Effect of Fabric Structure on the Tensile Stress Relaxation of Net Warp Knitted Fabrics

Azita Asayesh* and Sanaz Yousefi

***Abstract*- Under constant strain, there is a decreased stress with time in viscoelastic materials, which is called stress relaxation. Textiles experience various long lasting deformations during manufacture and application. Consequently, stress relaxation occurs in these materials. This phenomenon can cause disturbances in textile performance in technical applications such as surgical mesh, pressure garments, varicose stockings, pressure bandages, etc. Thus, by considering the factors affecting stress relaxation of the fabric, the ability to design and produce appropriate products increases. In the present study, net warp knitted fabrics with five different structures including Tricot, Pin hole-net, Sandfly, quasi-Sandfly, and quasi-Marqussite have been produced and the effect of fabric structure on the stress relaxation of the fabrics in the course and wale directions have been investigated. To investigate the stress relaxation of the fabrics, a new index, named stress relaxation index was introduced. This index is obtained by multiplication of initial stress by the porosity of the fabric divided to the mass per unit area of the fabric. The results demonstrated that fabric structure has remarkable effect on the stress relaxation of the fabrics, and by increasing the stress relaxation index, stress relaxation of the fabric in both directions increases. Fabrics with Pin hole-net and quasi-Marqussite structures showed the highest and lowest stress relaxation in the course direction, respectively. Meanwhile, fabrics with Tricot and Sandfly structures exhibited the highest and lowest stress relaxation in the wale direction, respectively.**

***Keywords*: stress relaxation, warp knitted, fabric structure, net fabric**

I. INTRODUCTION

Stress relaxation is a time-dependent behavior in textiles, which happens with the release of stresses when the textile is under constant strain during a period of time. This phenomenon can cause disturbances in textile performance in technical applications such as surgical mesh, pressure garments, varicose stockings, pressure bandages, etc. Therefore, the investigation of stress relaxation is critical for predicting the behavior of the fabric, especially in cases that stress relaxation of the fabric affects the efficiency of the product [1].

Surgical mesh is a porous fabric which is often used for hernia reconstruction. Generally, surgical meshes are produced from polypropylene, polyester, and polytetrafluoroethylene monofilaments using warp knitting technology [2]. Since these meshes are as replacement for abdominal wall, they are under constant strain in the body. Consequently, considering the stress relaxation of these meshes is crucial to ensure no recurrence of the disease [3].

Gil *et al.* [4] considered the stress relaxation behavior of polypropylene surgical meshes and found that increasing the strain level leads to increase the initial stress and stress relaxation of the meshes, and stress relaxation occurs faster.

In a research by Kirilova [3], the stress relaxation of commercial surgical meshes was surveyed in the wale and course directions. All considered meshes exhibited orthotropic mechanical properties, and the stress relaxation of the meshes in course direction was higher than that in wale direction.

In another research by Kirilova *et al.* [5], the stress relaxation of heavy and light surgical meshes was studied. All investigated meshes demonstrated orthotropic mechanical properties, and heavy meshes revealed stress relaxation two times higher than the stress relaxation of light meshes.

Hashemi *et al.* [6] investigated the effect of fabric structure, strain percentage and loading direction on the stress relaxation of two-bar warp-knitted fabrics with longer underlaps in back bar (reverse locknit, sharkskin, and queens' cord). They observed that increasing the strain and length of underlap in the back guide bar, increases the stress in the fabric, but decreases the stress relaxation percentage of the fabric. Moreover, stress relaxation percentage in wale direction is higher than that in course direction for reverse locknit and sharkskin3, but this is

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inverse for sharkskin4 and queens' cord.

In a research by Ardakani *et al.* [7] the impact of fabric structure as well as strain value and course density on the stress and stress relaxation of the warp-knitted structures with longer underlaps in front bar (locknit, three- and four-needle satin, and loop raised) was surveyed. The results revealed that increasing the strain and length of underlap in the front guide bar leads to an increase in the stress and stress relaxation percentage of the fabric. Furthermore, fabrics with higher course density demonstrated higher stress and stress relaxation percentage.

As one of the structural parameters of the fabric, knit pattern is a decisive factor that affects the stress relaxation of knitted fabrics and subsequently their performance in applications such as surgical mesh. Although several investigations have been assigned to the stress relaxation behavior of various fabrics [8-13], no study is available in which the stress relaxation of net warp knitted fabrics has been considered from the point of fabric structure. Due to the lack of research in this field, the purpose of this study is to investigate the effect of fabric structure on the stress relaxation behavior of net warp knitted fabrics, to identify whether changing the fabric structure will enhance their functionality in applications such as surgical mesh.

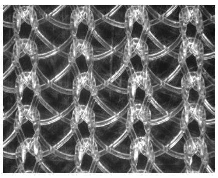
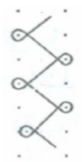
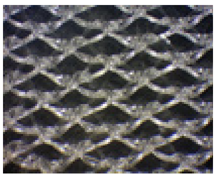
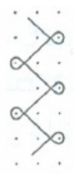
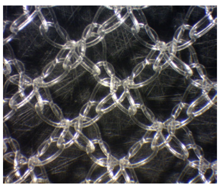
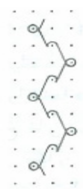
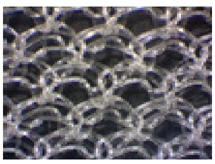
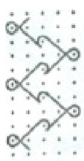
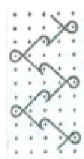
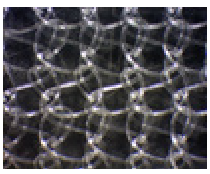
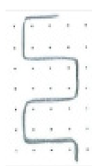
II. EXPERIMENTAL

A. Materials and Methods

A.1. Fabric Production

Net warp knitted fabrics with various structures including Tricot, Pin hole-net, Sandfly, quasi-Sandfly, and quasi-Marqussite were produced on two guide bars Raschel warp knitting machine (Karl Mayer, Id: 51547, Gauge (N.P.I) 12) using polypropylene monofilament. The yarn fineness was 270 denier (diameter: 0.2 mm), and half threading (1 full 1 empty) of guide bars was used for all structures. The images of the fabrics and lapping movement of guide bars

TABLE I
STRUCTURAL AND PHYSICAL PROPERTIES OF PRODUCED FABRICS

Knit pattern	Image of the fabric	Front guide bar lapping	Back guide bar lapping	Porosity (%)	c.p.c (cm^{-1})	w.p.c (cm^{-1})	Mass per unit area ($g.m^{-2}$)
Tricot				38.5	9	3.8	139
Pin-hole-net				40.6	10.1	6.3	118
Sandfly				44.7	5.6	6.5	100
Quasi-Sandfly				41.1	5.4	6.8	105
Quasi-Marqussite				49.4	9.9	3.7	91

for different fabric structures are demonstrated in Table I.

B. Heat Setting

The produced fabrics were heat set using hot-air at 120 ºC for 1 min, by a laboratory stenter (model: Ernst Benz) to stabilize the structure of the fabrics and prevent curling.

C. Sructural Evaluation

C.1. Density

The number of course per centimeter (c.p.c) and wale per centimeter (w.p.c) were evaluated in five different points of the fabrics and the average values were reported (Table I).

C.2.Mass Per Unit Area

The mass per unit area of the fabrics was calculated by weighting 5 samples (12×12 cm^2) from each fabric structure, and dividing the weight to the area of the sample. The average values are shown in Table I.

C.3. Porosity Measurement

Since the structure of produced fabrics was porous, their porosity was measured utilizing image processing method. For this purpose, the image of the fabric was taken with a microscope (model: Dino-Lite). Then, the picture was transformed into a binary image. In the binary image, the black color represents the polypropylene monofilament and the white color denotes the pores. Then, by counting the number of pixels in black and white parts of the image, the porosity of the fabric was calculated as follows:

$$\text{Porosity } (\%) = \frac{\text{Number of white pixels}}{\text{Number of total (black + white) pixels}} \tag{1}$$

D. Mechanical Tests

In the present study, the effect of fabric structure on the stress relaxation of net warp knitted fabrics has been surveyed in the course and wale directions. To this end, the following tests were conducted.

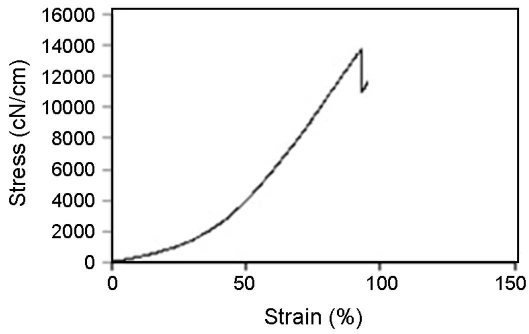


Fig. 1. Stress- strain curve of Tricot fabric in the course direction.

D.1. Tensile Test

The tensile test was performed on the fabrics utilizing an Instron-5566 with a 500 N load cell at a speed of 20 mm/min, to identify elastic region for different fabric structures. To prevent mesh curling, samples were cut in 7×20 cm^2 and tested with the effective size of 5×10 cm^2. From each fabric structure, five samples were strained up to rupture. A typical stress–strain curve of one of the fabrics has been illustrated in Fig. 1. The initial linear region of the curve represents the elastic region. Thus, the maximum elastic strain is obtainable from the stress–strain curve (Table II).

D.2. Stress Relaxation Test

Stress relaxation test was conducted using an Instron 5566 with a 5 kg load cell at a speed of 20 mm/min. The same sample size was chosen as the tensile test. Fabrics were extended up to a definite strain level by moving the upper jaw of the instrument. Then, stress values were recorded over 1800 s at regular intervals (0.5 s). In order to investigate the effect of fabric structure and loading direction on the stress relaxation of the fabrics, five specimens of each fabric structure were extended at 10% strain as common strain in the course and wale directions (Table II). The variations of stress were plotted against time at certain time intervals for a period of 1800 s, and finally, the average stress decay curve was plotted.

TABLE II
STRUCTURAL AND PHYSICAL PROPERTIES OF PRODUCED FABRICS

Fabric code	Elastic modulus in the course direction (cN.cm^{-1})	Elastic strain in the course direction	Elastic modulus in the wale direction (cN.cm^{-1})	Elastic strain in the wale direction
Tricot	3.17×10^3	0%-20%	3.98×10^3	0%-26%
Pin-hole-net	2.80×10^3	0%-14%	0.95×10^3	0%-44%
Sandfly	1.15×10^3	0%-48%	0.83×10^3	0%-24%
Quasi-Sandfly	1.43×10^3	0%-22%	2.99×10^3	0%-23%
Quasi-Marqussite	0.56×10^3	0%-40%	2.15×10^3	0%-28%

III. RESULTS AND DISCUSSION

The results of this research were statistically studied by one-way analysis of variance (ANOVA) at 95% significance level, using statistical software package (SPSS).Where a group of effects appeared statistically significant, Duncan's post-hoc test was used to determine whether the differences between multiple pairs were statistically significant. A statistically significant difference was reported if $p<0.05$.

The stress relaxation at each time was calculated using Eq. (2):

$$\text{Stress relaxation at time } t = \Delta\sigma_t = \sigma_i - \sigma_t \quad (2)$$

Where, σ_i is the stress at the beginning of the test or initial stress, and σ_t is the stress at time t.

The effect of fabric structure and loading direction on the stress and stress relaxation of the fabrics has been discussed in the following.

A. Effect of Fabric Structure on the Stress and Stress Relaxation

A typical stress decay plot for Tricot fabric in the course direction is displayed in Fig. 2. It is evident that the stress in the fabric decreases with time. Based on Fig. 2, stress relaxation process in the fabric consists of three sections: fast stress relaxation region (I); slow stress relaxation region (III); and the region between these two, or transition region (II). The fast stress relaxation region mainly consists of elastic deformation and ends quickly. Most of stress relaxation process happens in the slow stress relaxation region, in which the stress in the fabric decreases slowly and fabric response to the applied strain is viscoelastic.

A.1. Course Direction

The effect of fabric structure on the stress decay of the fabric in the course direction is illustrated in Fig. 3a. This figure clarifies that the stress in the fabric decreases with time, and fabric structure has remarkable effect on the stress of the fabric in every moment of the time, including

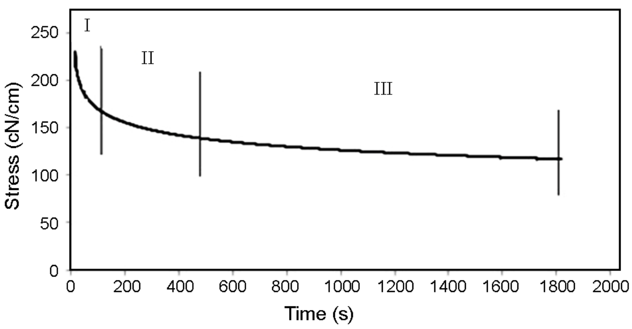
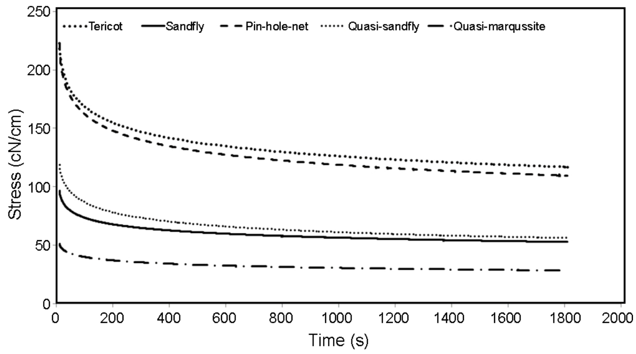


Fig. 2. A typical stress decay plot for Tricot fabric in the course direction.



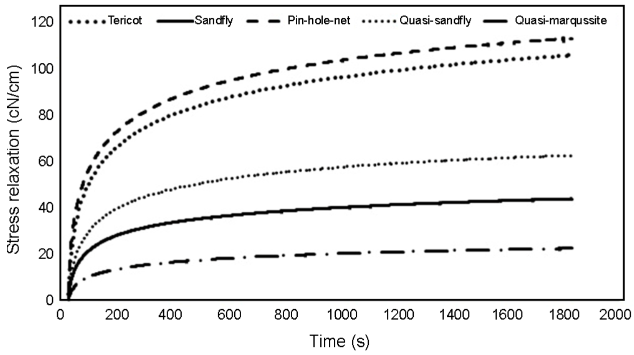


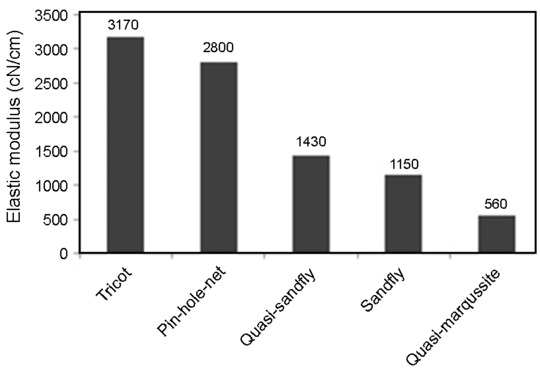
Fig. 3. Effect of fabric structure on: (a) stress decay and (b) stress relaxation of various fabrics in the course direction under 10% strain.

the initial stress and the residual stress values. Tricot and quasi-Marqussite fabrics demonstrate the highest and lowest initial and residual stress values, respectively.

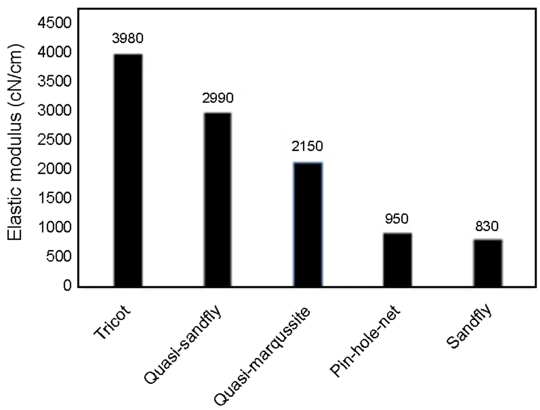
The difference of stress values in various fabric structures is due to the different elastic modulus of the fabrics. Regarding to Hooke's law, owing to apply constant strain to all fabric structures, the produced stress in the fabric structure corresponds to its elastic modulus. As can be seen in Fig. 4a, by decreasing the elastic modulus of the fabric from Tricot to quasi-Marqussite, the stress of the fabric in every moment of the time, including the initial stress and the residual stress, decreases (Fig. 3a).

Besides, statistical result at 95% significance level showed that the effect of fabric structure on the initial stress and the residual stress is outstanding (p-value=0).

Fig. 3b shows the effect of fabric structure on the stress relaxation of the fabric in the course direction. According to the figure, the stress relaxation of the fabrics increases with time, but the rate of stress relaxation decreases gently. In the other word, the slope of the stress relaxation graph decreases with time. Moreover, fabric structure has notable effect on the stress relaxation of the fabric. Pin hole-net and quasi-Marqussite fabrics display the highest and lowest stress relaxation, respectively. Based on Table III, the stress relaxation of Pin hole-net is 5.02 times higher than



(a)



(b)

Fig. 4. Elastic modulus of various fabric structures in: (a) course direction and (b) wale direction.

the stress relaxation of quasi-Marqussite. Furthermore, statistical results verified that the effect of fabric structure on the stress relaxation is remarkable (p-value=0).

The initial stress and existing space between yarns in the fabric structure are two important factors affecting the stress relaxation of the fabrics. Under constant strain, as the produced stress in the fabric is higher, the stress relaxation will be higher as well. Furthermore, as the existing space between yarns in the fabric structure is higher, the slippage and movement of the yarns inside the fabric structure occurs easily and hence the release of stresses in the fabric structure increases. According to the effect of two mentioned factors, to consider the stress relaxation of the fabrics, a new index was defined. This index, which is named stress relaxation index, is obtained by multiplication of initial stress by the porosity of the fabric divided to the mass per unit area of the fabric as follows:

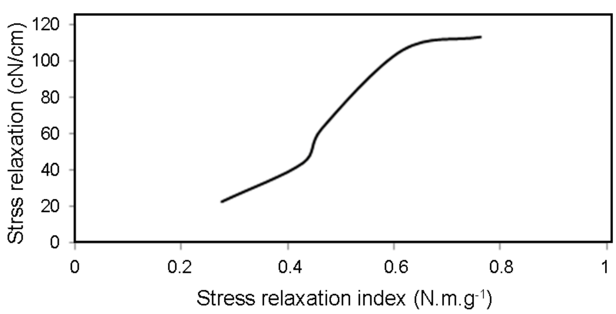


Fig. 5. Relation between the fabric stress relaxation and stress relaxation index in the course direction.

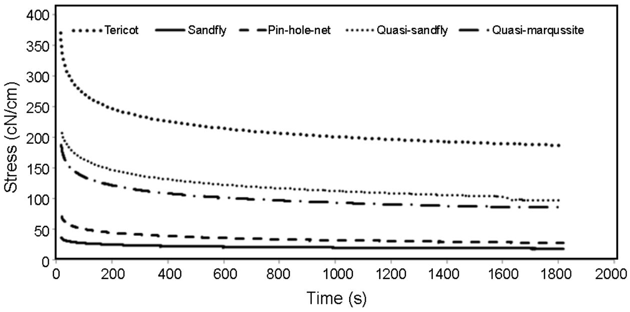
$$\text{Stress relaxation index} = \frac{\text{Initial stress} \times \text{Porosity of the fabric}}{\text{Mass per unit area of the fabric}} \quad (3)$$

It is clear that increasing the initial stress leads to increase in the stress relaxation index. As well, by increasing the porosity of the fabric, the stress relaxation index increases due to increment of spaces between yarns in the fabric structure. Moreover, by increasing the mass per unit area of the fabric, the stress relaxation index decreases. This is due to decrement of fabric porosity, which in turns decreases the spaces between yarns in the fabric structure.

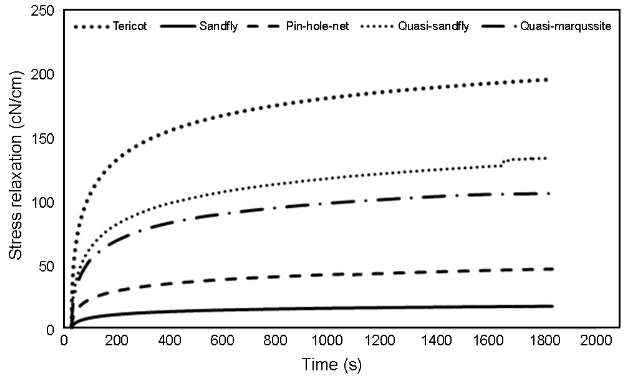
The stress relaxation index of different fabric structures was calculated and presented in Table III. As can be seen, Pin hole-net and quasi-Marqussite fabrics have the highest and lowest stress relaxation index, respectively. The relation between fabric stress relaxation and stress relaxation index is illustrated in Fig. 5. This figure confirms that by increasing the stress relaxation index from quasi-Marqussite to Pin hole-net, the stress relaxation of the fabrics displays ascending trend.

TABLE III
STRESS RELAXATION INDEX OF VARIOUS FABRIC STRUCTURES IN THE COURSE DIRECTION UNDER 10% STRAIN

Fabric code	Initial stress (t=0 s) ($cN.cm^{-1}$)	Residual stress (t=1800 s) ($cN.cm^{-1}$)	Stress relaxation= Initial stress- Residual stress ($cN.cm^{-1}$)	Mass per unit area ($g.m^{-2}$)	Porosity (%)	Stress relaxation index ($N.m.g^{-1}$)
Tricot	222.8	116.9	105.9	139	38.5	0.6166
Sandfly	96.6	52.7	43.9	100	44.7	0.4296
Pin-hole-net	222.6	109.5	113.1	118	40.6	0.7629
Quasi-Sandfly	118.9	56.2	62.7	105	41.1	0.4645
Quasi-Marqussite	50.8	28.3	22.5	91	49.4	0.2767



(a)



(b)

Fig. 6. Effect of fabric structure on: (a) stress decay and (b) stress relaxation of various fabrics in the wale direction under 10% strain.

A.2. Wale Direction

The effect of fabric structure on the stress decay of the fabric in the wale direction is exhibited in Fig. 6a. It is evident that the stress in the fabric decreases with time, and fabric structure has significant effect on the stress of the fabric in every moment of the time, including the initial stress and the residual stress values. Tricot and Sandfly fabrics demonstrate the highest and lowest initial and residual stress values, respectively. As declared previously, the difference of stress values in different fabric structures is due to their elastic modulus. According to Fig. 4b, by decreasing the elastic modulus of the fabric from Tricot to Sandfly, the stress of the fabric in every moment of the time, including the initial stress and the residual stress decreases (Fig. 6a). Statistical result confirmed that the effect of fabric structure on the initial stress and the residual stress is remarkable (p-value=0).

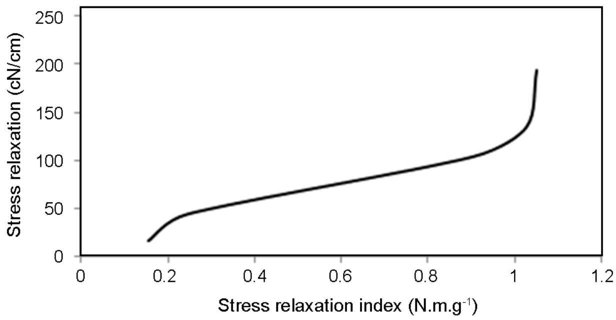


Fig. 7. The relation between fabric stress relaxation and stress relaxation index in the wale direction.

Fig. 6b displays the effect of fabric structure on the stress relaxation of the fabric in the wale direction. This figure signifies that the stress relaxation of the fabrics increases with time, but the rate of stress relaxation decreases gradually. Furthermore, fabric structure has important effect on the stress relaxation of the fabric. Tricot and Sandfly fabrics exhibit the highest and lowest stress relaxation, respectively. Considering Table IV, the stress relaxation of Tricot is 11.47 times higher than the stress relaxation of Sandfly. Statistical result affirmed that the effect of fabric structure on the stress relaxation is significant (p-value=0).

As stated formerly, the initial stress and existing space between yarns in the fabric structure are two decisive factors affecting the stress relaxation of the fabrics. Consequently, the stress relaxation index introduced previously was calculated and presented in Table IV for different fabric structures. As can be seen, Tricot and Sandfly fabrics have the highest and lowest stress relaxation index, respectively. The relation between fabric stress relaxation with stress relaxation index is illustrated in Fig. 7. This figure reveals that by increasing the stress relaxation index from Sandfly

TABLE IV
STRESS RELAXATION INDEXES OF VARIOUS FABRIC STRUCTURES IN THE WALE DIRECTION UNDER 10% STRAIN

Fabric code	Initial stress (t=0 s) (cN.cm^{-1})	Residual stress (t=1800 s) (cN.cm^{-1})	Stress relaxation= Initial stress- Residual stress (cN.cm^{-1})	Mass per unit area (g.m^{-2})	Porosity (%)	Stress relaxation index (N.m.g^{-1})
Tricot	380.8	186.9	193.9	139	38.5	1.0521
Sandfly	35.3	18.4	16.9	100	44.7	0.1566
Pin-hole-net	72.2	27.5	44.7	118	40.6	0.2475
Quasi-Sandfly	231.4	96.8	134.6	105	41.1	1.0277
Quasi-Marqussite	190.0	85.8	104.2	91	49.4	0.9044

to Tricot, the stress relaxation of the fabrics shows ascending trend.

IV. CONCLUSION

The purpose of this study is to consider the effect of fabric structure and loading direction on the stress relaxation of net warp knitted fabrics. To this end, warp knitted fabrics with various structures including Tricot, Pin hole-net, Sandfly, quasi-Sandfly, and quasi-Marqussite were produced on two guide bars Raschel warp knitting machine using polypropylene monofilament, and the stress relaxation of the fabrics in the course and wale directions was measured. In order to evaluate the stress relaxation of the fabrics, a new index, was defined. This index, which is named stress relaxation index is obtained by multiplication of initial stress by the porosity of the fabric divided to the mass per unit area of the fabric.

The results of this research can be concluded as follows:

1. The stress in the fabric decreases with time. At the beginning of the stress relaxation, the rate of stress relaxation is high, but gently decreases thereafter.
2. Fabric structure has remarkable effect on the stress of the fabric in every moment of the time, including the initial stress and the residual stress, as well as stress relaxation.
3. Tricot and quasi-Marqussite display the highest and lowest initial and residual stress values in the course direction, respectively.
4. Pin hole-net and quasi-Marqussite reveal the highest and lowest stress relaxation in the course direction, respectively.
5. Tricot and Sandfly exhibit the highest and lowest initial stress, residual stress and stress relaxation values in the wale direction, respectively.
6. By increasing the stress relaxation index of the fabrics, their stress relaxation increases in both directions.
7. Considering the advantages of lighter weight, higher porosity and lower stress relaxation, quasi-Marqussite can be the most suitable knit pattern for application such as surgical mesh.

Compliance with Ethical Standards

Conflict of Interest: The authors confirm that there are no known conflicts of interest associated with this publication.

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Guide for Authors

JOURNAL OF TEXTILES AND POLYMERS

1- Manuscripts should be electronically submitted in English via www.itast.ir. The journal desires to receive manuscripts, reviews and notes dealing with all phases of textile and polymers in relation to science and technology. A manuscript that has not been published or submitted elsewhere may be submitted for review by JOURNAL OF TEXTILES AND POLYMERS. Only original papers will be accepted for reviewing if they are strictly prepared in accordance with the instructions for authors. It is the authors' responsibility to take written permission to use materials that have appeared in other publications.

2- First name and surname of the authors and their affiliations, and the email address of the corresponding author should be indicated.

3- A short abstract (up to 150 words) of the main contributions in the paper is compulsory. Authors should prepare up to 5 single and/or combined keywords. The keywords should appear after the short abstract.

4- Based on authors' preference, the paper should be divided into sections and if necessary subsections and sub subsections. The first section should be preferably an Introduction and the last section Conclusions. Acknowledgement should be typed below the section Conclusions.

5- Manuscripts should be formatted in "portrait" layout and in one column. Use 12-point font size (Times New Roman), with 1.5 lines spacing.

6- Images should have a width of either 8 cm (preferred) or 16 cm. In both cases the line arts should be at least 600 dpi, and the photos should be a minimum of 300 dpi. Letters, numbers, and symbols in the figures should be clearly legible and their size should be equal to font size 8 to 10, bold in Microsoft Word. Place figure captions below the figures. When referencing your figures within your paper, use the abbreviation "Fig." even at the beginning of a sentence. Place each figure immediately after the paragraph that first refers to it. No borders are allowed around the figures. Since the color figures are printed grayscale in hardcopy version the selection of suitable markers is critical. The color figures are only available in online version.

7- Tables should be prepared in a width of 8 cm (preferred) or 16 cm (for the tables with many columns). Tables should be numbered with Roman Numerals. Place table titles above the tables. All columns of the tables should have an explanatory heading. Generally, tables should not have gray background. When referencing your tables within your paper use the word "Table" and do not abbreviate it. Place each table immediately after the paragraph that first refers to it.

8- Mathematical equations and formulas should be typed in *MathType* equation editor. The equations should be numbered in the order of appearance. They should be referred in the main text as for example Eq. (2). Be sure that the symbols in your equation have been defined before the equation appears or immediately following. All the symbols should be typed in italics (T might refer to temperature, but T is the unit tesla).

9- Express all units in the International System of units (SI). You may include English units in parentheses in special instances, such as for specifications that were originally supplied in non-metric units. An exception is when English units are used as identifiers in trade, such as "3½-in disk drive." Authors may also use common non-SI units such as Å, cal, eV, g, Hz, ppm, and °C. Abbreviations for units are not italicized. There should be a nonbreaking space (in Microsoft Word by holding down the **Ctrl** and **Shift** keys as you press the **Spacebar**) between the number and the unit:

5 g, 4 MHz, 2.2 µF, 75 Ω

except for percentages:

37%

In a series of measurements, indicate the unit at the end:

3, 6, and 8 cm.

except for percentages and degrees:

2 °C to 10 °C (not 2 to 10 °C)

15% to 25% (not 15 to 20%)

Use appropriate capitalization. The symbol k (*kilo*) is used as a multiplier of 1000 whereas the capitalized letters M (mega) and G (giga) refer to the SI power-often multipliers 10^6 and 10^9, respectively.

Express derived units in exponent form with nonbreaking spaces between the elements of the derived unit:

kg m^{-2}, W m^{-2} K^{-1}, J kg^{-1} K^{-1}

10- References should appear at the end of the article in the order they are cited in the paper. Identify the references in the text by numerals in square parentheses, for example [1].

Two consecutive reference numbers should be separated by comma, for example [1,2], while three or more consecutive reference numbers should be indicated such as [3–8]. Two or more non-consecutive reference numbers should be separated by comma(s), for example [2,5,12]. According to the type of publications, references should be completed as follows:

Examples for books:

[1] F.T. Simon, "Color Order", in *Optical Radiation Measurements*, 1st ed., vol. 2, F. Grum and C. J. Bartleson Ed. New York: Academic, 1980, pp. 165-235.

[2] S. Westland and C. Ripamonti, *Computational Color Science Using Matlab*, Chichester: John Wiley & Sons, 2004, pp. 141-162.

Examples for periodical journals:

[3] D.D. Lee and H.S. Seung, "Learning the parts of objects by non-negative matrix factorization", *Nature*, vol. 401, no. 21, pp. 788-791, 1999.

[4] S. Peyvandi, S.H. Amirshahi, J. Hernandez-Andres, J.L. Nieves, and J.J. Romero, "Generalized inverse-approach model for spectralsignal recovery" *IEEE T. Image Process.*, vol. 22, no. 2, pp. 501-510, 2013.
Abbreviation names of journals could be found in (http://www.efm.leeds.ac.uk/~mark/ISIabbr/)

Example for journals when are available online:

[5] M. GhanbarAfjeh, S. Ghanean, and F. Mazaheri, "Colorimetric and spectral properties of natural colorants used in handmade traditional Persian carpets", *J. Text. Polym.*, [Online], vol. 1, no. 2, pp. 98-104, 2013. Available: http://itast.org/joomla/Downloads/Journal/Vol1No2/7.pdf

Example for documents when are available online:

[6] Y. Zhao, A.L. Taplin, M. Nezamabadi, and R.S. Berns, Technical Report, Munsell Color Science Laboratory, Center for Imaging Science, Rochester Institute of Technology; 2004. Available:http://www.artsi.org/PDFs/Acquisition/Sinar_Repo rt_June2004.pdf

Example for data when are available online:

[7] University of Joensuu Color Group. Spectral Database. Available: http://cs.joensuu.fi/~spectral/databases/download/munsell_spec_matt.htm

Example for papers presented at conferences:

[8] F.H. Imai and R.S. Berns, "High-resolution multispectral image archives: a hybrid approach", In: *Proceedings of the IS&T/SID Sixth Color Imaging Conference: Color Science, Systems, and applications, IS&T/SID, Color Imaging Conference*, Scottsdale, AZ, United States; pp 224-227, 1998.

Example for papers presented at conference when are available online:

[9] F. Agahian, B. Funt, and S.H. Amirshahi, "Representing outliers for improved multi-spectral data reduction", In: *CGIV 2012 Sixth European Conference on Colour in Graphics, Imaging, and Vision*, Amsterdam, 2012. Available: http://river-valley.tv/representing-outliers-forimproved-multi-spectral-data-reduction/

Examples for theses (M.S.) and dissertations (Ph.D.):

[10] S. Peyvandi, "Statistical analysis of metamer sets in metameric decomposition and spectral reconstruction (in Persian)", *Ph.D dissertation*, Dept. Text. Eng., Amirkabir University of Technology, Tehran, Iran, 2012.

[11] V. Babaei, "Reconstruction of reflectance spectra from colorimetric data by modifying of general inverse and matrix R methods (in Persian)", *M.Sc. thesis*, Dept. Text. Eng., Amirkabir University of Technology, Tehran, Iran, 2009.