A Study of Mechanical Properties of Net Warp Knitted Fabrics

A. A. A. Jeddi[i]; M. Hasanpur Dehnavi[ii]; S. Ajeli[iii] and Z. Khorramtoussi[iv]

ABSTRACT

In this paper, mechanical properties of net warp knitted fabrics are studied and major parameters influencing these properties are discussed. Mechanical behavior includes tensile modulus, lateral contraction, and relaxation. Mechanical tests based on these properties were executed after producing fabrics in workshop. An experimental method based on video recording and image analysis is presented to characterize the lateral contraction of these fabrics during uniaxial tensile deformation. The obtained information is analyzed by statistical software and results executed. Test results show that mechanical properties of these textiles not only depend on material and machine parameters but also on the knit design structure parameters (for example run-in, course repeat, underlap, etc.), and that cause change on the number, size and shape of holes of these fabrics are also very important. At last, we defined an index and linear equation from results of this study that can help the procedure to predict mechanical behavior of these fabrics before producing.

KEYWORDS

Net warp knitted fabrics, uniaxial tensile, lateral contraction, index identifying.

[1] INTRODUCTION

Nowadays textiles have found their position and role in human's living more and more as flexible structures with specific efficiency. In this regard, net warp knitted fabrics are highly important because of their usage in industries, military and especially medicine. Geotextiles and protective nets are among other usages of these textiles. There are many medical fabrics produced using warp knitting technique, e. g., dialysis filters, valves, artificial vessels, and cardio-protective fabrics and Cardiac Support Device (CSD). CSD fabric is produced normally with sand fly structure and its mechanical properties lead to protection of heart from deformation [1, 2, 3 and 4].

The mechanical properties of textile structures under various kinds of loads have been subject of investigation for the last four decades. Knowledge of mechanical behavior is essential for predicting their end use performance. The load applied in any particular direction produces strains in other directions as well, due to the existence of coupling coefficients. Hence, to correctly predict the mechanical response of fabrics under single end and combined loading conditions, one must have knowledge of these coupling coefficients. Textile mechanical properties depend on three other factors including fiber, yarn and fabric, as well as their internal relations [1, 5, 6 and 8].

In this point of view, in order to access an ideal and integrated model for predicting such properties, researchers have used different methods among them we may refer to geometrical, finite element, image processing and energy methods. In all methods, theoretical assumptions must be proven by experimental result.

Study of textile mechanical properties is different with other types of materials, since they do not obey the continues environments mechanics. Because of being multicomponents, textile are not homogeneous and isotropic materials and their high elasticity result in different behavior in comparison to other materials like metals. Therefore, investigation of mechanical property of such structures must be accomplished with specifics related preferences.

The aim of this study is to investigate the effect of structural parameters of net warp knitted fabrics on

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mechanical properties of these textiles including tensile modulus, lateral contraction, relaxation and tensile tenacity. Investigation of these parameters is important in order to estimate these fabric properties in their application process, especially in medical applications.

[2] SOME POINTS ABOUT MECHANICAL PROPERTIES UNDER DISCUSSION

A. Tensile Modulus

Behavior of any substance under the effect of increasing force is shown by force-elongation curve. The first of a number of quantities related to the shape of the tensile stress-strain curve is the initial modulus, which is equal to the slope of the Stress-Strain curve at the origin (after removal any crimp). This slop usually remains constant over the initial portion of the curve. Most of the curves have sharp slope at the beginning of the curve. This phenomenon is reverse for textile. Stress-Strain curve of textile is similar to that of flexible substances. After an initial period with a steep slope, extension suddenly becomes much easier. It is in this region that the yield point occurs. Secondary modulus is the slope of the stress-strain curve after this point. This modulus is usually more than the initial one for textiles [1, 7 and 9].

In fabrics, because of the components of loops movement upon each other, force-elongation curve slope is too little (initial modulus (E_1)) and it takes some time until all components of a loop structure are arranged alongside the force (Figure (1)). At the time when all structure components of fabrics are arranged alongside the force, secondary modulus of fabrics (E_2) may also be accessible over force- elongation curve [13].

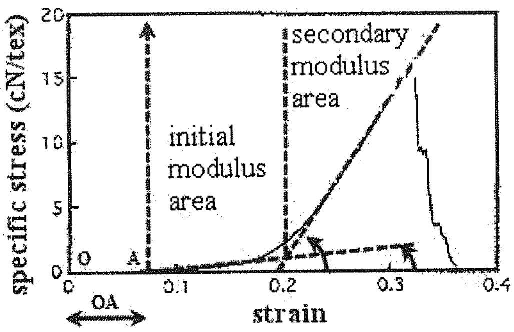


Figure 1: Schematic Stress-Strain curve in textiles.

Setting sample tightly or loosely between two edges of tensile testing machine is among the factors affected the shape of the curve, which cause moving loose sample chart to the right of graph. This effect would partially decrease by the help of pretension exerted on sample by the machine upon beginning of this test. However, because of high elasticity, it is not completely settle in these samples. It can be compensated by transition of origin of coordinates. In this respect, point (O) may be regarded as origin of coordinates [1, 7 and 16].

In order to compare fabric structure modulus, it is necessary to obtain fabrics modulus regardless of their density as:

$$E = \frac{E_f}{(cpc) * a} \qquad (1)$$

$$E = \frac{E_f}{(wpc) * a} \qquad (2)$$

where,

E_f : Fabrics modulus

cpc: number of courses per centimeter

wpc: number of wales per centimeter

a: width of the test sample (edge of Instron width)

In this study, fabrics modulus is referred to initial modulus of texture structure (E_1') and secondary modulus of texture structure (E_2'). In addition, the ratio of two modulus is used which are independent from samples density and encompasses the effect of two initial and secondary modulus.

B. Lateral Contraction

In textile, lateral contraction is the most commonly used coupling coefficient for correlating strains in two perpendicular directions. The term lateral contraction was originally defined for linear elastic materials, but in textile mechanics, the term also has been used to describe coupling between transverse and longitudinal strains in a nonlinear deformation region. For homogeneous and isotropic materials, rate of lateral contraction result from axial force is a fix quantity. This parameter, like modulus, is of mechanical property of materials. This quantity varies in a very small range of 0.25 to 0.35 for various materials.

In textile mechanics, the word "Lateral Contraction" is used instead of Poisson's ratio for such a reason that it implies nonlinear behavior and nonelastic transformational nature of these substances [6].

It is hard to determine pressure forces specifications in structures positioned in a 90-degree angle in proportion with direction of exerting forces.

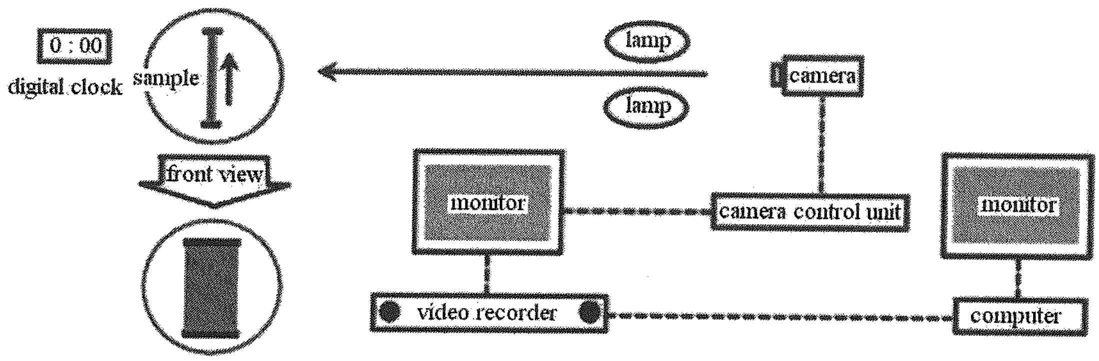


Figure 2 : Schematic of experimental set-up for measuring lateral contraction by using video recording method.

Although, scientists tried hard to propose theoretical numbers for prediction of lateral contraction, there are no correct results since bending and tearing of fibers as well as bond dissociation energy should be taken into account in calculations.

Another source of problem is jamming (the loops of adjacent wales and courses make contact with each other and the arms of the loop make contact at the point of the minimum loop width [17]), which is a limiting factor for lateral contraction and appears when yarns become dense in fabrics. Regarding such a complexity, theoretical findings are not discussed and lateral connection factor's parameter is measured by empirical methods [6, 10, 11 and 12].

One way to find out such a difference is to measure lateral connection factor with a video-recording device for picturing during tension process and then performing deformation analysis in a certain series of time using a computerized system. The method is shown schematically in Figure 2 [6].

Measuring lateral contraction in a uniaxial experiment requires uniform transformation in the measuring area. Researchers suggest that lateral contraction to be done in the center of sample. It is based on the Saint Venant'principle [14]. This principle implies that tension resulted from two edges of force on a surface, when forces are statically equal, is different in the area of force exertion. However, tension is uniform in a rather far distance. They achieved average values of calculated amounts in favorite places from the center for calculation of lateral relation coefficient. Bias Singh et al. [14] proved that when length of sample is greater than 15 cm, lateral deformation in center of sample would be independent of sample's length and edges effect would be trivial in center of sample. Edges effects would gain greater importance by reduction of samples' width and such a trend causes more estimation of lateral contraction. Because the effects resulted from edges are eliminated in areas far from them, measurements are performed in the middle of samples. Dimensions of test fabric sample should be established in such a manner that drawn circle on fabric possesses enough space from edges, about sample width inside of the edge. In other words, if sample width inside of edge is (b) and circle diameter is (d), the length of fabric sample inside of edge should be at least equal to ($2b+d$).

C. Relaxation time constant

When a tension is exerted to a viscoelastic substance, it shows time-related transformation. When tension is released, the substance would not completely return to its original condition. Resilient elongation section is an indicator of reserved energy in elastic part and lost energy in viscous part of a substance.

Simulation is used to determine a viscoelastic behavior. Reduction of tension in these substances,
with a given fixed extra length, resulted from time passing is called Relaxation [1].

Whenever tension is released, a substance would not completely return to its original condition. Therefore, simulation is used to determine its viscoelastic behavior that is a combination of springs to show elastic and shock absorbers to show viscosity property.

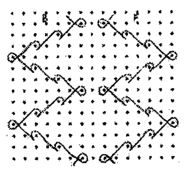
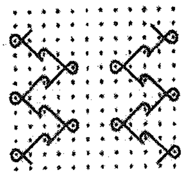
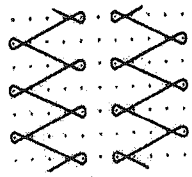
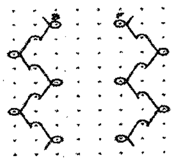
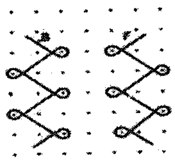
[3] EXPERIMENTAL (PRODUCTION AND METHOD)

In this study, the basic net fabrics are included: pinhole, sand fly, with equal pinhole, equal sand fly, and equivalent to six-course atlas, which are produced in two precisions, (two machine gauges) and two counts. Production of six-course atlas is not possible in a normal situation due to not setting up principles regarding net fabrics products. A 24-Guage Rachel machine of Karl Mayer Co. was used for production of fabrics. For yarn feeding, two warp yarn snow, each with 5 cords with 36-textured polyester, 150-count denier were used. Temperature condition and workshop relative humidity were 20 ^{0}C and 85%, respectively. Table 1 shows specifications of product fabrics as well as codifying, weave, texture structure, threading, and lapping chain.

All the experiments were completed by using an Instron machine, model (M12-13675-EN). This machine works based on Constant Rate of Elongation (CRE) and is composed of a force-exertion mechanical section and software (Merlin). According to (ASTM D2594-99a) standard, five samples from each type of fabrics at reciprocal direction of course and wale with speed of (300 mm/min) were tested. Sample dimensions with 15 cm in length and 5 cm in width was cut, correspond to course and wale, with respect to equal openings for width of samples.

In order to gain lateral contraction, fabric is placed inside the edge and filming while being put under strain. Then by using the film and computer programs, some pictures are prepared in a certain period, which present our favorite elongation(10, 20, 30, 40, and 50 percent) and next by picture processing, dimensional changes are calculated.

Table 1: Specifications properties of product fabrics: codifying, fabric structure, threading and lapping chain.

EQUIVALENT TO SIX-COURSE ATLAS (EA6)	EQUAL SANDFLY **(ESF)**	EQUAL PIN-HOLE **(EPH)**	SAND FLY **(SF)**	PIN-HOLE **(HP)**		
11001100	11001100	11001100	10101010	10101010	FRONT & BACK	**Guide Bar**
4-0/8-12/16-20/ 24-28/20-16/12-8	4-0/8-12/16-20/12-8	4-0/16-20	8-12/8-4/4-0/4-8	8-12/4-0	FRONT	**lapping chain**
24-28/20-16/12-8/ 4-0/8-12/16-20	16-20/12-8/4-0/8-12	16-20/4-0	4-0/4-8/8-12/8-4	4-0/8-12	BACK	
					**Lapping movement**	

According to Figure 3 drawn circle with diameter of (d) is transformed on fabric while is under strain and the diameter of circle which is alongside of force (d_1) is increased and its vertical diameter (d_2) is decreased. By using following relation, we calculate lateral relation coefficient:

$$\nu = \left|\frac{d_2 - d}{d_1 - d}\right| \qquad (3)$$

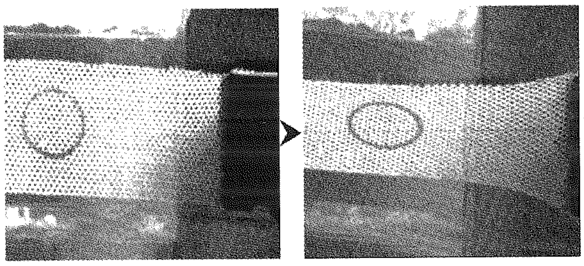


Figure 3: Sample image used for measuring lateral contraction.

Measuring camera error

Because during filming-process of under strain sample, camera is fixed and sample is moving and changes of light angle affected camera's lens, measurement of drawn circle dimensions would face with an error. In order to measure amount of this error, correspond to Figure 4, we draw on a paper a circle having dimension of the main circle. The paper is shooting by camera with the same conditions governed over the main experiment. Then we get the size of drawn circles diameter. By making a comparison of these lengths with length of the main circle diameter in zero elongation, we can calculate relative and absolute error.

In this experiment for maintaining all conditions of samples equally, our length and width of sample is 5 and 15 cm, respectively. The sample is pulled (with a speed of 300 mm/min) to gain elongation of 50% and then remained in this manner for 16 minutes. By passing time, tension drop has achieved and amount of force is lesser momentarily. The quantity of force is recorded in minutes of 0, 0.5, 1, 2, 4, 8 and 16.

In order to weave fabrics with half-gauge, Lapping movement, equivalent to these textures were used, with a difference that threading of guide bars in this manner is an empty process. Single-fold textured filament yarns were used for production of samples with half-yarn count. Samples images of produced fabrics whit their primary properties are shown in Tables 2 and 3.

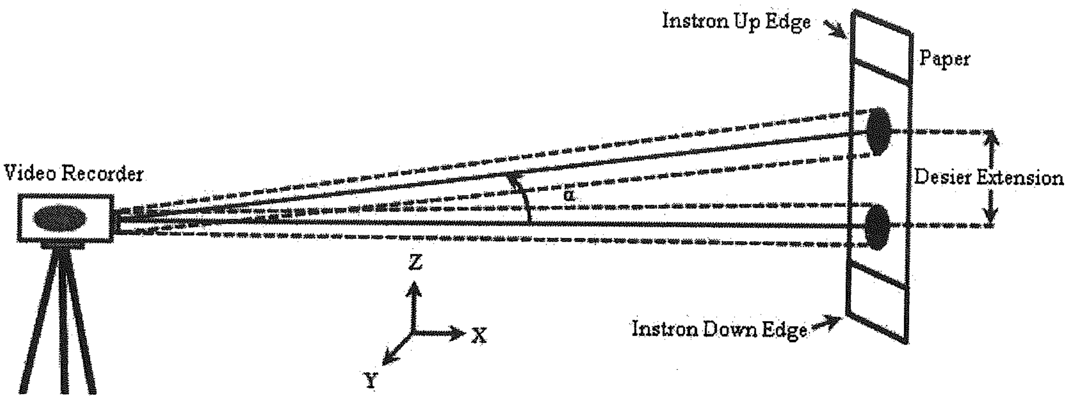


Figure 4 : camera error in measuring lateral contraction test.

TABLE 2 : IMAGES OF SAMPLE FABRICS PRODUCED FOR MECHANICAL TESTS.

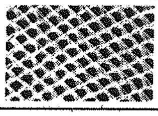
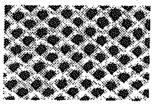
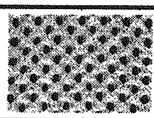
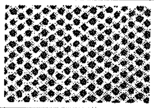
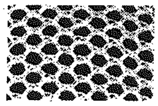
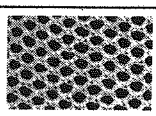
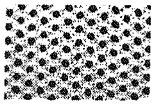
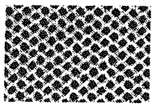
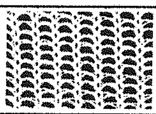
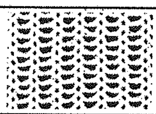
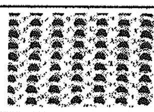
Half Gauge & Count	Half Gauge	Equal	Normal	
				**Pin-Hole**
				**Sand fly**
				**Equivalent to six-course Atlas**

TABLE 3 : PRIMARY PROPERTIES OF SAMPLE FABRICS PRODUCED FOR MECHANICAL TESTS.

Density		Run-in (cm)		Contraction (%)	Weight (g/m^2)	sample	row
wpc	cpc	Back Bar	Front Bar				
6.42	6.33	344	306	28.86	76.55	PH	**1**
5.86	5.58	248	224	22.15	72.03	SF	**2**
7.91	7.62	516	459	42.28	92.72	EPH	**3**
6.87	6.72	350	285	33.56	84.09	ESF	**4**
7.28	6.95	500	407.2	37.32	83.76	EA6	**5**
7.48	7.33	357	325	38.93	111.80	PHG1/2	**6**
6.94	6.64	263	248	34.23	115.31	SFG1/2	**7**
7.16	6.85	527	425	36.24	98.31	EA6G1/2	**8**
8.20	8.05	373	342	44.30	46.14	PHG1/2-1	**9**
7.09	6.89	282	263	35.57	51.11	SFG1/2-1	**10**
7.09	6.77	551	437	35.57	40.42	EA6G1/2-1	**11**

[4] RESULTS AND ANALYSIS OF MECHANICAL TESTS

All data driven from accomplished mechanical tests are shown in Table 4 and 5 that these show:

A. Texture structure effects on modulus

Summary of statistical results is shown in Table 6. As it is obvious, for all samples initial and secondary models of fabrics (E_1 and E_2) and their texture structure (E_1' and E_2') is mostly spread through course direction than wale, except for equal six-course atlas which do not show any bidirectional difference between its initial model, and its secondary modulus in the direction of course is more than wale direction. According to the definition, there is a reverse relation between modulus and strain. By observing samples elongation charts, it is seen that strain is lesser in the direction of course than wale, except for EA6.

For all samples, difference between initial and secondary modulus in course direction is lesser than wale, in such a manner that it causes secondary modulus ratio to initial modulus ($E_2/E_1 = E_2'/E_1'$) in wale direction to be more than course direction. At first, when curves are increased by a light slope, texture structure of fabrics faces with force, and yarns are slowly separated from texture structure and openings within fabrics start a deformation process. After a certain length of elongation, yarns may not any longer move in relation with each others in the texture structure. In other words, yarns are set parallel to each others in structure, that is jamming phenomenon is occurred in fabrics. In continuation, yarns are more effective than texture structure and tolerate the main part of exerted force. Therefore, both factors of yarn and texture structure have determinant role in amounts of mechanical property of fabrics. Therefore, such an attitude affected by direction of yarns' arrangement.

Splitting texture gauge of samples to a half would only cause secondary modulus to be increased through course direction. As it is mentioned earlier, secondary modulus is mostly affected by yarn than texture structure and because of occurrence of jamming phenomenon, yarns are not any longer able to move in relation with each others and so, tolerate the main part of exerted force without any repositioning in respect to each others. Dimensional form of fabrics openings in half-gauge status, with respect to production method and their texture design, are so arranged that openings dimensions are not changed in direction of wale, however, openings dimensions are double in course direction. In other words, circular openings of pinhole fabrics are transformed to oval-shape openings and diamond-shape openings of Sand fly fabrics are transformed to diamond openings with double elongation. In course direction, half-gauge would cause elongation of textures' under lap. If we suppose that (u) is a force exerted to yarns inside of texture structure by edges of Instron machine, therefore, according to Figure 5 a force is exerted alongside yarns inside texture structure is ($f = u.\cos(c)$).

TABLE 4 : RESULT FROM MECHANICAL PROPERTIES TEST (MODULUS).

E_2/E_1	$E'_2(N)$	$E'_1(N)$	$E_2(N)$	$E_1(N)$	$\varepsilon(\%)$	$f(N)$	direction	sample	row
157.99	26.1573	0.1656	827.88	5.24	78.43	188.36		**PH**	1
90.00	23.5484	0.2616	657	7.30	76.67	256.87		**SF**	2
218.07	18.8877	0.0866	719.62	3.30	90.72	181.8	**course**	**EPH**	3
150.02	22.8155	0.1521	766.6	5.11	71.99	256.39		**ESF**	4
117.01	18.1154	0.1548	629.51	5.38	112.3	230.76		**EA6**	5
227.01	17.1847	0.0757	551.63	2.43	87.26	166.22		**PH**	6
147.92	18.1741	0.1229	532.5	3.60	102.67	147.49		**SF**	7
275.99	14.9335	0.0541	590.62	2.14	103.28	161.74	**wale**	**EPH**	8
209.96	14.6084	0.0696	501.8	2.39	112	167.22		**ESF**	9
157.00	23.9816	0.1527	872.93	5.56	95.52	207.55		**EA6**	10
268.29	24.0109	0.0895	880	3.28	85.54	217.83		**PHG1/2**	11
154.26	31.7813	0.2060	1055.14	6.84	86.85	329.49	**course**	**SFG1/2**	12
219.09	31.4076	0.1434	1075.71	4.91	93.5	277.11		**EA6G1/2**	13
277.57	10.8356	0.0390	405.25	1.46	129.46	149.8		**PHG1/2**	14
193.24	12.3069	0.0637	427.05	2.21	146.28	139.34	**wale**	**SFG1/2**	15
139.06	18.5670	0.1335	664.7	4.78	127.31	215.31		**EA6G1/2**	16
166.21	11.4388	0.0688	460.41	2.77	75.96	100.09		**PHG1/2-1**	17
74.07	13.9402	0.1881	480	6.48	72.67	113.2	**course**	**SFG1/2-1**	18
99.24	11.5504	0.1161	390	3.93	84	126.4		**EA6G1/2-1**	19
372.22	8.1883	0.0220	335	0.90	94	84.85		**PHG1/2-1**	20
209.93	8.3724	0.0398	296	1.41	117.33	79.88	**wale**	**SFG1/2-1**	21
91.84	10.1583	0.1106	360	3.92	117.92	102.6		**EA6G1/2-1**	22

TABLE 5 : RESULT FROM MECHANICAL PROPERTIES TEST (LATERAL CONTRACTION AND RELAXATION).

Tension Changes (%) in the first 30 Seconds	50% V	40% V	30% V	20% V	10% V	direction	sample	row
0.26	1.57	1.34	1.32	1.21	0.54	course	PH	1
0.27	1.75	1.65	1.49	1.37	0.78		SF	2
0.23	1.37	1.36	1.35	1.24	0.85		EPH	3
0.27	1.69	1.68	1.53	1.39	0.57		ESF	4
0.18	0.88	0.81	0.81	0.75	0.51		EA6	5
0.18	1.19	1.18	1.06	0.9	0.8	wale	PH	6
0.17	1.06	1.05	1	0.94	0.93		SF	7
0.20	1.31	1.23	1.23	1.15	0.67		EPH	8
0.15	1.25	0.86	0.83	0.82	0.77		ESF	9
0.24	1.47	1.27	1.16	1.15	0.5		EA6	10
0.29	1.48	1.41	1.33	1.15	0.93	course	PHG1/2	11
0.26	1.53	1.3	1.21	1.03	0.38		SFG1/2	12
0.23	2.17	1.04	1.04	0.9	0.69		EA6G1/2	13
0.12	1.5	1.07	0.77	0.7	0.6	wale	PHG1/2	14
0.14	1.25	0.6	0.56	0.56	0.5		SFG1/2	15
0.19	1	0.99	0.98	0.95	0.92		EA6G1/2	16
0.23	1.37	1.3	1.27	1.02	0.5	course	PHG1/2-1	17
0.27	1.71	1.55	1.39	1.23	0.53		SFG1/2-1	18
0.24	1.61	1.57	1.56	1.46	0.86		EA6G1/2-1	19
0.15	1.07	1.02	0.97	0.91	0.79	wale	PHG1/2-1	20
0.13	1.09	0.9	0.83	0.78	0.75		SFG1/2-1	21
0.21	1.11	0.95	0.94	0.91	0.87		EA6G1/2-1	22

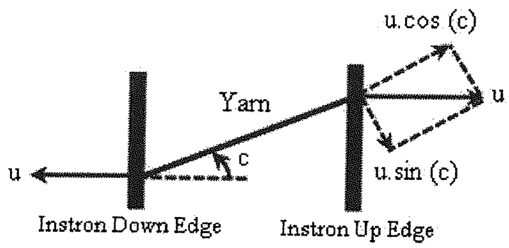


Figure 5 : load on yarn in instron edge.

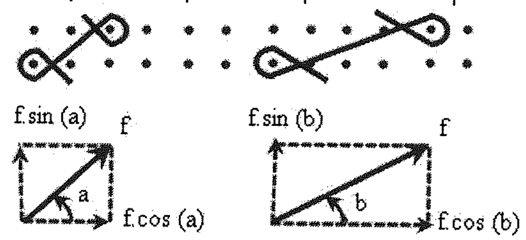


Figure 6 : Effect of changing underlap on yarn load.

According to Figure 6 whatever is more the number of underlap, yarn would be set more horizontally inside fabrics structure. Therefore, building angles would be smaller and the component alongside of force, because of growth of (cos(a)), is increased. This means that yarn, coincide with force exertion, shows grater amount of resistance, and therefore, fabrics resistance against force is increased, that is increasing of modulus. Therefore, with growth of underlap's length amount of modulus, with equality in other conditions, is increased.

Bilateral analysis of variance shows that reciprocal effect between yarn count and fabric direction is not existed about initial modulus of fabrics. Therefore, in such a manner, one may speak about the main effect of these two variables alone. By splitting yarn count to a half, there is no change in initial model of samples that is initial modulus (fabric and texture structure) is not affected by yarn count. The cause may readily be explained from sliding and movement of yarns upon each others, which causes yarns, in this manner, not be affected by load. On the other hand, results of bilateral analysis of variance show that reciprocal effect between yarn count and fabric direction is existed for the secondary modulus of fabrics, so, in this manner, one cannot speak about the main effect of these two variables alone, and texture direction should be taken into account simultaneously. With splitting yarn count to a half, secondary model of samples is reduced which is more severe in course direction.

About reduction of secondary modulus, with splitting yarn count to a half, according to relation of modulus definition it is natural that modulus are bi-directionally reduced, since making count in to a half is similar to splitting yarn cross section to a half, and it causes that half of the force to be exerted on yarn. But, about why modulus is not really split to a half, we may say that because usage of a single-fold and double-fold yarn, instead of yarn of a half count, for this purpose, parameters like friction between two single-fold yarn, overlapping of weak and strong points of two yarns of single-fold with each others, etc. can affect the results of the experiment. About this issue that why this effect is occurred in more severe course, one may refer to the effect of ($\cos(a)$) which was mentioned in previous analysis. With respect to texture design of yarns' structure, it is clear that yarns' angle with axis alongside of a sample course of fabrics is lesser than yarns' angle with axis alongside of a sample wale of fabrics. Therefore, according to (4) component of force at the direction of course is usually more than wale direction. This means that according to Figure 6 we will always have:

$$f.\cos(a) \rangle f.\sin(a) \qquad (4)$$

TABLE 6: SUMMARY OF STATISTICAL OF MODULUS ON THE SAFETY LEVEL 0.95.

	variable	E_1	E_2	E'_1	E'_2
Sig.	course	0.476	0.0276	0.375	0.13
	wale	0.484	0.329	0.348	0.138
	Count (C)	0.524	.000	0.507	.000
	Direction (D)	0.058	.000	0.063	0.001
	Count*direction	0.953	0.007	0.991	0.012

Identification of Index for modulus' ratio

Experiments results show that ratio of secondary modulus to primaries' is a function of following variables:

$$(E_2/E_1)_{c,w} = f(c.r, u.l, r.i) \qquad (5)$$

In this function, parameters are as follows:

c.r: Number of course in a reiteration of texture structure

u.l: Number of under laps in a reiteration of texture structure

r.i: Ratio of a guide-bar consumed yarn in each reiteration of texture structure (this ratio is assumed according to the suggestion of Karl Mayer Co. in order to estimate amount of a guide-bar consumed yarn for consumption of different (o.l.) over lap and underlap (u.l.). For example, consumed yarn, with a respect to a needle space, is 2 and 1 for over lap and underlap, respectively.

Square of course amount, in a reiteration of texture structure, and square root of the ratio of underlap amount to current length, in a reiteration of texture structure, is used for determining the index. The reason is referred to the amount of correlation coefficient (r^2) of modulus ratio and index. By using trial and error method in determination of a formula, mathematical relations set based on their direct or negative relation to amounts of two modulus' ratio. This index should be defined in such a manner that not only does it show changes trend, but also it enjoys from high correlation coefficient too. By using various algebraic relations and obtaining amount of correlation coefficient, finally index amount is defined as the following relation, which possesses the highest correlation coefficient:

$$I = (c.r)^2 * \sqrt{\frac{u.l}{r.i}} \qquad (6)$$

Table (7) shows data related to variables and amount of index calculated from the above formula.

TABLE 7: VARIABLES VALUE AND AMOUNTS OF INDEX

I	$u.l$	$r.i$	$c.r$	sample
0.71	4	8	2	PH
0.55	4	11.5	4	SF
0.82	8	12	2	EPH
0.65	6	14	4	ESF
0.63	8	20	6	EA6

Linear relation achieved by amounts of two modulus and index ratio for tested fabric samples in course and wale direction is as follows:

$$(E_2/E_1)_c = -170.18 + 471.42I \qquad (7)$$

$$(E_2/E_1)_w = -132.03 + 499.41I \qquad (8)$$

Correlation coefficient (r^2) is 96.43% and 90.92% for (7) and (8), respectively, which shows a relatively high correlation of index with modulus ratio. Figure 7 shows relationship between Index and modulus ratio.

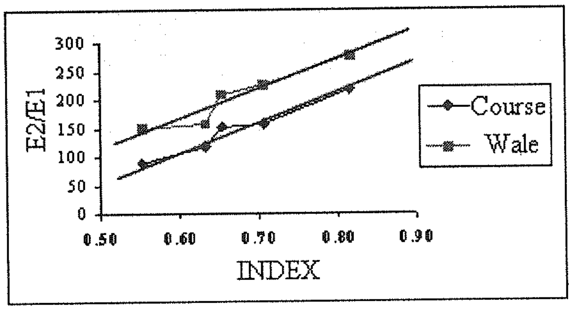


Figure 7 : relative between index and modulus ratio.

B. Effect of texture structure on lateral contraction

The following results are gained by above explained method:

Lateral contraction of fabrics, contrary to rigid materials, because of its viscoelastic property, is not equal in different periods and as it is shown amount of lateral contraction is variable in different elongation.

Except for 10 percent elongation, there is a unique trend in lateral contraction amounts in 20, 30, 40, and 50 percent elongation. In 10% elongation, uncertainty of changes trend in lateral contraction of samples may be related to high elasticity of samples and their crimp and curl as well as low dimensional stability and even placing samples tightly or loosely inside the edges of Instron, which is a result of an experimenter's fault.

Direction of fabric's strain has no effect on the amount of samples lateral contraction. It is shown by the charts that the trend of lateral contraction is like the trend of changes in fabrics sample modulus. Though, direct relationship of modulus with lateral contraction may be inferred easily through following relations:

$$\nu = \varepsilon_y / \varepsilon_x , \quad \sigma_x = E_x \varepsilon_x \Rightarrow \quad \nu = \frac{E_x . \varepsilon_y}{\sigma_x} \quad (9)$$

$$\sigma_y = E_y \varepsilon_y \Rightarrow \quad \nu = \frac{E_y}{\sigma_y . \varepsilon_x} \quad (10)$$

Results show that the trend of changes of lateral contraction ratio in course direction is opposite to wale direction. It is arranged in such a manner that average of lateral contraction ratio in course and wale direction is constant:

$$(\nu_c + \nu_w) = cte \quad (11)$$

Slope amount of average line for elongation of 20, 30, 40, and 50 percent is 0.027, 0.047, 0.052, and 0.034 respectively, which is near to zero.

Reversing trend of changes of lateral contraction ratio in course direction is easily intelligible from the concept of lateral contraction which because of force elongation of one side, a length contraction (vertically) of other side would be resulted.

Experiments also show that with splitting samples gauge to a half, lateral contraction ratio is reduced in wale direction. However, such a trend is seen smoother in course direction. The main factor affected in reduction of lateral contraction in wale direction with respect to splitting gauge to half and structure of these fabrics texture is halving of the number of openings or holes in course direction of fabrics, however, number of holes in wale direction are intact. This means that holes dimensions are fixed in wale direction but doubled in course direction. It is inferred from the results that with splitting yarns count to half, lateral contraction ratio in course and wale directions is reduced, except for equal six-course atlas fabrics.

The above results have gained from accomplished experiments about lateral contraction by help of statistical analysis, and a summary of them is shown in the following table.

TABLE 8:SUMMARY OF STATISTICAL OF LATERAL CONTRACTION ON THE SAFETY LEVEL 0.95

	variable	20%	30%	40%	50%v
Sig.	Direction (D)	0.051	0.054	0.066	0.056
	Gauge (G)	0.212	0.321	0.384	0.439
	Count (C)	0.237	0.305	0.404	0.430

C. Effect of texture structure on relaxation

Experimental analysis shows that quantity of tension drop is of great importance within the first 30 seconds of the experiment and during other steps, it is not so remarkable. In our sample, tension drop has occurred within the first 30 seconds of the experiment and then force amounts became stable. This experiment is verified by T-test with its dependent samples. Figure (8) shows a chart for a Sandfly fabric.

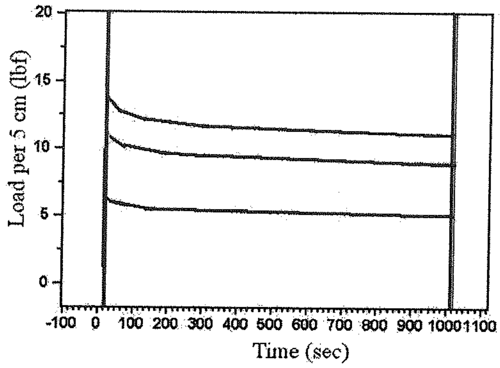


Figure 8 : Sample of Relaxation curve of Sand fly fabric.

Since fabrics structures are affected by various factors like yarn structure, fabric structure, fiber structure, type, and so on, a modeling process may not be used as easily as fibers in this regard. Therefore, modeling relations of Maxwell model may not be used here. According to the above results, percentage of force changes in a time lag of 30 seconds is assumed as criteria of tension drop of samples in an elongation of 50%. With respect to highly elasticity property of these fabrics, occurrence of tension drop in the first minutes of experiment is natural.

TABLE 9:SUMMARY OF STATISTICAL RELAXATION ON THE SAFETY LEVEL 0.95.

	Max-0.5 min	0.5-1 min	1-2 min	2-4 min	4-8 min
Sig.	0.048	0.050	0.053	0.051	0.051

With respect to the above results, if we consider percentage of force changes in this time-space of 30 second as a criterion, it is seen that changes trend for samples is more like changes trend of lateral contraction. With respect to this feature, discussed analysis of lateral contraction results' justification might be true here too.

Study of reciprocal variance analysis shows that interaction between gauge and fabric direction, is not existed in the first 30 seconds of the experiment. Therefore, in this manner, we may speak of the main effect of these two variables alone. Results show that percentage of tension changes in the first 30 seconds is reduced. When a material is drawn and its length is remained fix, in regard to molecular point of view, some of intermolecular bonds are torn and internal tension in molecules' body gradually released as well as bonds and finally relaxation occurred [1]. Whatever more the number of underlap, it would be drawn and elongated more. Therefore, number of molecular bonds is more and there is a greater possibility for existence of weak molecular bonds too. Therefore, rupture of bonds occurred more and tension drop is quickly emerged. Whatever more density, the number of underlaps in a surface unit would be also more and therefore, number of intermolecular bonds is more too. Therefore, according to given explanations, tension drop would occur more quickly [18]. With respect to given explanations, since in fabric samples with gauge and half yarn count, number of molecular bonds is less; possibility of weak bonds is also less. Therefore, the number of rupture is less and tension drop is occurred more slowly.

TABLE 10:SUMMARY OF STATISTICAL RELAXATION ON THE SAFETY LEVEL 0.95.

	Count (C)	Gauge (G)	Effect of D on C	Effect of D on G	C*D	G*D
Sig.	1.00	0.43	0.001	0.00	0.504	0.232

[5] CONCLUSION

Results of accomplished experiments show that mechanical property of net warp knitted fabrics is extremely affected by their parameters of texture structure. Results indicate that change in dimension, amount, and shape of fabrics' holes would change number of modulus, lateral contraction, and tension drop of these fabrics.

1- For all fabric samples, initial and secondary modulus and their texture structure are more in course direction than wale, except for six-course atlas which there is no and bidirectional difference between its initial modulus, but in secondary one is more in wale than course direction. Ratio of secondary to initial modulus is more in wale than course direction. Splitting texture gauge of samples to a half causes only elongation of secondary modulus in course direction. Such a splitting would not show changes in initial modulus of samples, but it causes secondary modulus of samples to be decreased. This reduction is intense in course direction. Structural index presented in this study for modulus can help producers relatively predict appropriate texture design for their desirable tensile property before production of fabrics.

2- Lateral contraction of fabrics is not equal over time and its quantity is different in various elongations. Direction of fabric tensile has no effect on lateral contraction of samples. Changes trend lateral contraction ratio in course is opposite to wale direction. This feature is organized in such a manner that average of lateral contraction ratio in course and wale direction is equal to a fix quantity. By splitting gauge of samples to a half, lateral contraction ratio in course and wale direction is reduced, but in course direction, this trend might be show more slowly. By splitting yarns count to a half, lateral contraction ratio in course and wale direction is reduced, except for six-course atlas.

3- In this fabrics sample the most part of tension reduction occurs within the first 0.5 minute. Percentage of tension changes in this time space of 30 seconds is considered as samples tension drop criterion in 50% elongation. Percentage of tension changes in the first 30 seconds of experiment is not different bi-directionally; however, by splitting the gauge, percentage of tension changes in the first 30 seconds is reduced. Percentage of tension changes in the first 30 seconds of experiment is not different bi-directionally; however, by splitting the yarns count, percentage of tension changes in the first 30 seconds is reduced.

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