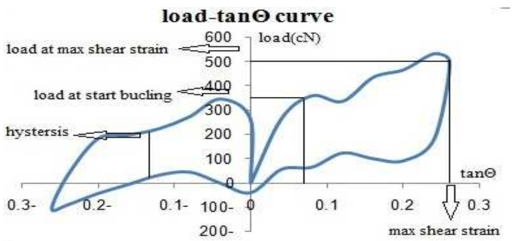

Figure 4. A typical shear hysteresis diagram

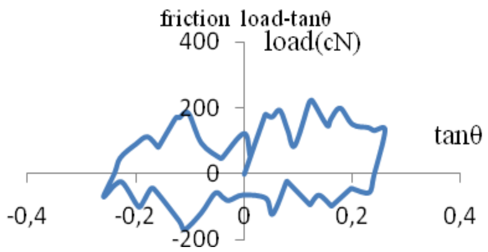

Figure 5. Friction diagram

Hysteresis value was determined by averaging hysteresis value between four different shear strains. Shear strain value at the start of buckling was obtained from buckling test which is described in section 2.4. and corresponding shear stress was calculated using Eq. (2).

$$shear\ stress = \frac{shear\ load}{width\ of\ sample} \tag{2}$$

The experimental results of shear parameters are shown in Table 3.

Table 3. Shear parameters for two different fabric loop lengths

Loop length 3.11 (mm)			Loop length 2.7 (mm)			
Stress at start of buckling ((cN/cm	Shear Hysteresis	Shear Stress at max shear strain ((cN/cm	Shear Stress at start of buckling ((cN/cm	Shear Hysteresis	Stress at max shear strain ((cN/cm	Shear parameters / Sample's dimension
16.86 (2.89)	153.1 (31.48)	27.52 (5.53)	7.78 (2.13)	112.2 (19.85)	18.49 (0.86)	10×5 w
19.44 (1.24)	111.8 (22.69)	24.42 (1.85)	21.35 (1.89)	75.2 (16.35)	27.35 (2.92)	10×5 c
11.83 (5.48)	84.2 (15.65)	10.46 (3.98)	2.90 (1.42)	78.3 (14.38)	7.79 (0.53)	10×7 w
16.77 (2.48)	85.8 (17.48)	17.87 (2.99)	4.02 (1.95)	38.7 (11.52)	14.2 (10.52)	10×7 c
4.34 (2.53)	71.1 (20.26)	4.72 (2.34)	4.26 (0.69)	68.3 (18.19)	5.41 (3.83)	10×10 w
1.13 (0.77)	31.4 (10.68)	11.77 (4.47)	3.22 (2.88)	19.6 (3.97)	17.92 (8.85)	10 c ×10

Note: W is shearing parallel to wale and C is shearing parallel to course. The data in brackets are SD values.

2.4. Shear buckling tests

Without mounting the apparatus on tensile tester, movable clamp was moved forward slowly by hand at almost uniform speed until the first buckling wave was appeared. Then, the movement is continued until created buckling waves reach to their maximum number and depth. At these points, the elongation shown by the indicator is registered. Then this process was repeated in reverse direction (return movement) and corresponding parameters were obtained. The results are shown in Table 4.

Table 4. Shear strain (tanθ) at start and maximum buckling in forward and return movement

Loop length 3.11(mm)				Loop length 2.7(mm)				
Shear strain at maximum buckling (return movement)	Shear strain at start of buckling (return moveme nt)	Shear strain at maximum buckling (forward movement)	Shear strain at start of buckling (forward moveme nt)	Shear strain at maximu m buckling (return movemen t)	Shear strain at start of buckling (return moveme nt)	Shear strain at maximu m buckling (forward moveme nt)	Shear strain at start of buckling (forward moveme nt)	Shear buckling parameters / sample's dimension
0.34 (0.09)	0.04 (0.02)	0.32 (0.08)	0.07 (0.01)	0.27 (0.12)	0.018 (0.008)	0.28 (0.11)	0.06 (0.01)	10×5 w
0.2 (0.1)	0.03 (0.01)	-	0.08 0.03))	0.2 (0.15)	0.017 (0.008)	0.21 (0.13)	0.09 (0.03)	10×5 c
0.28 (0.11)	0.03 (0.01)	0.27 (0.06)	0.06 (0.02)	0.24 (0.1)	0.017 (0.01)	0.25 (0.13)	0.05 (0.02)	10×7 w
0.2 (0.1)	0.02 (0.01)	0.21 (0.11)	0.06 (0.02)	0.21 (0.13)	0.02 (0.01)	0.24 (0.12)	0.06 (0.02)	10×7 c
0.226 (0.09)	0.024 (0.04)	0.22 (0.09)	0.04 (0.02)	0.199 (0.06)	0.01 (0.005)	0.19 (0.08)	0.04 (0.02)	10×10 w
0.201 (0.09)	0.022 (0.01)	0.21 (0.08)	0.04 (0.01)	0.197 (0.09)	0.018 (0.008)	0.2 (0.1)	0.04 (0.02)	10×10 c

Note: W is shearing parallel to wale and C is shearing parallel to course direction. The data in brackets are SD values.

In all tests, in addition to examining shear buckling parameters, the number of buckling waves observed at maximum buckling was studied. These results are shown in Table 5, 6.

Table 5. The number of buckling waves observed in tests

Loop length 3.11(mm)			Loop length 2.7 (mm)			
Frequency observed	Wave number at return movement	Wave number at forward movement	Frequency observed	Wave number at return movement	Wave number at forward movement	Number of waves / Sample's dimension
9	3	3	3	2	3	10×5 w
1	3	4	7	3	3	
10	5	Without buckling	2	5	2	10×5 c
			2	3	4	
			4	5	5	
			1	4	5	
			1	5	4	
6	2	2	1	3	3	10×7 w
			2	2	3	
4	2	3				
			7	2	2	
2	5	4	6	4	4	10×7 c
1	4	5				
2	4	3	3	5	4	
5	4	4	1	4	5	
8	2	2	10	2	2	10×10 w
2	1	2				
1	1	2	3	4	4	10×10 c
1	4	2				
5	4	4	1	3	4	
1	3	3	4	3	3	
2	3	4	2	4	3	

Table 6. Typical images of buckling waves

Sample dimension	5×10 W	5×10 C	7×10 W	7×10 C	10 ×10 W	10 ×10 C
Loop length 2.7(mm)						
Loop length 3.11(mm)						

3. Results and discussion

The experimental results of shear buckling parameters were statistically analyzed using ANOVA test at 5% confidence limit along wale and course directions as shown in Table 7.

Table 7. A summary of ANOVA statistical analysis results for shear buckling parameters

		Shear buckling parameters						
Treatment parameters	Shear direction	Shear strain at start buckling (forward movement)	Shear strain at maximum buckling (forward movement	Shear strain at start buckling (return movement)	Shear strain at maximum buckling (return movement	Shear Hysteresis	Stress at start buckling	Stress at maximum shear strain
sample	wale	+	+	-	+	+	+	+

dimension	course	+	+	-	-	+	+	+
Loop length	wale	-	+	+	+	-	-	-
	course	-	+	+	-	-	-	-
Dimension and loop length simultaneously	wale	-	-	-	+	-	-	-
	course	-	+	-	-	-	+	-

Note: the factors which significantly influenced on shear buckling parameters are shown by + sign.

3.1. The effect of fabric sample dimensions on shear buckling parameters

According to Table 7, the dimension factor has significantly influenced on shear and buckling parameters in forward movement while the results related to start of buckling in return movement and maximum buckling in return movement are not statistically significant.

Shear buckling parameters against dimension factor are shown in Fig. 6 , 7 and 8.

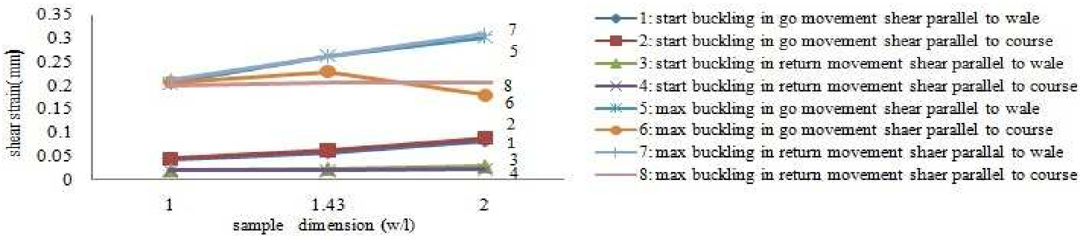

Figure 6. Shear strain diagram at the different buckling modes

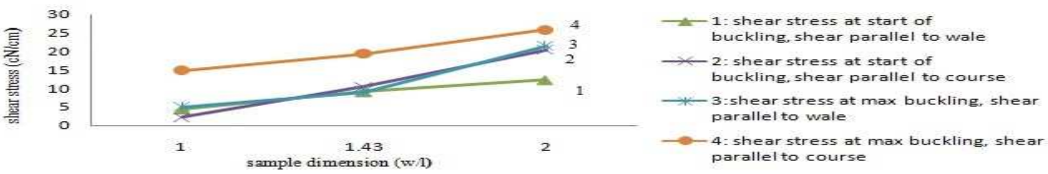

Figure 7. The diagram of shear stress and hysteresis against sample dimension

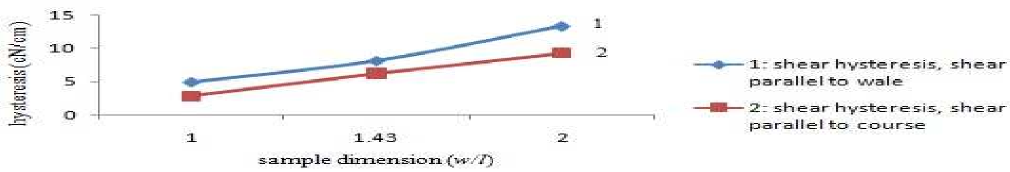

Figure 8. the diagram of shear hysteresis against sample dimension

By reviewing the diagrams, it is clear that by increase of *w/l* (ratio of width to length), almost all investigated parameters increased. The observation results shown that fabric sample at *w/l*=2 exhibit considerable resistance to shear buckling and thus is not reached to the maximum buckling (shear parallel to course direction). It was also observed that the buckling waves at *w/l=2* (shear parallel to wale direction) appeared simultaneously with equal distances and 45° angles. Treloar [10] also found that, with increase of *w/l* ratio, stress distribution is gradually uniformed and buckling waves appear with delay. It was shown that with increase of shear strain particularly at maximum shear strain, shear stress is increased. This leads to more energy loss or hysteresis at return cycle as shown in Fig.8. Generally, it is shown that shear stress values at start of buckling and maximum shear strain are much higher along course than wale direction, while shear hysteresis along course direction is less than wale direction. Carnaby and Postle [11] also found that for fully relaxed plain knitted fabrics, shear rigidity are higher along course than wale direction. Generally, it is indicated that with increase of *w/l* ratio, fabric resistance against shear buckling is increased.

3.2. The effect of loop length on the shear buckling parameters

According to Table 7, the effect of loop length on shear buckling parameters is almost in-Significant. However, loop length has significantly influenced on some buckling parameters such as shear strain at maximum buckling in forward movement, shear strain at start of buckling in return movement, shear strain at maximum buckling in return movement (shear parallel to wale). The results are shown in Fig. 9, 10, and 11.

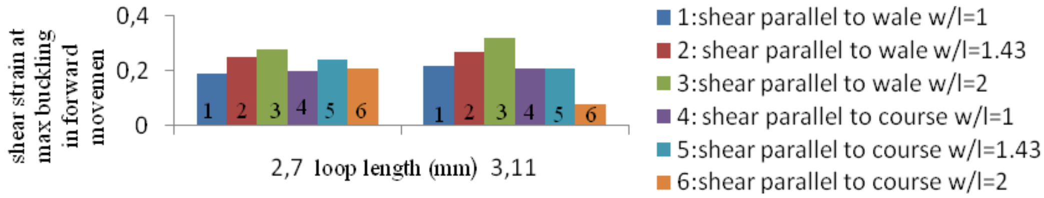

Figure 9. The diagram of shear strain at max buckling in forward movement against loop length

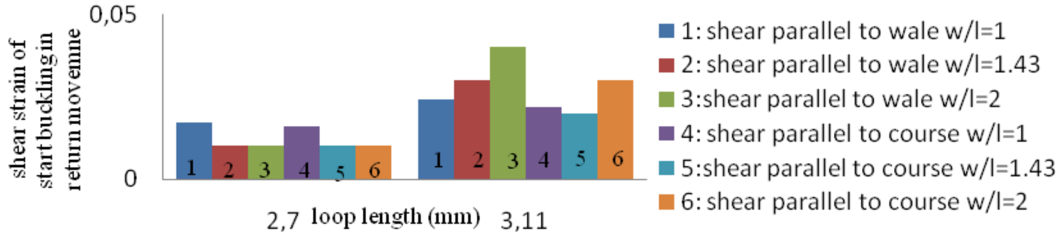

Figure 10. The diagram of shear strain at start of buckling in return movement against loop length

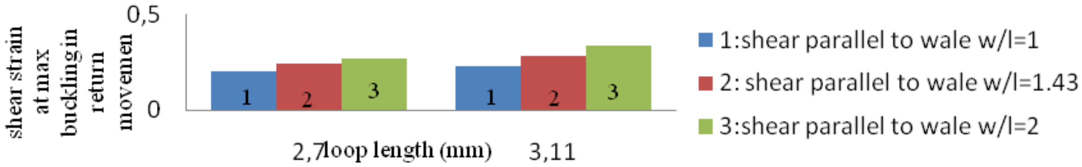

Figure 11. The diagram of shear strain at max buckling in return movement against loop length

As shown in Fig. 9 with increase of loop length, shear strain at maximum buckling along wale direction in forward movement increases while for the case of parallel to course direction the trend is vice versa. However, Fig. 10, 11 show that with increase loop length, graphs at both cases (shearing parallel to wale and course) have growing trend. In fact, with increase loop length and reducing tightness factor of fabric, more space between the loops is created so that the displacement of the loops under shearing condition performs more freely.

3.3. Analysis of the number of buckling waves

By considering Table 5 and images of buckling waves following results can be found:

- With repeating tests, almost we can attribute certain number of waves to a definite *w/l* ratio when shear applied parallel to wale direction on the other hand when shear is applied parallel to course direction, different results are obtained.

- By comparing the obtained results it is found that significant differences between two loop lengths were not observed. Except in one case when *w/l*=2 in loop length of 3.11 (mm) (shear parallel to course direction), buckling waves was not appeared.
- By changing the dimension of fabric samples, a determined trend for the number of buckling waves was not observed. The samples at *w/l*=1 (square shape) exhibited minimum number of buckling waves with more depth than other samples.

4. Conclusion

The aim of this paper was to study the effect of dimension and loop length on the behavior of shear buckling of plain weft-knitted fabric. An apparatus was designed and constructed in order to apply shear buckling on the fabric sample. This apparatus mounted on a tensile tester and shear-hysteresis diagrams were obtained. Three different dimensions of fabric sample (*w/l* ratio, *w* is fabric width and *l* is fabric length) with two loop length were prepared and shear buckling tests (shear parallel to wale and course direction) were performed.

The results showed that dimension and loop length of fabric were effective factors on shear buckling parameters. With increase *w/l* ratio and transformation from square to rectangular shape, some parameters such as shear strain and stress at start and maximum of buckling, and hysteresis (shear parallel to wale and course directions) are increased. With increase loop length, shear strain at start of buckling and shear strain at maximum buckling in forward and return movement (shear parallel to wale and course directions) are increased. However, loop length is not effective factor on shear stresses and hysteresis. The results also showed that the number of buckling waves along two wale and course directions is different.

By noting that some tests were done manually leading to some errors, it is recommended that image processing method can be used for evaluating shear buckling parameters accurately and by modifying the apparatus, the friction effect of the apparatus can be minimized.

5. References

1. Hearle j.w.s. and Grosberg p. and Backer. S; *Structural Mechanics of fibres, yarns, fabric,* john wiley & Sons. Inter since, 1969, pp. 355-369, 371-387.
2. Zhang Y.T. and Fu, Y.B; *International Journal of Engineering science (2000),* Vol 38, pp.1895-1906.
3. Ly Nhan G; *Textile research journal (1985),* Vol 55, pp.744-749.
4. Behre B; *Textile research journal (1961),* Vol 31, pp. 87-93.
5. Cusick G.E; *Journal of the Textile Institute (1961),* Vol 52, pp. 395-406.
6. Cusick G.E; *Textile research journal (1964),* Vol 34, pp.1102
7. Grosberg P. and Park B; *Textile research journal (1968),* Vol 38, pp.1205-1207.
8. Lindberg J., Behre B. and Dahlberg B; *Textile research journal (1961),* Vol31, pp.99-122
9. Morner B. and Eeg-Olofsson; *Textile research journal (1957),* Vol 27, pp.611.
10. Treloar L. R. G*; Journal of the Textile Institute (1965),* Vol 56, pp.533-550**.**
11. Carnaby G. A. and Postle R*; Journal of the Textile Institute(1974),* Vol 65, pp. 87-101.