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Investigation of Auxetic Performance and Various Physical Properties of Fabrics Woven with Braid Yarns

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ABSTRACT

In this study, the auxetic performance and various physical properties of fabrics woven with braid yarn were examined. Fabrics were woven in plain weave with conventional warp and braid weft yarn. Experimental results showed that fabrics woven with braid weft yarn exhibited an auxetic behavior by giving Negative Poisson's Ratio (NPR) up to a certain elongation value under tension in the warp direction. In addition, it was observed that the NPR of fabric was affected by the thickness of the braid yarn and the tightness (compactness) of the fabric. It was found that the use of braid yarn in woven fabric improved various physical properties such as tensile strength, thermal resistivity and abrasion resistance. Use of braid yarns increased the tensile strength in the weft direction where braid yarns were used, increased thermal resistivity values at the fabric woven with thick and bulky braid yarns and also increased abrasion resistance.

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KEYWORDS

Auxetic effect, negative Poisson's ratio, braid yarn, woven fabric, fabric's physical parameters

1. INTRODUCTION

The design of multifunctional woven fabrics by developing basic performance properties of conventional woven fabric structures has become necessary to obtain composite textile structures mostly used in technical textiles where high performance is required. Since auxetic structures could show many improved performance features, it would be possible to bring many functional properties to the structure in one step by developing auxetic woven fabric structures.

Poisson's ratio is one of the essential properties used in many engineering fields to determine the material structure [1]. Poisson's ratio (v) is defined as the negative ratio of the transverse strain occurring perpendicular to the force applied to a material to the longitudinal strain in the direction that the force is applied. Auxetic materials are the type of materials with a Negative Poisson's Ratio (NPR). As opposed to materials with a positive Poisson's ratio, auxetic materials expand laterally when stretched and contract laterally when compressed [1-6]. Increased mechanical properties (breaking strength, abrasion resistance, indentation resistance, fracture toughness, shear resistance, etc.), variable permeability, improved acoustic absorption, and high energy absorption properties make auxetic materials superior to conventional materials [1,3,7-12].

In literature studies, it is explained that conventional fabric structures show positive Poisson's Ratio (PR) values due to contracting laterally when stretched [13,14]. A study on the worsted fabrics states that fabrics with higher weft yarn density have a higher Poisson's ratio value. And also, it is stated that this ratio is related to the structural stiffness of the fabric [13]. In a study investigating the effects of various mechanical properties of yarns and structural parameters of fabrics on the Poisson's ratio of a woven fabric, it was pointed out that, in general, the yarn spacing (i.e., the distance between two adjacent yarns in a fabric) ratio and the yarn diameter ratio between warp and weft yarns have more significant effects on the Poisson's ratio of a woven fabric than the yarn Young's modulus ratio [14]. Warp and weft yarns that intersect in the woven fabric structures are crimped due to the paths that they have to follow around each other as a result of this intersection. When the fabric is stretched in one direction, due to the stretching of the yarn in the loading direction, the yarn crimps decrease until they reach zero. Axially stretched yarns cause the yarns perpendicular to the loading direction to be more crimped. As a result, the fabric contracts in the lateral direction, and a positive PR is obtained [15,16].

In the literature, there are two approaches for auxetic fabric production. The first is creating an NPR effect through

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knitting or weaving in a special geometric configuration using conventional fibers and yarns [17-20]. The second is to use directly auxetic fibers and yarns so that the NPR effect can be created using simple woven or knitted structures [21-23].

In studies on yarn development with auxetic properties, a yarn structure with auxetic properties is presented with multifilament yarn construction consisting from components that do not have auxetic properties. The helical auxetic yarn (HAY) structure was first presented by Hook [24,25]. This yarn structure was obtained by helically winding a high stiff filament around a thick and low stiff filament. Under longitudinal stretching, the high stiff filament straightens and displaces the lower stiffness filament into a curved shape. As a result of this, the yarn structure is expanded in the lateral direction [24,25]. It was stated that the starting wrap angle of HAY had the greatest effect on the auxetic behavior and the other parameters which influence auxetic performance were found to be the diameter ratio of wrap to core fibers and the fibers' inherent Poisson's ratio. In the literature, it is stated that the auxetic structures can be obtained by combining two or more multifilament structures appropriately [3,26].

The term braid refers to the placement of the sheath yarns, which are made of one or more filaments. They are released from the reels placed on the carriers in the braiding machine, and they cross the axis of the yarn diagonally without making a full rotation around each other. A basic braid structure is circular, with half of the yarn bundles moving clockwise at a certain angle to the braid yarn axis and the other half moving counterclockwise by alternately passing over and under the first group bundles [27-28].

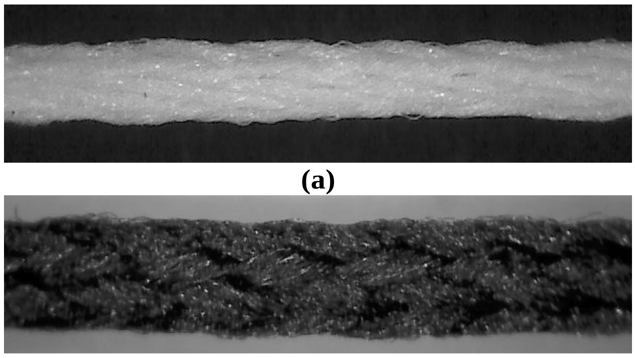
In the literature, a novel type of braided yarn structure exhibiting auxetic behavior was proposed. In this study, it was found that parameters such as the initial wrap angle, the initial braiding angle and the braiding yarn diameter were all important on the auxetic effect of tubular braided structure. It was stated in this research that the negative Poisson' s ratio could be achieved in a structure with the use of a wrap yarn having higher modulus than that of the braiding yarns and core yarn. Also, it was stated that braided yarn structure with a lower initial wrap angle, a higher initial braiding angle and a larger braiding yarn diameter had a better auxetic performance [29].

In this study, the changes in Poisson's ratio of the fabrics woven with braid weft yarns of different thicknesses are investigated. With the use of braid yarns in the formation of woven fabric, the deformation state of the braid weft yarns that intersect with the conventional warp yarns in the fabric under tension and the possible auxetic behavior are evaluated. In addition, various physical and thermal comfort tests were carried out to examine the effects of the use of braid yarn in woven fabric structures on the physical performances.

2. MATERIAL AND METHOD

2.1 Material

In the experimental study, braid polyester yarns consisting of 12 sheath yarns were used as weft yarn. Braid yarns were supplied from Yayteks İplik Mak. Ltd. Şti. (Bursa) company. Microscopic images (30 times magnification) of braid yarns used as weft are presented in Figure 1.



(a)

(b)

Figure 1. Microscopic images of braid yarn (Mag: 30X)
a) F1 fabric's weft yarn b) F2 fabric's weft yarn

Fabrics in plain weave structure were woven using polyester braid yarn in the weft and conventional textured polyester yarn in the warp on the hand weaving loom (Gülas Makina), as presented in Figure 2.

Figure 2. Weaving loom

Structural parameters and microscopic images of fabrics with 20 times magnification are presented in Table 1 and Figure 3, respectively.

In addition, the positioning of the braid weft yarns in the fabric structure is presented in Figure 4 for the F2 fabric.

In addition, a conventional sample fabric structure was investigated to compare the Poisson's ratio change tendencies of fabric woven with braid yarn and fabric woven with conventional yarn. For this reason, it was preferred to use a plain weave conventional fabric sample with the same yarn type (100% textured polyester) and yarn counts (300 denier) in warp and weft. In this way, the tendency of Poisson's ratio change of a conventional plain woven fabric sample was presented.

2.2 Method

2.2.1 Performed tests on fabrics

Various physical and thermal comfort tests were carried out to examine the effects of the use of braid yarn in woven fabric structures on the physical performances. For this purpose, fabrics' maximum strength, elongation, air permeability, thermal resistivity, abrasion resistance, and fabric thickness changes under different compression pressures were investigated. Fabric samples were conditioned at 65±2% relative humidity and 20±2°C for 24 hours by the ASTM D 1776-08 [30] standards before all the mentioned tests.

Tensile tests

Tensile measurements of fabrics at warp and weft directions were conducted using Shimadzu AG-X plus tensile testing machine by ISO 13934-1 (2013) standard test method [31]. Fabric sample strip dimensions were kept at 100 mm×50 mm, and the tensile speed were set at 10 mm/min. Fabrics were photographed by a digital microscope (INSIZE ISM-PRO) with a time interval of 5 seconds until a total elongation of 10 mm (60 seconds) is reached during the tensile test. The setup of the testing system is presented in Figure 5.

Table 1. Structural parameters of fabrics

Fabric code	Yarn properties		Yarn count [denier]		Yarn density [thread/cm]		Fabric mass per unit area [g/m^2]
	Warp	Weft	Warp	Weft	Warp	Weft	
F1	Textured Polyester	Circular braided yarn with 12 sheath yarn (sheath yarn count: 150 denier)	600	1962	10	8	404
F2	Textured Polyester	Circular braided yarn with 12 sheath yarn (sheath yarn count: 510 denier)	600	6210	10	6	575

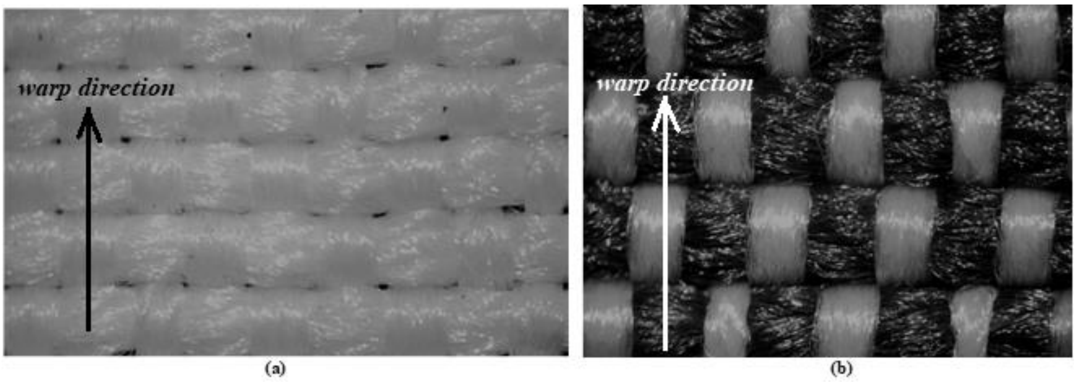


Figure 3. Microscopic images of fabrics (Mag: 20X) a) F1 fabric b) F2 fabric

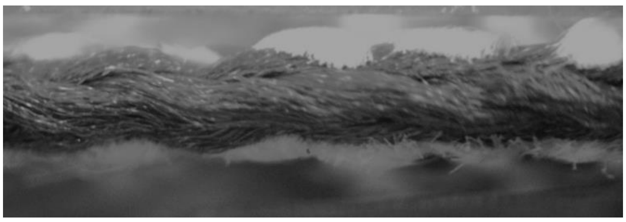


Figure 4. Cross-section view of F2 fabric (Mag: 30X) (transverse section of the warp yarns - longitudinal section of weft yarn)

With the help of markers placed on the fabric (Figure 6), the changes in the width (average of x values) and length (average of y values) of the fabric were calculated with the help of the software developed in MATLAB over the images taken every 5 seconds.

The distances between markers placed on the fabric were measured with the help of a method [32] developed using MATLAB for both the free state and stretched state to calculate the strains in both transverse and longitudinal fabric directions. Poisson's ratio (v) was calculated [1] using Equation (1) as follows;

Figure 5. Measurement setup

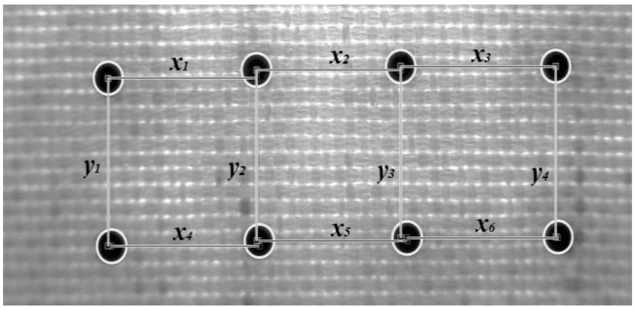


Figure 6. Placement of markers on fabric

$$\nu = -\ (\text{transverse strain} / \text{longitudinal strain}) \quad (1)$$

Changes of the F1 and F2 fabrics in the transverse direction under different elongation values up to 10 mm in warp direction are presented in Figures 7 and 8, respectively. In Figures 7 and 8, the distance between the first and last markers placed on the fabric was indicated in order to visually demonstrate the transverse expansion effect of the fabric. In the calculation of Poisson's ratios, the distance between each marker was measured with the help of MATLAB, as shown in Figure 6, and average values were taken.

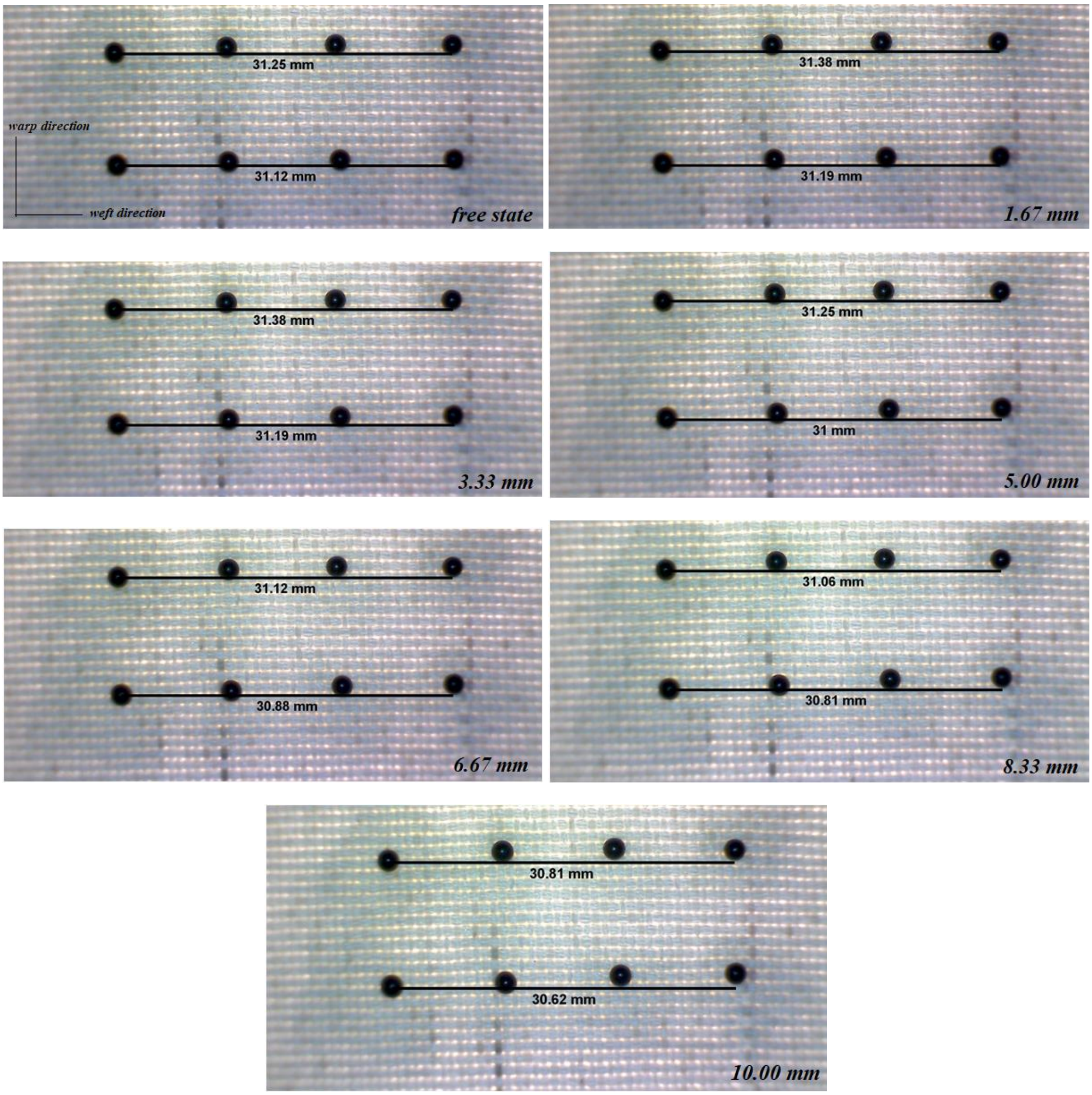


Figure 7. Changes of the F1 fabric in the transverse direction under different elongation values in warp direction

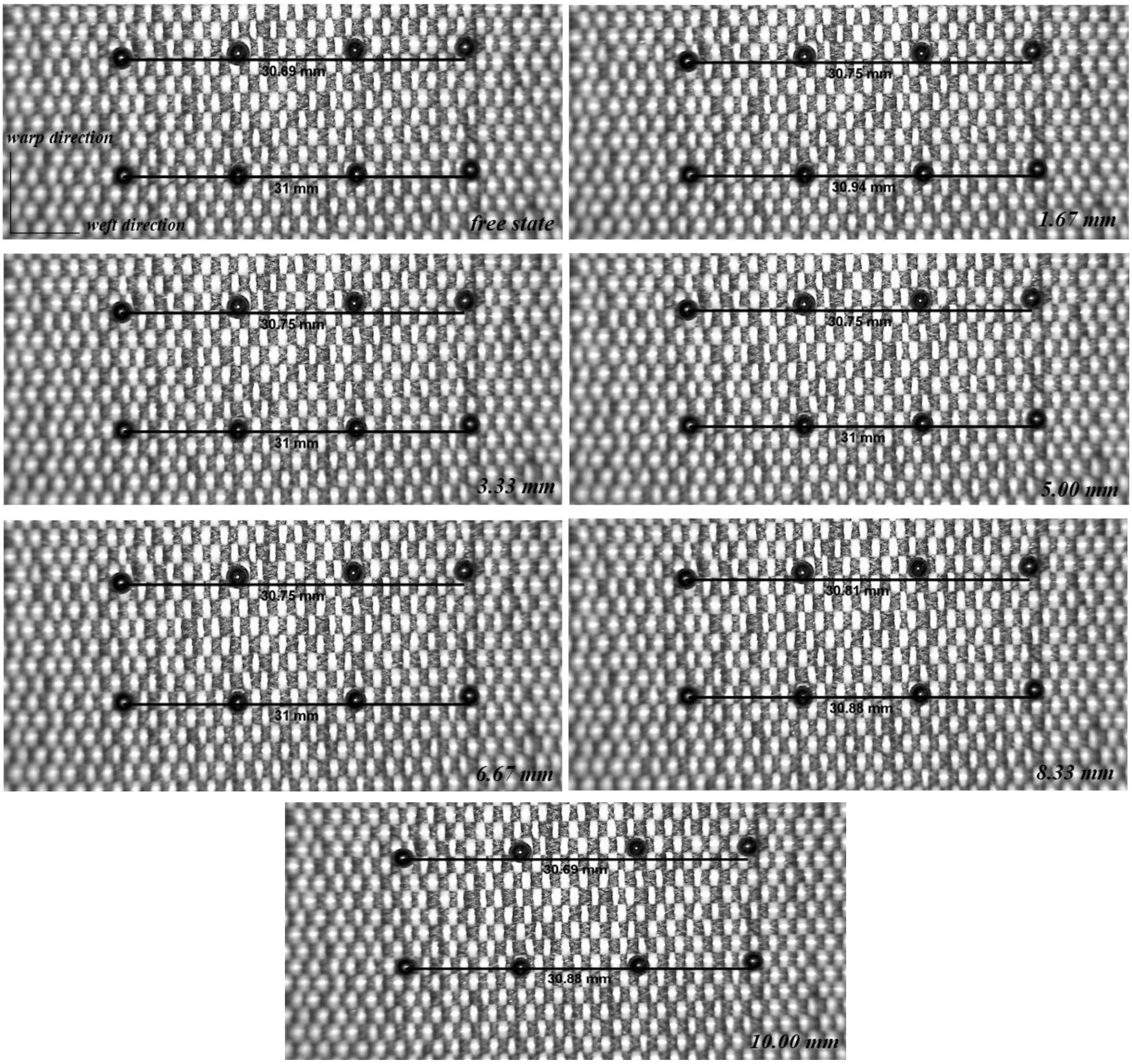


Figure 8. Changes of the F2 fabric in the transverse direction under different elongation values in warp direction

Mass per unit area and thickness of fabric

Mass per unit area of fabrics were measured according to ASTM D3776 [33]. The thickness of fabrics was measured according to ASTM D1777-96 [34] standard with James Heal's R&B Cloth thickness tester.

Measurement of yarn crimp

Yarn crimps in fabric samples were measured according to ASTM D3883-04 [35]. Percentage crimp values and crimp amplitude values were calculated using Equations (2) – (4), respectively [35,36];

$$\text{Yarn crimp (\%)} = \frac{\text{Straightened yarn distance} - \text{Distance in the fabric}}{\text{Distance in the fabric}} \times 100 \quad (2)$$

$$\frac{h_1}{P_2} = \frac{4}{3}\sqrt{c_1} \quad (3)$$

$$\frac{h_2}{P_1} = \frac{4}{3}\sqrt{c_2} \quad (4)$$

where, h_1 and h_2 are the warp and weft yarn crimp amplitudes; c_1 and c_2 are the warp and weft yarn crimps; and P_1 and P_2 are the thread spacing of individual warp and weft yarns (Figure 9), respectively.

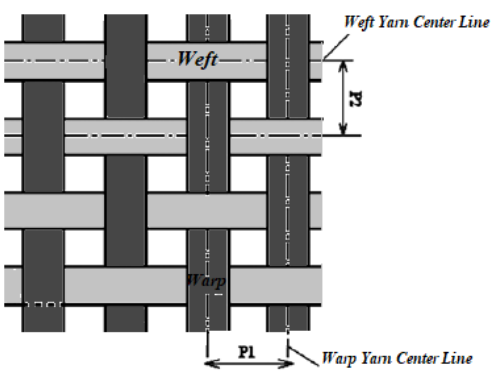


Figure 9. Schematic presentation of the thread spacing of individual warp (P_1) and weft (P_2) yarns

The crimp values of the yarns in the fabric were measured (Equation (2)), and the crimp amplitude values were calculated according to Equations (3) and (4). It was found that the braid weft yarns in the fabric structure did not take measurable yarn crimp in contrast to warp yarns, and the crimp and crimp amplitude values of the warp yarns are presented in Table 2.

Air permeability

Air permeability of fabrics was measured based on EN ISO 9237 [37] standard using an SDL Atlas Digital Air Permeability Tester Model M021A. Measurements were performed by applying 100 Pa air pressure per 5 cm^2 fabric surface.

Thermal Resistivity

Thermal resistivity (*r*) is defined as the material's resistance against heat flow. Thermal resistance of fabrics was measured by using the Alambeta instrument. The thermal resistance is connected with fabric thickness and thermal conductivity coefficient by Equation (5) [38].

$$r = \frac{h}{\lambda} \quad (m^2KW^{-1}) \qquad (5)$$

where,

r: thermal resistance,

h: fabric thickness (*m*),

λ: thermal conductivity coefficient (*W/mK*)

Abrasion test

The abrasion tests of the fabrics were carried out under the load of 9 kPa, in the Nu-Martindale abrasion test device by the standard of ASTM D 4966 [39]. The fabrics were abraded in 30000 abrasion cycles.

Microscopic Analysis

Microscopic images of the fabrics were taken under a microscope (Mshot Digital Microscope Camera MS60) coupled to a digital camera.

3. RESULTS AND DISCUSSION

3.1 Analysis of the Poisson's ratios

The Poisson's ratio – elongation curves of the fabrics are presented in Figures 10 and 11. F1 fabric was woven with thin braid weft yarn and F2 fabric with thick braid weft yarn. In Figures 10 and 11, it was seen that the fabrics woven with braid weft yarn demonstrated NPR value under tension in the warp direction. It was observed that NPR was obtained up to an elongation value of 3.33 mm in the fabric woven with thin braid weft yarn and up to 6.67 mm in the fabric woven with thick braid weft yarn.

Table 2. Warp yarn crimp amplitude values

Fabric Code	Warp yarn crimp [%]	Thread spacing of individual yarns [cm]		Warp yarn crimp amplitude [cm]
		Warp (P_1)	**Weft (P_2)**	
F1	10	0.1	0.125	0.053
F2	10	0.1	0.167	0.070

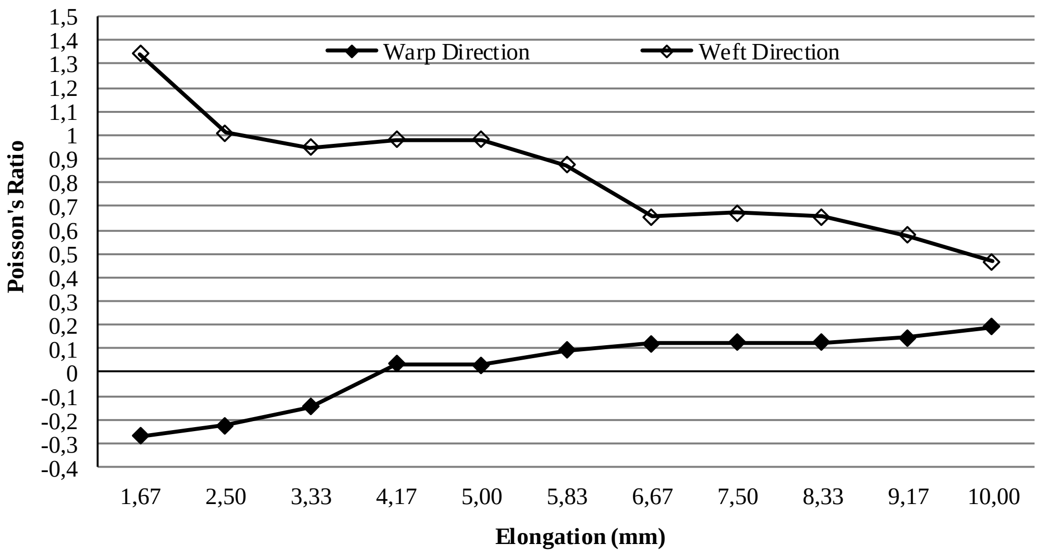


Figure 10. Poisson's ratio – elongation curve of F1 fabric

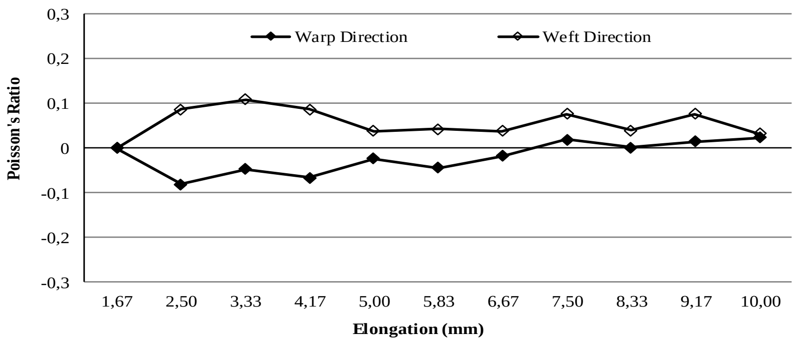


Figure 11. Poisson's ratio – elongation curve of F2 fabric

The warp yarns of the fabrics were of conventional structure. It was observed that braid weft yarns had a transverse expansion effect in the fabric, and NPR could be obtained in fabrics subjected to tension in the warp direction. It was considered that this was because the braid weft yarns in a structure with an entrant form that intersect diagonally with each other showed a widening effect in the transverse direction due to the effect of warp yarn compression under the tensile tension in the warp direction. It was observed that this transverse widening effect continued up to higher elongation values in fabric structure with the thick braid yarn.

However, when Figures 10 and 11 were examined, it was seen that while the maximum Poisson's ratio was obtained as ≈ -0.3 values for the F1 fabric (woven with thin braid weft yarn), the maximum Poisson's ratio was obtained as ≈ -0.1 for the F2 fabric (woven with thick braid weft yarn). As could be seen from Figure 3, this result might be because the F1 fabric was in a less tight (in a more open) form and the F2 fabric was in a tighter form due to its thick weft yarn structure. In the F1 fabric with a more open structure, it was considered that the braid weft yarns' transverse expansion behavior could occur more easily under the tensile tension in the warp direction. In the F2 fabric, it was assessed that the weft yarns could not expand easily in the transverse direction because the thick braid yarns created a tighter fabric structure. Due to this situation, it was observed that a higher negative Poisson's ratio could be obtained in the F1 fabric with thin braid weft yarn compared to the F2 fabric.

In Figures 10 and 11, when the changes in the weft direction Poisson's ratios of the fabrics were examined, it was seen that the Poisson's ratios showed a positive change. However, it was observed that the Poisson's ratio values of the F2 fabric with thick braid weft yarn under tension in the weft direction remained in the range of close to zero values such as 0.0 - 0.1 during the 10 mm elongation. Whereas, it was seen that F1 fabric with thin braid weft yarn demonstrated higher positive Poisson's ratio values under weft directional tension. This result showed that the transverse contraction behavior of the fabric was lower when thick braid weft yarn was used in fabric structure, under weft-directional tension (ie, when the tension applied to the fabric was applied in the direction of braid weft yarns) compared to the use of thin braid weft yarn in the fabric structure.

To examined the Poisson's ratio change of a fabric woven with conventional yarns, the Poisson's ratio–elongation tendency of a conventional fabric sample under tension is presented in Figure 12. It was seen that this conventional fabric had a positive Poisson's ratio under elongation. Considering the effects of factors, such as the warp and weft yarn counts were the same, and the fabric was woven in a plain weave structure, it was observed that the change of the Poisson's ratio–elongation curve was obtained with a similar tendency in the warp and weft directions. It was observed that the Poisson's ratios of a conventional fabric sample have a positive increasing tendency as the increased elongation value in the warp and weft direction.

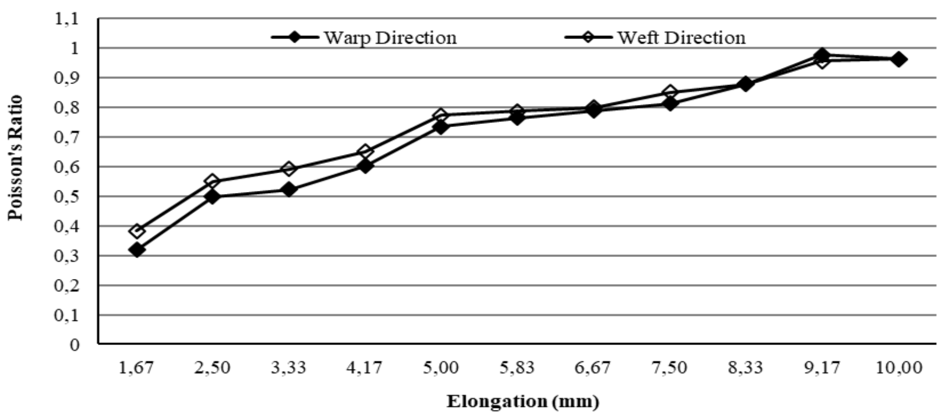


Figure 12. Poisson's ratio–elongation curve of a conventional fabric sample

3.2 Analysis of the tensile strength and elongation

The tensile strength and elongation values of fabrics are presented in Figure 13 and 14, respectively. In Figure 13, it was seen that the maximum fabric strength values in the weft direction, in which braid yarns were used as weft, were significantly higher than those in the warp direction. Although the weft yarn forming the F2 fabric was thicker than the weft yarn forming the F1 fabric, it was observed that the weft directional fabric strength of the F1 fabric was higher. It was thought that this might be due to the higher weft yarn density value per unit area of the F1 fabric (8 thread/cm) than F2 fabric (6 thread/cm). It was also observed that the use of braid yarn as weft yarn significantly increased the maximum strength values in the weft direction.

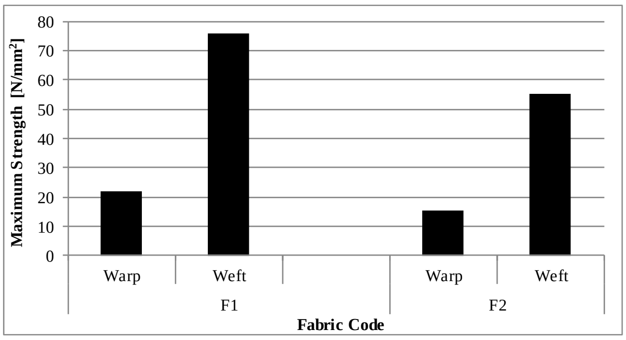


Figure 13. Tensile strength values of fabrics

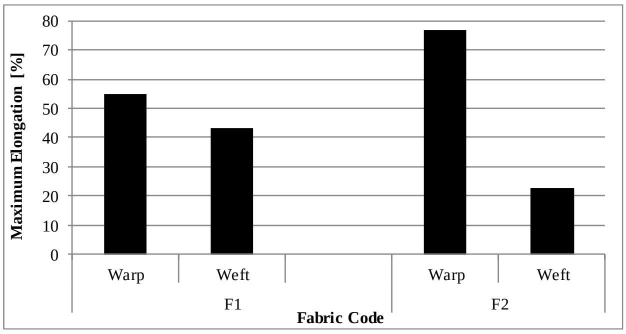


Figure 14. Maximum elongation (%) values of fabrics

In a study on the auxetic performance properties of woven fabrics [40], it was stated that a significant difference was observed between the warp and weft directional elongation values of the fabrics in which the NPR effect was obtained. In addition, it was stated that the warp directional elongation values were significantly higher than the weft directional elongation values in these fabric structures, and it was stated that the NPR effect observed in the warp direction of these fabrics was affected by this result [40].

In Figure 14, it could be seen that a similar result was obtained as stated in this literature. In Figures 10 and 11, it was seen that the NPR effect in F1 and F2 fabric was obtained in the warp direction. In Figure 14, it was observed that there was a difference between the warp and weft directional elongation values of fabrics. It was considered that greater elongation of the yarns in the warp direction could cause the fabric to expand more in the transverse direction under elongation. In particular, due to the use of conventional yarns as warp in this study, the elongation of conventional warp yarns intersecting with braid weft yarns showed a significant widening effect in the transverse direction.

Also, it was seen that the difference between warp and weft directional elongation values was significantly higher in the F2 fabric compared to the F1 fabric. This result suggested that it might be related to the fact that the NPR effect continued under the longer elongation values in the F2 fabric structure, as seen in Figure 11, compared to the F1 fabric.

In Figure 14, it was observed that there was a difference between the warp directional elongation values of F1 and F2 fabrics. The reason for this was thought to be as explained below. The property and yarn density of the warp yarns were kept constant (Table 1). It was seen from Table 2 that the warp yarns had the same crimp value in both fabric structures. However, depending on the braid weft yarn thickness used in the fabrics, the weft yarn density value differed. As shown in Table 1, the weft yarn density of F1 fabric woven using thin braid weft yarn is 8 thread/cm, while the weft yarn density of F2 fabric woven using thick braid weft yarn is 6 thread/cm. The crimp amplitude values of the fabrics are presented in Table 2. It was seen that the crimp amplitude values of the warp yarns in the F2 fabric were higher than the crimp amplitude values of the warp yarns of the F1 fabric. Although there was less weft yarn per unit area, it was seen that the crimp amplitude values of the warp yarns in the F2 fabric, which were crimped around the braid weft yarns which have a very high thickness value (6210 denier), were higher. In this case, as seen in Figure 14, it was considered that the elongation values of the warp yarns in the F2 fabric were higher than the warp yarns in the F1 fabric.

From the results obtained, it was observed that there was a difference between the warp and weft directional elongation values in both fabric structures where the NPR effect was obtained. And it was seen that a longer-lasting NPR effect (Fig. 11) was obtained in the F2 fabric, in which this difference was higher. Also, it was observed that the warp directional elongation values were higher in these fabrics where the NPR effect was obtained in the warp direction. As a result, it was thought that more elongation of the yarns in the warp direction might cause the fabric to expand more in the transverse direction under elongation, causing the NPR effect.

3.3 Analysis of the fabric thickness

Auxetic materials expand under elongation and contract under compression. A local contraction is observed when compression occurs in an isotropic auxetic material. There is a material flow that condenses under the applied load, creating a denser material area with higher resistance to compression [1-3, 5,6].

For this reason, besides the behavior of woven fabric structures using braid yarns under tension, the changes in fabric thickness under different compression pressure values were also investigated. The thickness values of the fabrics under three different compression pressures (5, 10 ve 20 g/cm^2) are presented in Figure 15.

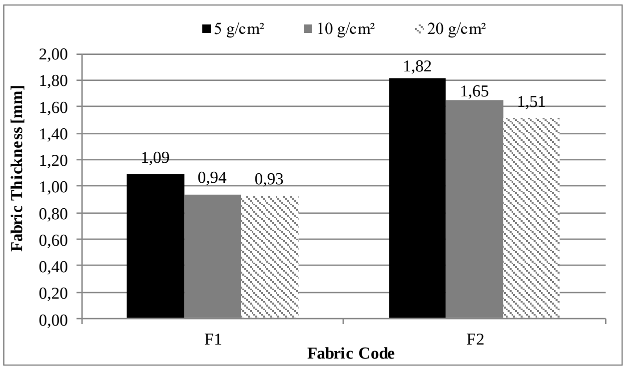


Figure 15. Fabric thickness

In Figure 15, when the pressure was increased from 5 g/cm^2 to 10 and 20 g/cm^2, it was observed that the F1 fabric thickness values decreased by 13.76% and 14.67%, respectively. However, it was observed that there was no significant change in fabric thickness values under compression pressures of 10 and 20 g/cm^2. This result was thought to be due to the condensation of the material towards the inner region under compression due to the entrant geometry of the braid weft yarn.

It was observed that the F2 fabric thickness decreased by 9.34% and 17.03% when the pressure was increased from 5 g/cm^2 to 10 and 20 g/cm^2. There was observed a decrease of 8.48% between the fabric thickness values under compression pressures of 10 and 20 g/cm^2. It was considered that the reason why the fabric thickness values were approximately constant under the compression pressures of 10 and 20 g/cm^2 in the F1 fabric, and the decrease in the F2 fabric was due to the fact that the braid weft yarn structure used in the F2 fabric was thicker and bulkier than the braid weft yarn in the F1 fabric.

In addition, when the pressure values were increased from 5 g/cm^2 to 10 g/cm^2, it was observed that the F1 and F2 fabric thickness values decreased by approximately 13.76% and 9.34%, respectively. In other words, it was observed that the decrease in thickness value was lower in the F2 fabric woven with thick braid weft yarn. It was thought that this situation might be due to the fact that the effect of condensing the material towards the inner region in the thick braid yarn structure under the compression effect might be more compared to the thin braid yarn structure.

3.4 Analysis of the air permeability

The air permeability values of fabrics are presented in Figure 16. It was seen that the air permeability value of F2 fabric with thick braid weft yarn was approximately 2.08 times lower than those of F1 fabric with thin braid weft yarn. Also, considering the fabric thickness values in Figure 15 (for 5 g/cm^2 compression pressure), it was seen that the thickness value of the F2 fabric was 1.67 times higher than the thickness value of the F1 fabric.

In Figure 3, it was observed that the F1 fabric had a more open (a more porous) structure than the F2 fabric. It should be noted that this porous structure also increased the air permeability value. It was seen that the F2 fabric, which was woven using thick and bulky braid weft yarn, had a more compact structure. Considering the parameters such as the use of weft yarn with thick and bulky braid, and therefore the high fabric thickness and its more compact structure compared to the F1 fabric, it was observed that the air permeability value of F2 fabric had decreased significantly.

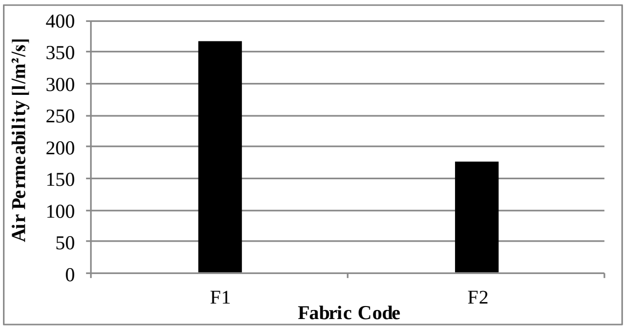


Figure 16. Air permeability values of fabrics

3.5 Analysis of the thermal resistivity

The thermal resistivity values of fabrics are presented in Figure 17. It was observed that the thermal resistivity value of the F2 fabric was 3.02 times higher than that of the F1 fabric. This result was affected by the yarn thickness and, therefore, the fabric thickness. In addition, it was considered that the effect of braid yarn structure should be taken into account. The braid yarns used in fabrics consist of 12 sheath yarns in tube form. This tubular structure was an essential parameter to consider that the stagnant air protection in the structure might be higher. In this case, the thermal resistivity value of the fabric might increase.

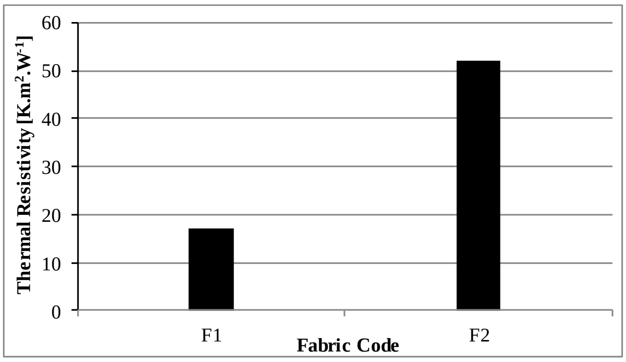


Figure 17. Thermal resistivity values of fabrics

The thermal conductivity of the fabric structure depends on the number of air gaps in the fabric. The ideal insulating material is the stagnant air, and the thermal conductivity of stagnant air is much lower than that of all fibers. A high amount of air should be present in a textile material's inner structure with high thermal insulation. Bulky materials can hold excess air in them due to their structure [41,42].

The results obtained showed that very high thermal resistivity values could be obtained from compact fabrics woven by using braid yarn structures and appropriate yarn density values. One of the reasons why the thermal resistivity value of the F1 fabric was lower than that of F2 was thought to be due to the fact that the F1 fabric has a more open structure than the F2 fabric, as seen in Figure 3. From the experimental results, it was predicted that the thermal resistivity values of the fabrics could be improved further by creating a more compact fabric structure by weaving at higher weft density values in the fabric structures where thin braid yarns were used.

3.6 Analysis of the abrasion resistance

Evaluation of abrasion resistance of fabrics woven with braid weft yarn was made. Microscopic images of original (non-abraded) and 30000 times abraded fabric samples (10 times magnified), were presented in Figures 18 and 19. When the fabric surfaces were examined, it was seen that the conventional warp yarns break at 30000 abrasion cycles. No breakage was observed in weft yarns with a braid structure. It could be foreseen that the fabric structures to be woven by using braid yarn structures in both warp and weft could form fabric structures with high abrasion and wear resistance.

4. CONCLUSION

This study evaluated the changes in Poisson's ratio of the fabrics woven with braid weft yarn and the possible auxetic performance properties. Fabrics were woven in plain weave with conventional warp and braid weft yarn. As a result of the experimental study, it was observed that fabrics woven with braid weft yarns exhibited an auxetic behavior by giving Negative Poisson's Ratio (NPR) under warp directional tension. In addition, it was observed that NPR of fabric was affected by the thickness of the braid yarn and the tightness (compactness) of the fabric.

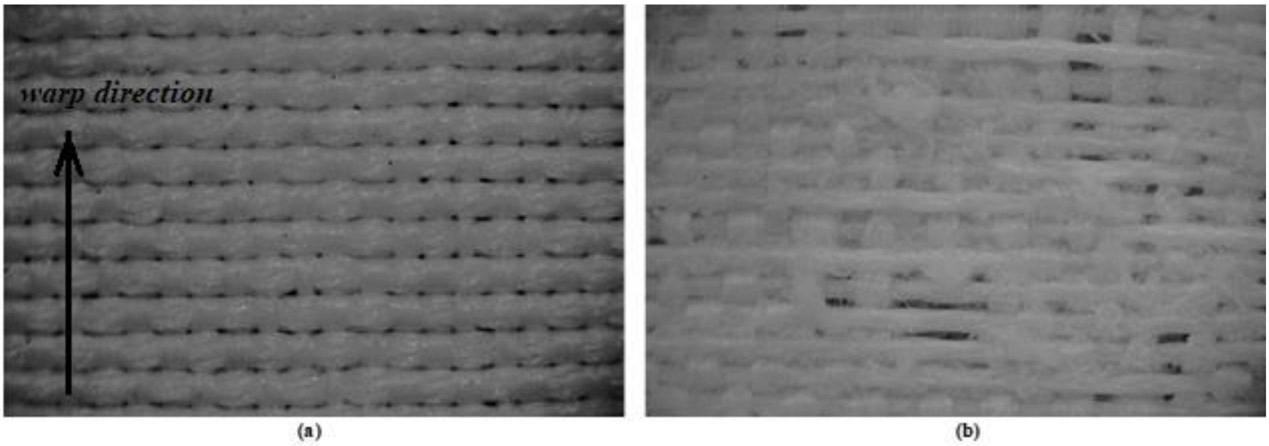


Figure 18. Microscopic images of F1 fabric a) non-abraded b) 30000 abrasion cycles (Mag: 10X)

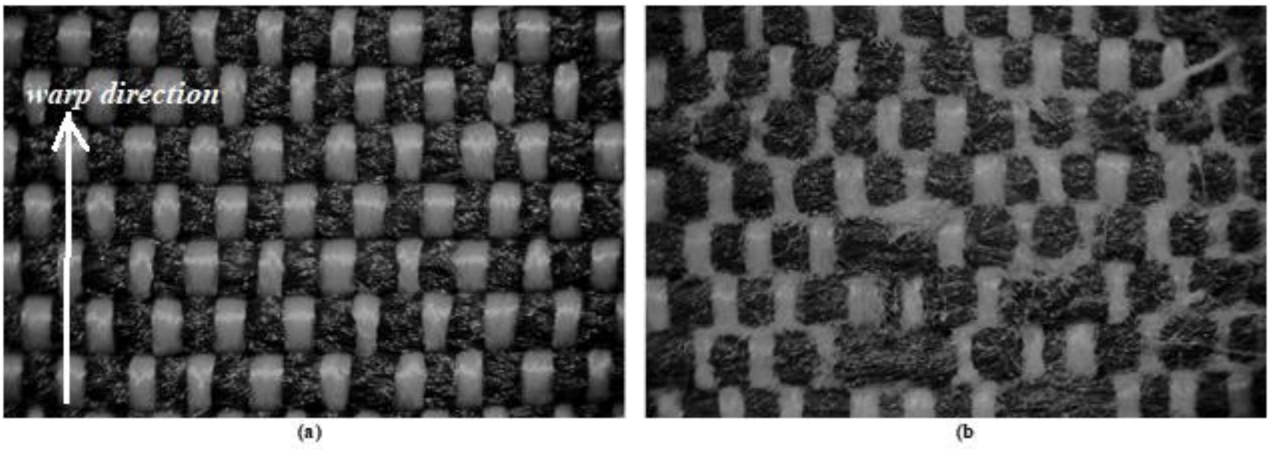


Figure 19. Microscopic images of F2 fabric a) non-abraded b) 30000 abrasion cycles (Mag: 10X)

Braid yarn structure consists of yarn components that make diagonal entrant intersections with each other. Using braid yarns in the formation of woven fabric as a weft, the deformation state of the braid weft yarns that intersect with the conventional warp yarns in the fabric under tension was evaluated. Under the warp-directed tension applied to the fabric, the compression effect of the warp yarns on the braid weft yarns which have an entrant form could cause a transverse expansion effect in the braid weft yarns in the fabric. As a result, it was observed that fabrics with braid weft yarn exhibited an auxetic behavior by giving NPR under warp directional tension.

In addition, it was observed that the fabrics gave higher NPR values because the braid yarn structures, which showed transverse expansion with the effect of compression by the warp yarns, could move more easily in the fabric with a less tight (in a more open) structure. It was observed that a lower NPR could be obtained in a tight fabric structure due to the restriction of the transverse expansion effect of the braid yarns in the fabric structure. It was found that the thickness of braid weft yarn affected the auxetic performance of the fabrics. Also, it was seen that the auxetic performance continued under higher elongation values in the fabric woven with thick braid weft yarn compared to the fabric woven with thin braid weft yarn.

In addition, it was found that the use of braid yarn in woven fabric structures provided an NPR effect to the structure and improved various physical performance properties. It was observed that in fabrics woven with braid weft yarns, the weft directional tensile strength values of the fabrics significantly increased compared to the warp directional tensile strength values in which conventional warp yarns were used. It was observed that very high thermal resistivity values could be obtained in compact fabric structures woven with thick and bulky braid yarns. When the effect on abrasion resistance was examined, it was seen that there was no break in braid yarns in the abrasion cycles where the breakage occurred in conventional yarns. It could be predicted that the fabrics to be woven by using braid yarns in both warp and weft directions could create fabric structures with high abrasion and wear resistance.

As a result of the experimental study, it could be concluded that braid yarns could be used in the formation of auxetic woven fabric designs and improved various physical performance properties of fabrics.

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