Geometrically Poisson's Ratio of the Polyester Double-bar Warp-Knitted Structures on the Jamming Point

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***Abstract*—The main aim of this study is to present a new theory which shows the relationship between the warp knitted structures and some parameters of the fabric stiffness matrix. One of the important factors in this matrix is Poisson's ratio that influence on the mechanical behavior of knitted fabric. The theoretical loop model based on geometry is used to investigate the tensile behavior of the fabric. The proposed loop model is basically based on the previously published assumption of fabric structure. This geometrically loop model is assumed to be two dimensional, but this model is applicable to analysis of the three dimensional structures as well. The specimen fabrics are produced with various two bar warp knitted fabric structures with changing the underlap length of the front or back guide bar (Tricot, Locknit, Reverse Locknit, Satin and Sharkskin) from polyester yarn. A uni-axial tensile tester is used for measuring the experimental work and geometrical parameters such as wale and course spacing of the fabrics are obtained during the extension. The model predicts the variation of Poisson's ratio with longitudinal strain in all structures on the jamming point. Comparison between experimental and theoretical results for variety of fabric structures shows reasonable agreement between predicted and measured extension behavior of warp knitted fabric.**

Key words: Jamming, warp-knitted structure, Poisson's ratio, geometrical loop model

I. INTRODUCTION

Understanding the stress-strain relationship is very important and useful issue in the study of mechanical behavior of materials. Stiffness matrix is known for the explanation of this relationship and the components of this matrix show the main properties of the materials. For the fabric structure with assuming that the fabric is an orthotropic material and ignoring the thickness, this matrix has five mechanical characteristics as E1, E2, ν1, ν2 and G where E1 and E2 are the elastic modulus; ν1 and ν2 are the Poisson's ratio in the wale and course direction respectively and G is the shear modulus. According to ν1/E1= ν2/E2, four properties of these parameters are independent [1-3].

These parameters can be obtained from experimental tests, although many researchers attempted to determine these characteristics of fabric through theoretical analysis as well as experimental methods.

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Major improvement in this field accrued when Popper determined the Poisson's ratio of a simple plain weft-knitted fabric by a loop model under biaxial stress [4]. The application of the energy minimization technique is described by De Jong and Postle which computing the initial weft and warp knitted fabric tensile modulus and Poisson's ratio [5-7].

Recently, many researchers worked on finding Poisson's ratio of fabrics with different structures. A new test method for determination the Poisson's ratio and elastic modulus of knitted fabric was proposed based on the orthotropic theory [8]. A semi-implicit particle-based method was used for fabric Poisson effect. This new model was verified via the simulation of a uni-axial tension test and compared with the results of finite element analysis [9]. In the other study, digital image processing technique was used for measuring the Pseudo Poisson's ratio of the woven fabric [10]. Based on weft-knitted geometrical structure, the negative Poisson's ratio was proposed and analyzed [11]. Besides, the effect of weight reduction treatment on changes in the Poisson's ratio of a microfiber polyester woven fabric treated was studied with four different sodium hydroxide concentrations [12]. In a new study, a predicted geometrical model based on 3D straight line was developed for warp-knitted fabrics [13].

This study focused on determined experimental and theoretical value of the Poisson's ratio of the double-bar warp-knitted fabric in the jamming position.

II. THEORETICAL LOOP MODEL

As Figure 1 shows, in this study to display a loop configuration of the standard double-bar warp knitting fabric geometry, Raz loop model was used [14].

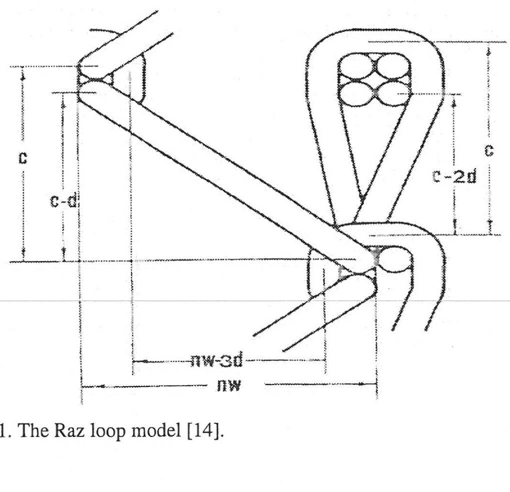


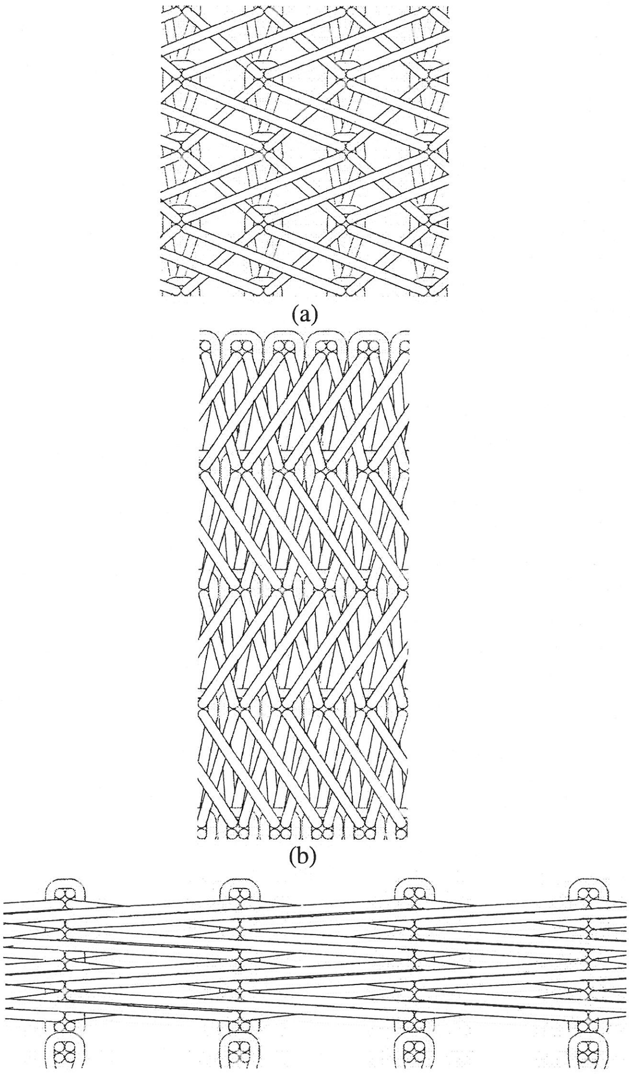
Fig. 1. The Raz loop model [14].

Eq. (1) was suggested for the calculation of the loop's length.

$$L=\sqrt{(c-d)^2+(nw-d)^2}+\sqrt{(c-2d)^2+d^2}+\sqrt{(c-2d)^2+4d^2}+15.4d \quad (1)$$

Where, L represents the loop's length; d is the yarn diameter; n is the size of the underlap and c and w are the course and wale spacing, respectively.

This model was modified by using graphic program for the two guide bars fabric for example locknit structure (Figure 2a).When, uni-axial normal stress is applied to a warp knitted fabric in wale and course directions, the yarn sliding and loops continue extension until the jamming happens in the structure of the fabric. (Figures 2b and 2c)



(a) (b) (c)

Fig. 2. Warp knitted fabric geometry structure. (a): Locknit loop structure, (b and c): Jamming extension of the loop structure on the wale and course direction, respectively.

Following the Figures 2b and 2c, two below geometry parameter could be directly obtained from the jamming point of the geometry structure of the loop fabric.

$$w'_{wale}=4d \quad (2)$$

$$c'_{course}=3d \quad (3)$$

Where, w' and c' are wale and course spacing after extension on jamming point, respectively. The wale and course index in Eqs. (2) and (3) show the direction of extension.

The loop length equation for jamming statement is available by following equations.

$$L'_{wale}=\sqrt{(c'_{wale}-d)^2+(nw'_{wale}-d)^2}+\sqrt{(c'_{wale}-2d)^2+d^2}+\sqrt{(c'_{wale}-2d)^2+4d^2}+15.4d \quad (4)$$

$$L'_{course}=\sqrt{(c'_{course}-d)^2+(nw'_{course}-d)^2}+\sqrt{(c'_{course}-2d)^2+d^2}+\sqrt{(c'_{course}-2d)^2+4d^2}+15.4d \quad (5)$$

Where, L'_{wale} and L'_{course} are the loop length in wale and course directions on jamming point, respectively.

In the other hand, the numbers of loops in specimen are constant and do not change during the fabric extension, then the loop's length by assuming yarn is inextensible and is constant too, therefore:

$$L'_{wale}=L'_{course}=L \quad (6)$$

By using Eqs. (2), (3) and (6) into Eqs. (4) and (5) the w'_{course} and c'_{wale} could be obtained. As a further step in the prediction of the stress-strain properties of the warp-knitted structure, the Poisson's ratio can be determined by taking the negative ratio of the course wise strain to the wale wise strain. This is important that, in usual uses of fabric the extension do not goes to plastic area or break point. Therefore, the Poisson's ratio in wale wise extension could be calculated by Eq. (7).

$$\nu_{wale}=-\frac{\varepsilon_{course}}{\varepsilon_{wale}} \quad (7)$$

Where, ε_{course} and ε_{wale} are course wise and wale wise strain, respectively and can be found from Figure 3 as follows:

$$\varepsilon_{course}=\frac{w'_{wale}-w}{w} \quad (8)$$

$$\varepsilon_{wale}=\frac{c'_{wale}-c}{c} \quad (9)$$

Also, by considering Figure 4, the ν_{course} could be calculated as follows:

$$\nu_{course}=-\frac{\varepsilon_{wale}}{\varepsilon_{course}} \quad (10)$$

Where;

$$\varepsilon_{course}=\frac{w'_{course}-w}{w} \quad (11)$$

$$\varepsilon_{wale}=\frac{c'_{course}-c}{c} \quad (12)$$

TABLE I
CHARACTERISTICS OF WARP KNITTED FABRICS

Fabric structure	Density	Fabric code	Number of underlap F.B.	Number of underlap B.B.	Run-in (cm/rack) F.B.	Run-in (cm/rack) B.B.	CPC	WPC
	Loose	Tl			202	189	12.0	13.2
Tricot	Medium	Tm	1	1	165	145	16.2	14.0
	Tight	Tt			141	129	20.6	13.6
	Loose	Ll			225	192	11.8	13.0
Locknit	Medium	Lm	2	1	182	145	16.2	16.6
	Tight	Lt			160	131	22.0	15.8
	Loose	S3l			261	198	11.6	14.0
Three needle Satin	Medium	S3m	3	1	224	150	16.4	16.4
	Tight	S3t			209	130	19.8	16.4
	Loose	S4l			306	195	12.2	14.8
Four needle Satin	Medium	S4m	4	1	261	151	16.8	15.8
	Tight	S4t			245	132	21.6	15.2
	Loose	RLl			201	221	12.0	13.2
Reverse Locknit	Medium	RLm	1	2	160	180	16.6	15.2
	Tight	RLt			142	162	21.0	14.2
	Loose	SH3l			205	256	12.2	13.2
Three needle Sharkskin	Medium	SH3m	1	3	162	216	17.2	13.6
	Tight	SH3t			144	211	21.2	13.4
	Loose	SH4l			210	306	11.0	12.4
Four needle Sharkskin	Medium	SH4m	1	4	161	261	17.0	13.2
	Tight	SH4t			150	252	22.0	12.6

FB, front guide bar; BB, back guide bar; CPC, course per cm; WPC, wale per cm. rack = 480 courses.

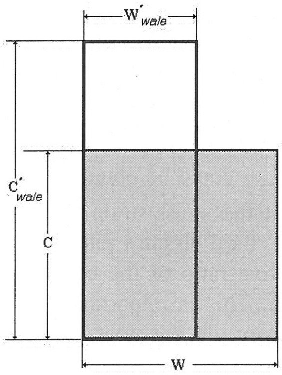


Fig. 3. Wale wise strain of fabric.

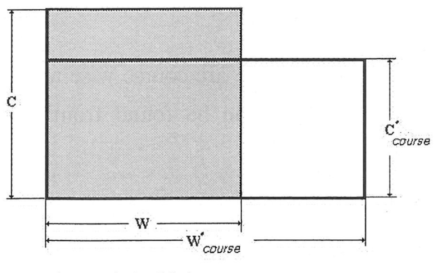


Fig. 4. Course wise strain in fabric.

III. MATERIALS AND METHODS

Warp-knitted fabrics were produced from polyester filament yarn count 8.33 Tex. The fabrics were produced on Liba tricot machine with gauge 28(numbers of needle per inch) with positive yarn feed. All samples were double guide bars fabrics in three different densities i.e. Tricot, Locknit, Revers Locknit, three and four needle Satin and Sharkskin. The specifications of the fabrics are shown in Table I.

To measurement the wale and course Poisson's ratio of the fabrics, the Instron tensile tester was used. The length and wide of specimen was 20cmx5cm. Two series of experiments were carried out. In the first series, all specimens were elongated in wale direction and in the second, they were extension in course direction. A digital camera used to capture the image during the test. The CPC and WPC of the specimens were measured in this test when the jamming accrued in the fabrics structure. Then, the Poisson's ratio was calculated by Eqs. (7) and (10) based on the theory suggested for jamming point. Results of experimental work are shown in Table II.

IV. RESULTS AND DISCUSSION

By realizing the initial c and w of various fabric structures and the loop's length, Eqs. (1), (4) and (5) can be combined with the geometric Eqs. (2) and (3) to obtain all theoretical geometry parameters as shown in table III.

When the fabric was elongated in the wale direction, smaller underlap in front or back guide bar was used to solve the equations because of the limitation of this underlap in movement in loop model and fabric deformation, during the wale wise fabric elongation, the yarns of the underlap loop was sliding and adding to the length of legs until jamming happen. However, in course wise elongation the longer underlap effected on the equations because of the same reason. In course direction extension of the fabric, the yarn of the legs loop was sliding and adding to the underlap.

Figures 5 and 6 show the relationship between the Poisson's ratio of the fabrics that were obtained from the loop model and experimental approach.

TABLE II
EXPERIMENTAL GEOMETRY RESULTS OF FABRIC STRUCTURES

Fabric	Wale wise extension			Course wise extension		
structure	CPC_J	WPC_J	V_{wale}	CPC_J	WPC_J	V_{course}
Tl	11.00	28.00	5.81	37.00	4.40	0.34
Tm	14.50	27.50	4.19	37.50	6.20	0.45
Tt	17.00	28.50	2.47	37.00	8.40	0.72
Ll	11.00	26.50	7.00	37.00	6.00	0.58
Lm	15.00	27.50	4.95	37.00	9.00	0.67
Lt	18.50	28.50	2.36	38.00	11.67	1.19
S3l	11.00	26.00	8.46	38.00	7.67	0.84
S3m	15.00	28.00	4.44	37.50	9.67	0.87
S3t	16.50	27.50	2.02	37.00	10.33	0.79
S4l	11.50	28.50	7.90	37.50	8.33	0.87
S4m	15.00	28.00	3.63	37.00	10.33	1.03
S4t	17.50	28.00	1.95	37.50	11.67	1.40
RLl	11.00	28.00	5.81	38.00	6.40	0.64
RLm	15.00	27.00	4.10	37.00	8.33	0.67
RLt	17.00	27.50	2.06	37.50	11.00	1.51
SH3l	11.00	28.00	4.85	37.00	7.33	0.84
SH3m	15.00	28.50	3.56	37.50	9.67	1.33
SH3t	17.00	27.50	2.08	37.00	11.00	1.96
SH4l	10.00	28.00	5.57	37.50	8.33	1.45
SH4m	14.50	28.00	3.07	37.00	10.33	1.95
SH4t	17.00	28.00	1.87	37.00	11.67	5.09

CPC_J, WPC_J are the number of course and wale per centimeter on the jamming point, respectively.

TABLE III
THEORETICAL GEOMETRY RESULTS OF FABRIC STRUCTURES

Fabric	Wale wise extension			Course wise extension		
structure	CPC_J	WPC_J	V_{wale}	CPC_J	WPC_J	V_{course}
Tl	11.03	28.61	6.12	38.18	4.74	0.38
Tm	14.32	28.61	3.89	38.18	6.64	0.52
Tt	16.97	28.61	2.45	38.18	8.37	0.74
Ll	10.85	28.61	6.23	38.18	7.21	0.86
Lm	14.93	28.61	4.93	38.18	10.39	0.96
Lt	18.81	28.61	2.64	38.18	12.37	1.53
S3l	10.83	28.61	7.18	38.18	8.92	1.22
S3m	11.13	28.61	5.12	38.18	12.03	1.57
S3t	17.56	28.61	3.35	38.18	13.22	2.00
S4l	11.42	28.61	7.07	38.18	10.53	1.68
S4m	15.32	28.61	4.31	38.18	12.72	2.31
S4t	18.30	28.61	2.60	38.18	13.45	3.34
RLl	11.03	28.61	6.12	38.18	7.35	.86
RLm	14.92	28.61	4.16	38.18	10.04	1.19
RLt	17.48	28.61	2.50	38.18	11.11	1.62
SH3l	11.19	28.61	5.97	38.18	8.85	1.38
SH3m	14.87	28.61	3.35	38.18	10.72	2.05
SH3t	17.21	28.61	2.29	38.18	11.53	2.74
SH4l	10.13	28.61	6.60	38.18	8.88	1.80
SH4m	14.61	28.61	3.29	38.18	11.04	2.84
SH4t	17.19	28.61	2.00	38.18	11.44	4.18

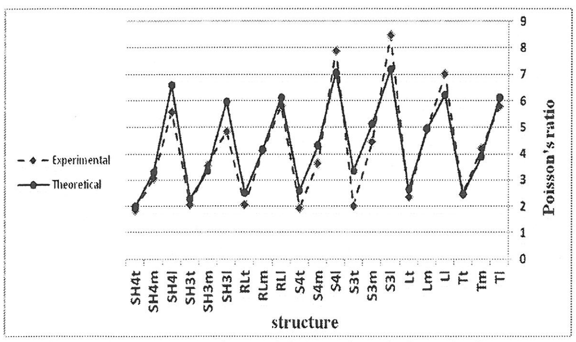


Fig. 5. Theoretical and experimental Poisson's ratio in wale direction.

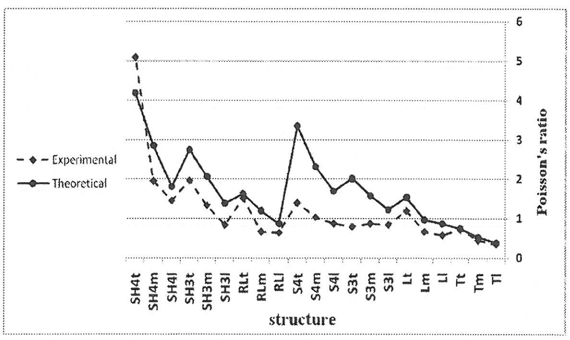


Fig. 6. Theoretical and experimental Poisson's ratio in course direction.

V. CONCLUSION

The stiffness matrix is one of the most important parameter of material that shows the mechanical properties of them. In this paper, the relationship between Poisson's ratio parameter of fabrics and the structures of warp knitted fabrics was investigated.

The most important parameter that affect on the Poisson's ratio is the underlap length of loop fabric and it was observed that in wale wise extension the smaller underlap in two guide bars and in course direction the longer one is an important parameter influence in the extension behavior of fabrics. The Poisson's ratio of the fabric was obtained from the experimental method and theoretical model on jamming point. The suggested model is based on loom state loop configuration. The results from the theoretical loop model in wale directions showed good agreement to the experimental method. In the course direction, more differences were observed between the theoretical and experimental results due to neglecting the effect of the underlap position of the front and back guide bars.

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