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Effect of pattern on air permeability, mechanical resistance and thickness of wovens

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ABSTRACT

This study examines the effect of different patterns on aesthetic properties, air permeability characteristics and mechanical performance of woven fabrics constructed with 100% cotton ring spun yarns. Weaving process were proceeded by using 28/2 Ne combed warp and 32/2 Ne carded weft yarns with identical manufacturing parameters. Fabrics with 5 dissimilar patterns were obtained and 5 measurements were done for each pattern type. Average yarn floats, crimp percentage and yarn settings were calculated and fabric thickness, abrasion resistance, air permeability and bi-directionally tensile strengths of these fabrics were tested. Test results showed that increasing the numbers of floating yarns made fabric more air-permeable but less resistant against to applied mechanical forces. Besides, it caused to increase in fabric thickness. All test results were statistically evaluated by ANOVA and Duncan comparison tests and it was seen that the effect of weave pattern was at significance level of $p<0.001$. Air permeability characteristics of wovens can be easily and inexpensively arranged by pattern effect. In order to satisfy mechanical and functional specifications, further studies should be performed on panama woven structures with different yarn floats.

1. Introduction

Designing is the process of preparing end product to meet functional and visual demands by considering basic criterias. By means of fabric designing, raw material selection and appropriate manufacturing parameters have crucial effect in order to handle sufficient performance of desired functional, visual and mechanical responce. Mechanics of textile fabrics are strictly depending on basic traditional route but further steps are different as comparing engineering fabric design with artistic one. In engineering fabric design, woven fabrics differentiate from other fabric types due to controllable manufacturing conditions on unit area of fabric structure during fabric weaving [1].

Cotton-based fabrics are mostly used textile surfaces in clothing industry due to their very good breathable characteristics and they present wide range of end products for summer and winter clothing by being manufactured with different surface manufacturing techniques [2]. In order to handle attractive apperance and extend lifetime of cotton-based garments, selecting of suitable pattern has crucial importance and preferred pattern can be given by different manufactuing methods such as knitting, braiding and weaving. Individual controlling of structural yarns in 2-D woven fabrics, namely warp and weft, makes possible to manufacture various fabrics easily with different characteristics. Because variability on controlling of individual yarns determines the number of total floats or interlacements which are related with weave pattern. Thereby, it can be possible to present wide range of fabrics having different characteristics either in fabric length, width or both [3].

As well as aesthetic properties of a woven fabric to be used in clothing industry, it is important to focus on its mechanical specifications. While putting on a garment or wearing it on daily use, it is exposed to various forces. In order to prolong garments' life, both structural and mechnical specifications should be considered in a whole as trying to reach aesthetic performance [4]. By appropriate pattern effect, woven fabrics can easily satisfy the required demands such as thermal [5], visual [6], textural [7] and mechanical [8,9] performances. In woven fabrics, pattern effect and structural components are responsible from the occurence of interyarn coincidence which determines resistance characteristics of fabric structure [10-14] and interyarn pores which determines air permability characteristics [14-18].

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There are many researches about the effects of basic fabric patterns, their derivatives (with less floating yarns such as 2/1 or 3/1 twill) and yarn structure either on air permeability or abrasion resistance of woven fabrics but not both of them. Besides, tensile behaviors of these patterns are not examined bi-directionally which garments are exposed to these forces as being dressed by users. In this study, woven fabrics with different patterns having long yarn floats were manufactured by using 100% cotton weft and warp yarns. Bi-directionally tensile strength, air permeability and abrasion resistance of various wovens were tested and thickness of samples were measured. Structural properties of fabrics were also calculated by corresponding formula. Obtained test results were correlated with corresponding fabric pattern.

2. Experimental Study

2.1 Materials

Unsized warp yarns and weft yarns were used for manufacturing of woven fabrics with various patterns. Specifications of warp and weft yarns are given in Table 1.

2.2 Methods

Fabrics used in this study were woven by CCI Evergreen Loom with a weaving width of 20 inch and reed width was 110/2. Woven fabrics were grey in color and directly tested without any further applications. Structural views of five woven fabrics are illustrated in Figure 1.

2.3 Characterization

Determination of structural parameters of woven fabrics: Due to the difference in fabric design and different number of yarn floats in patterns, structural parameters for each pattern should be calculated and clarified. For this reson, yarn diameters, crimp percentage, yarn settings and fabric weights were determined and associated with other test results.

Measurement of fabric thickness: Thickness of woven fabrics were tested with R&B Cloth Thickness Tester by considering TS 7128 EN ISO 5084 standard. The test was performed by taking measurements on five different surface areas of each sample.

Abrasion resistance test: The abrasion resistances of wovens were tested by Martindale Abrasion Tester according to yarn breakage method of ASTM D4157-02 standard (Figure 2(a)). Test was performed by increasing abrasing head rate (rpm) at certain intervals unless two yarn breakages were observed for each sample and abrasion resistance characteristics of samples were evaluated according to circle numbers [19].

Testing of air permeability: Measurements of air permeability of woven samples were performed by Prowhite Air Permeability Instrument according to TS 391 EN ISO 9237 standard as shown in Figure 2 (b). By applying 100 Pa air pressure onto 20 cm^2 area of samples, 5 measurements for each sample were taken from different areas of fabrics and average test results were calculated.

Bi-directionally tensile strength testing: Tensile strengths were tested by Instron 4411 testing device according to ASTM D1682 strip method. Five measurements were done for each pattern and average test results were considered for evaluating tensile behaviors of samples on corresponding direction.

In this study, it is reported that how weave pattern alters structural properties and affects thickness, air permeability characteristic and resistance of fabrics against to tensile and abrassive forces. Despite of many researches on fabric pattern, this paper differentiates from its counterparts via weaves with long yarn floats, testing mechanical and aesthetic properties of 2-D fabrics woven with folded yarns and determining structural properties of fabrics theoretically. Significance of test results were interpreted by ANOVA and Duncan comparison test.

Table 1. Properties of yarns used for weaving fabric

	Warp	Weft
Raw material	Cotton	Cotton
Spinning method	Combed ring	Carded ring
Count (Ne)	32/2	28/2
Twist (T/m)	778	648
Strength (Rkm)	28.32	17.57
U (%)	8.59	7.41
CV_m (%)	11.01	9.36
Fiber length (mm)	29	29
Fiber fineness (μ)	4.4	4.4

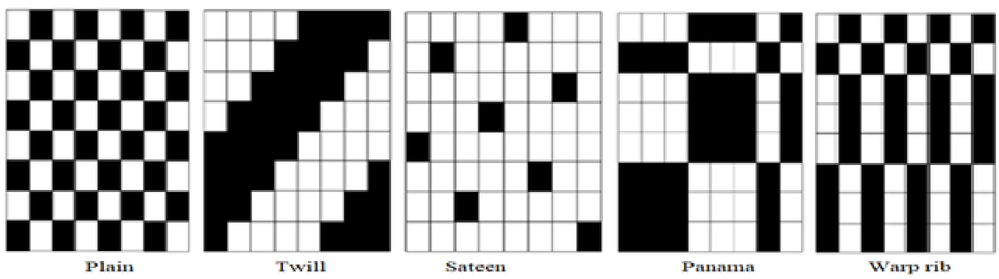

Figure 1. Structural views of wovens P $\frac{1}{1}$, T $\frac{4}{4}$, S $\frac{1}{7}$ (3), Pa $\frac{3\quad 1}{3\quad 1}$, W_R $\frac{3\quad 1}{3\quad 1}$

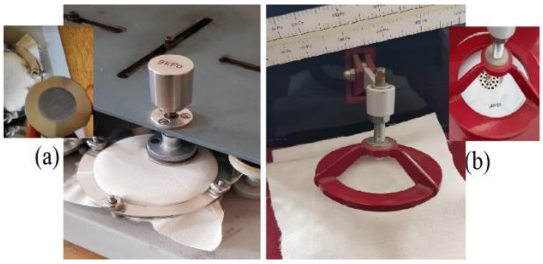

Figure 2. Testing of samples (a) abrasion resistance test (b) air permeability test

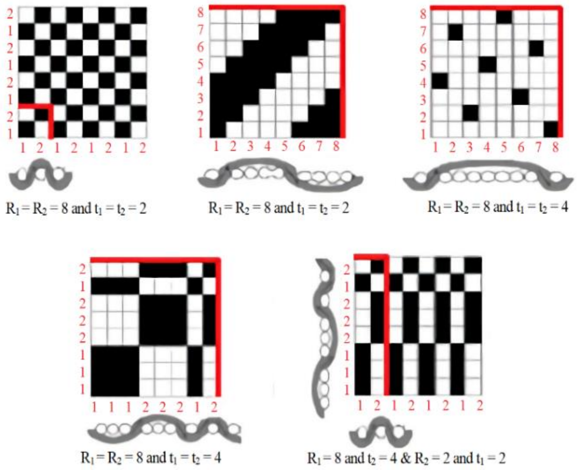

Figure 3. Weave repeats and interlacing points of patterns

3. Results and Discussion

3.1 Determination of Structural Properties of Wovens

In Figure 1, it is seen that warp and weft yarns intersect each other at right angles. But yarn length between two consecutive yarns in same direction differs due to pattern effect so average yarn floats for patterns and other structural properties for fabrics should be determined. Average yarn floats for warp and weft yarns were calculated according to Ashenhurst theory by the following formula [20]:

$$F_{1,2} = \frac{R_{2,1}}{t_{1,2}} \quad (1)$$

Where *F* is yarn float, *R* is no of yarn in repeat, *t* is no of point in interlacing, subscripts *1* and *2* refer to warp and weft, respectively.

Weave repeats are square weaves for all woven patterns but not for warp rib. This means that yarn interlacing is similar for warp and weft direction in fabrics with square weave repeats but different in fabric with warp rib pattern [20]. Yarn interlacing and weave repeats for patterns are illustrated in Figure 3.

According to Brierly's theory, yarn setting on loom depends on yarn properties and pattern type used for weaving. Brierly stated that yarn settings affected from yarn count, constant obtained from yarn type and yarn count system, average float length and weave constant. For woven fabrics with different yarn counts in warp and weft direction, yarn setting can be calculated from the following formula [21]:

$$S = \sqrt{K \times N_{ave}} \times F^{m} \quad (2)$$

$$N_{ave} = 2 \times \left[\frac{N_{warp} \times N_{weft}}{N_{warp} + N_{weft}}\right] \quad (3)$$

Where *S* is yarn sett/inch, *K* is constant based on yarn count and yarn type (200 for cotton yarn, 134 for worsted yarn, 61 for woolen yarn), N_{ave} is average yarn count in indirect system (N_e), *F* is average yarn float, *m* is weave constant (0.45 for plain and panama, 0.39 for twill, 0.42 for sateen, 0.42 for warp rib (take 0.42 for short and long float weaves and add +7-8% to result) [21,22].

Yarn diameters of warp and weft yarns were calculated from the formula [23,24]:

$$d_{1,2} = \frac{a}{\sqrt{N_{1,2}}} \quad (4)$$

Where *d* is yarn diameter, *a* is yarn correction factor (0.95 for cotton yarns), *N* is yarn count in indirect system (N_m), subscripts *1* and *2* refer to warp and weft, respectively.

Yarn crimp and weave angle for warp and weft yarns were also calculated from the following formula [25]:

$$Cos\ \theta_{1,2} = \frac{d_{1,2}}{d_1 + d_2} \quad (5)$$

$$Cos\ \theta_1 + Cos\ \theta_2 = 1 \quad (6)$$

Crimp percentage for warp and weft yarns can be calculated from the following formula [25]: All structural properties determined for fabrics with different weave patterns are given in Table 2.

$$C_{1,2} = \left[\frac{\pi\,(d_1 + d_2)}{180\sqrt{{d_{2,1}}^2 + 2 \times d_1 \times d_2}} \times Cos^{-1}\frac{d_{1,2}}{d_1 + d_2} - 1\right] \Big/ F_{1,2} \quad (7)$$

3.2 Measurement of Sample Thickness

Interlacing of warp and weft yarns caused a change in fabric thickness due to individual crossectional height of each yarn and various number of intersecting point on differently woven fabrics. According to the results, the highest (0.0085 mm) and lowest (0.0050 mm) fabric thickness were measured in sateen and plain woven fabrics, respectively. In Figure 4, it is seen that thickness of samples woven with derivatives of plain weave have also thinner fabric thickness and thickness increases by increasing yarn floats. During weaving process, weft and warp yarns intersect each other and this case limits the crossectional area of each yarn in intersection points. Interlacing number is directly related with weave pattern and thickness values are not identical in fabrics woven with same yarns. Increase in intersecting points among yarns causes thinner fabric manufacturing [26-28]. Additionally fabric thickness is affected from warp and weft sett in unilayer and multilayer fabrics. In this study, unilayer fabrics are woven and fiber type of yarns are identical but yarn counts are different from each other and yarn setts are variable for different weave patterns. Due to the intent of comparing fabric pattern effect on fabric thickness and wide range of difference on quantitative thickness values, it is resulted that weave pattern has a considerable effect on unilayer fabric thickness and yarn setting variation on fabrics.

3.3 Air permeability test

Air permeability is quantitative characteristic of a porous surface through which air passes. Volume of air passing through these fabrics was measured as approximately 150 dm^3/min. Mohammed [29] states that air permeability of sateen woven fabric is higher than those of hopsack and kautshok woven fabrics due to higher yarn floats and lower cross-over point on sateen. In this study, the longest yarn floats were observed in sateen woven fabrics both on warp and weft directions. In twill and panama woven fabrics, yarn floats were more than those of plain woven fabrics. This case clearifies the difference on air permeability that it is strongly related with yarn float variations by considering the patterns used in this study.

It was seen that air volume passing through plain fabric was 30 dm^3/min although constituting yarns of plain weave had the highest yarn intersection. In some studies, it is reported that air permeability is mainly dependent upon the textile fabric's weight and construction [30,31]. By changing the sequence of yarn floats and number of interlacings, air permeability of textile surfaces can be differed. Size, arrangement and shape of the pores are decisive parameters on permeability characteristics of a fabric [19]. Umar et. al. [32] reported that longer yarn floats were resulted from less interlacements and air permeability of fabric was developed by increasing yarn float. Plain woven fabrics were found too dense to be a permeable fabric. In our study, plain woven fabrics have poor air permeability and previous studies support this result. Figure 5 demostrates that sateen fabric is the most air-permeable sample.

It was observed that air permeability was highest in the sateen weave due to less interlacements. In contrast to this fact, plain woven fabrics were the least permeable fabrics in which warp and weft yarns intersected each other densely. This case is supported by Kullmann [33]. Kullman claimed that sateen woven fabrics were more sensitive to air pressure, they tend to elongate much more than other wovens so weave pattern had crucial effect on air permeability characteristics of fabric. Due to longer yarn floats and less interlacements in sateen weave, volume of air passing through the voids of yarns was measured higher than other wovens had. Air permeability decreased by diverging pattern from sateen to plain weave and fabrics woven with inter-patterns such as, twill and warp rib, had medium air permeability characteristics. Şekerden [34] studied that air permeability was higher in the fabrics woven with blended weft yarns having at least 70% cellulosic fiber and the effect of weave type on air permeability was lower than that of the fibre proportion if cellulosic fibre content was less than 70%. Below these values, air permeability was lower in the fabrics woven with sateen and twill weaves and fibre content and type in blended yarns had highly crucial effect on air permeability characteristic of woven than weave pattern. But in this study, unblended 100% cotton yarns with different yarn counts were used for weaving differently-patterned fabrics. Taştan et. al. [17] reported that increase in yarn twist improved air permeability characteristic. In this paper, fabrics were woven with 32/2 Ne combed warp yarns and 28/2 Ne carded weft yarns and dominant effect of pattern on air permeability was easily observed by using inexpensive weft yarn usage. Because giving more twist to yarns or combing process lead to increase in cost. Besides, long yarn floats result to low yarn consumption due to less crimp effect. So it can be resulted that air permability of woven fabrics can be inexpensively controlled by pattern affect with eliminating some spinning mill processes and giving less twist.

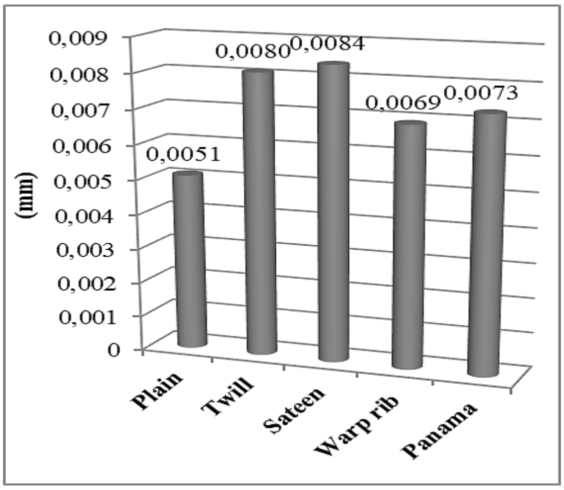

Figure 4. Average sample thickness according to patterns

Table 2. Structural properties of woven fabrics

Weave pattern		Yarn dia.	Ave. floats	Yarn / cm	Crimp (%)	Fabric weight (g/m^2)	Fabric thickness (mm)
Plain	Warp	0.182	1	22	0.21	192.95	0.0051
	Weft	0.195	1	22	0.20		
Twill	Warp	0.182	4	38	0.052	307.05	0.0080
	Weft	0.195	4	36	0.05		
Sateen	Warp	0.182	4	40	0.052	319.25	0.0084
	Weft	0.195	4	37	0.05		
Panama	Warp	0.182	2	30	0.105	252.32	0.0069
	Weft	0.195	2	28	0.10		
Warp rib	Warp	0.182	2	32	0.105	246.98	0.0073
	Weft	0.195	1	23	0.20		

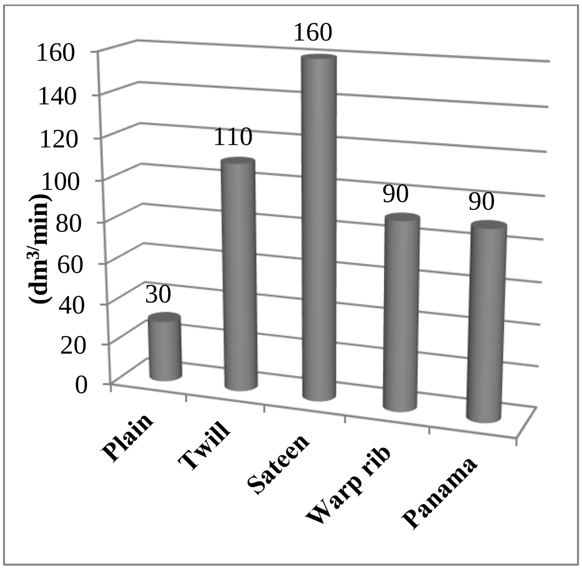

Figure 5. Air permeability test results of wovens

3.4 Abrasion resistance of samples

Abrasion resistance can be defined as the capacity to absorb stress energy occuring by a series of repeated rubbing. Figure 6 shows cycling number on which the woven samples are abrased. Plain and plain-derivated woven fabrics were found as more resistant to abrasion. Fan and Hunter [35] stated that fabrics resisted flat abrasive forces if a decrease was observable in yarn floats and an increase were available in tightness, thickness and weight of fabric. Sateen and twill fabrics woven from ring-spun or wrap-spun cotton yarns had slightly lower flex abrasion resistance than that of plain woven. Sateen or twill samples woven from yarns with same linear density, crimp and equal sett in warp and weft direction were found as more resistant to flat abrasion. In this study, fabrics were woven from 2-folded ring-spun cotton yarn and yarn setts were close to each other in sateen and twill wovens thereby it was not seen a slight difference on resistance of sateen and twill wovens. Plain wovens again had high flat abrasion resistance and results were supported by study of Fan and Hunter.

The least abrasion resistance among samples was observed in sateen woven fabrics and two yarn breakage was occured after 9800 cycle of abrasive head. Kaynak and Topalbekiroğlu [36] reported that long yarn float and less interlacement facilitated yarn lose due to easier movement of yarns by rubbing and increase in cycle caused more yarn lose in different woven fabrics. More resistant fabric to abrasion forces could be manufactured by abrading abrassive load over a greater number of fibres while preventing fibre removal from fabric.

3.5 Bidirectionally tensile strength testing of samples

Deteorations due to tensile stress were not same for all types of woven fabrics. Previous studies resulted that tensile strength of a fabric was not only related with characteristics of constituents yarns but also structure of fabric and tensile strength testing method [37-39]. According to the obtained test results of strip test method, plain-woven fabris were the most resistant to tensile forces with 106.4 MPa along warp direction. Besides fabrics woven with derivative patterns of plain weave such as panama and warp rib, had higher tensile strength values than those of sateen and twill woven fabrics. Ferdousa et al. (2014) stated that tensile behavior of a fabric was based on the weave pattern and low breaking strength was resulted from too much larger floats and too firmest interlacement [40]. In this study, warp and weft setts were variable on loom state for all weave types and this difference can be expressed as weave pattern has great importance on tensile strength behavior of structure than yarn sett. The lowest tensile resistance was tested on sateen woven fabrics which had the highest yarn setts and were found as most air permeable. The inverse relationship between tensile strength and air permability behaviors of a woven is glared as it is previously stated in literature reviews [41].

Fabrics having high degree of intersecting point elongate at break point more than other wovens. This case can be obviously seen by comparing panama and warp rib-woven fabrics. Although they are derivatives of plain weave, there is a clear elongation difference due to various numbers of intersecting point they have. Elongation at break due to forces applied along warp direction is related with density of weave and cloth setting [1]. Woven samples behaved differently against to tensile stresses along warp and weft directions. In Figure 7, it was shown that the highest tensile strengths were measured in fabric widths of warp rib- and sateen-woven fabrics, respectively. Some studies reported that tensile strength of plain woven fabrics were higher than that of twill wovens with same yarn settings and strength along weft direction could be developed by increasing weft sett [42, 43].

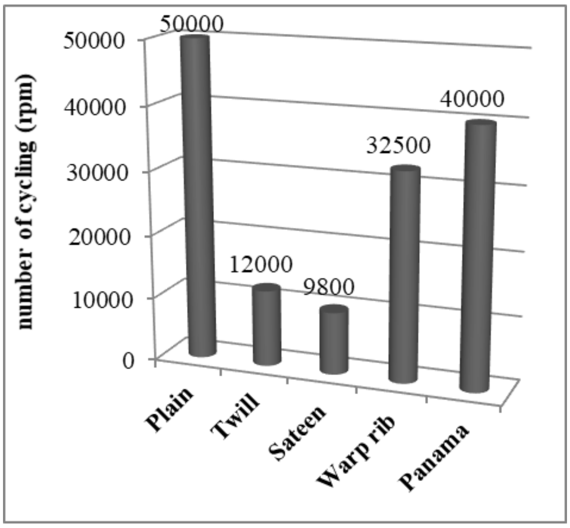

Figure 6. Number of cycling at which two yarn breakages observed

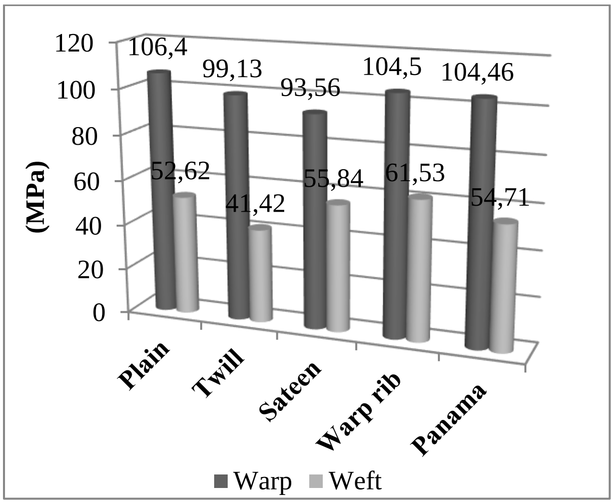

Figure 7. Ultimate tensile strength of wovens

Tensile strengths of plain woven fabrics along weft and warp directions were found as 52.62 MPa and 106.40 MPa, respectively. Due to balanced interlacing in plain weave, resistance to tensile loading on both directions were found higher than other weaves. But in sateen wovens, less number of interlacing point between yarns caused that weft yarns were exposed to resist tensile loading much more than interlacing forces. This case can be seen in derivatives with less yarn interlacements of basic patterns and high tensile resistance along weft direction can be observed in sateen weave [44]. Although long yarn floats of sateen wovens, tensile strength on weft direction compated with other wovens. In this study, warp and weft settings were variable and count of weft yarn was higher and twist on weft yarns were lower than those of warp yarns. Due to these reasons, resistance to tensile stress along weft direction was found lower and elongations at break for differently-patterned wovens were higher along warp direction but not along weft direction. Kurtça (2001) reported that lineer relationship was available between breaking and tensile strength of textile woven fabrics and breaking strength was basically dependent upon weave pattern and yarn characteristics. As increasing yarn count of weft yarn, both tensile and breaking strength decreased along fabric width, namely weft direction [45]. Although low tensile strength of sateen woven fabric along weft direction, percent elongation at break of weft yarns were close to other wovens had. It is seen that tensile properties of wovens are affected by weave pattern of fabric because components, namely yarns, are same for all fabrics with different weave patterns. On the other hand, the degree of yarn twist affects fabric elongation [1,45]. Reduction in twist improves cover and elongation but decreases yarn strength. Thereby, elongation and tensile strength properties of all samples along weft direction are poorer than those of warp direction. Figure 8 illustrates percentage strain of samples at breaking point.

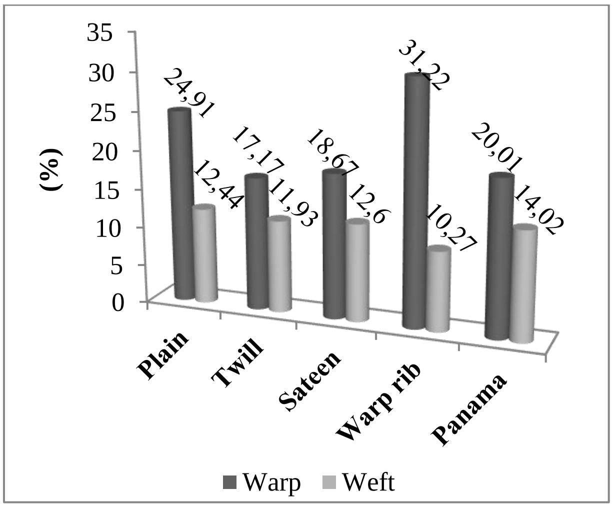

Figure 8. Tensile strain at break

Table 3. Statistical analysis of the effect of weave pattern on fabric properties

Pattern	Thickness	Air permeability	Abrasion resistance	Tensile Strength		Tensile Strain	
				Warp	Weft	Warp	Weft
Plain $\left(P\ \frac{1}{1}\right)$	$0,0050^{a}$ (0,00008)	$30,0020^{a}$ (0,01483)	50010^{e} (736,036)	$106,4^{c}$ (1,2159)	$52,60^{b}$ (0,8215)	$24,91^{d}$ (0,6337)	$12,44^{b}$ (0,2318)
Twill $\left(BT\ \frac{4}{4}\right)$	$0,0080^{c}$ (0,00008)	$107,62^{c}$ (4,3188)	120000^{b} (842,614)	$99,13^{b}$ (1,1145)	$41,42^{a}$ (0,7318)	$17,17^{a}$ (0,2325)	$11,93^{b}$ (0,3606)
Sateen $\left(S\ \frac{1}{7}\ (3)\right)$	$0,0085^{d}$ (0,00005)	$157,008^{d}$ (4,1875)	9810^{a} (888,397)	$93,562^{a}$ (1,0417)	$55,84^{c}$ (1,2461)	$18,67^{b}$ (1,1450)	$12,60^{b}$ (1,2000)
Warp rib $\left(R\ \frac{3\quad 1}{3\quad 1}\right)$	$0,0069^{b}$ (0,00011)	$86,530^{b}$ (4,1760)	32540^{c} (2055,298)	$104,5^{c}$ (1,7944)	$61,53^{d}$ (0,6213)	$31,22^{e}$ (1,5952)	$10,27^{a}$ (0,3126)
Panama $\left(P\ \frac{3\quad 1}{3\quad 1}\right)$	$0,0070^{b}$ (0,00018)	$85,220^{b}$ (4,1365)	40010^{d} (1895,850)	$104,46^{c}$ (3,2160)	$54,71^{c}$ (1,7961)	$20,008^{c}$ (0,6866)	$14,02^{c}$ (0,3435)
Sign.	$p<0,001$	$p<0,001$	$p<0,001$	$p<0,001$	$p<0,001$	$p<0,001$	$p<0,001$

Groups and significance of different weave patterns and also effects of these patterns on tested properties were statically interpreted by one-way ANOVA and Duncan comparison tests. All test results were found as statistically important with significance level of $p<0.001$ [36,46]. Despite of low standard deviation of warp rib, panama showed better distribution by means of homogenity. Warp rib and panama exhibited similar behaviors from the points of thickness, air permability and tensile strength along warp directions. Among all weave patterns, the highest standard deviation was determined in sateen weave for all tested parameters. Results of statistical analysis are given in Table 3.

4. Conclusions

Due to the inter-yarn pores available on inner and outer surfaces of fabric, possibility of variable numbers of yarn interlacement and controlling properties of structural components, woven fabrics have widespread usage either in clothing and other technical areas. By the way, woven fabrics take attentions of both artistic and engineering fabric designers. Because it makes possible to manufacture surfaces with demanded specifications for intended use. However, woven fabrics can exhibit variable mechanical and visual characteristics due to too many controllable parameters during weaving such as structural, operational or further process parameters.

In this study, the effect of fabric pattern on mechanical properties, permeability performances and thickness of woven fabrics are investigated and structural properties of fabrics are determined. Fiber type, yarn spinning method, reed width and fabric manufacturing technology were identical for all samples. Plain wovens were found as thinner, more resistant on warp direction and less air-permeable than those of other fabrics due to well-packaged yarn construction with high interlacement. Panama and warp rib which are derivatives of plain weave, exhibited similar characteristics but elongation at break was higher in warp rib fabric due to balanced long yarn floats. On the other hand, sateen fabric were more air permeable but thicker and less resistant against abrasive and tensile forces. Test results shows that panama woven fabrics which have average yarn setts among other fabrics can satisfy demands for mechanical, physical, structural and functional specifications.

Declaration

The author declared that no potential conflicts of interest with respect to the research, authorship and publication of this article. The author also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

Author Contributions

H.H. Aygün developed the methodology, improved the study, reported/illustrated the obtained test results and concluded the studied work.

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References

1. Gandhi, K. *Woven textiles: principles, technologies and applications.* 2012, England: Woodhead.
2. Khanzada, H., M. Khan and S. Kayani, *Cotton based clothing. In: Wang H., Memon H. (eds) Cotton science and processing technology*. 2020, Singapore: Springer.
3. Uddin, F. *Introductory Chapter: Textile Manufacturing Processes*. 2019, Croatia: InTechopen.
4. Clegg, A., W. Yu, J. Tan, C.K. Liu and G. Turk, *Learning to dress: Synthesizing human dressing motion via deep reinforcement learning.* ACM Transactions on Graphics. 2018. **37**(6): p. 1-10.
5. Asayesh, A., M. Talaei and M. Maroufi, *The effect of weave pattern on the thermal properties of woven fabrics*, International Journal of Clothing Science and Technology, 2018. **30**(4): p. 525-535.
6. Hussain, M.A.I., B. Khan, Z. Wang and S. Ding, *Woven fabric pattern recognition and classification based on deep convolutional neural networks*, Electronics, 2020. **9**: p. 1-12
7. Jing, J., M. Xu, P. Li, Q. Li and S. Liu, *Automatic classification of woven fabric structure based on texture feature and PNN*. Fibers and Polymers, 2014. **15**: p. 1092–1098.
8. Cao, J., R. Akkerman, P. Boisse, J. Chen, H. S. Cheng and E. F. de Graaf, *Characterization of mechanical behavior of woven fabrics: Experimental methods and benchmark results*, Composites Part A: Applied Science and Manufacturing, 2008. **39**(6): p. 1037-1053.
9. Jahan, I. *Effect of fabric structure on the mechanical properties of woven fabrics.* Advanced Research in Textile Engineering. 2017. **2**(2): p. 1-4.
10. Hossain, M.M., E. Datta and S. Rahman, *A review on different factors of woven fabrics' strength prediction*. Science Research, 2016. **4**(3): p. 88-97.
11. Turukmane, R. and R. Patil, *Structural behavior of fabric design on mechanical properties of woven fabrics.* Melliand International, 2019. **25**(1): p. 83-85.
12. Azeem M., Z. Ahmad, J. Wiener, A. Fraz, H.F. Siddique and A. Havalka, *Influence of weave design and yarn types on mechanical and surface properties of woven fabric.* Fibres & Textiles in Eastern Europe, 2018. **127**(1): p. 42-45.
13. Sardag, S. *Investigation of mechanical properties of fabrics woven with tencel/ cotton blend yarns.* Textile and Apparel, 2019. **29**(2): p. 162-170.
14. Havlova, M. *Air permeability and constructional parameters of woven fabrics*. Fibres & Textiles in Eastern Europe, 2013. **21-2**(98): p. 84-89.
15. Sarıoglu, E. And O. Babaarslan, *Porosity and air permeability relationship of denim fabrics produced using core-spun yarns with different filament finenesses for filling.* Journal of Engineered Fibers and Fabrics, 2019. **14**(1): p. 1-8.

16. Ceven, E.K. and G. Karakan Günaydın, *Investigation of some mechanical and air permeability properties of shirting fabrics produced from compact yarns made of natural and synthetic fibres.* Uludağ University Journal of The Faculty of Engineering, 2019. **24**(2): p. 445-460.
17. Tastan, E., M. Akgun, A. Gurarda, and S. Omeroglu, *Investigation of the effect of different structural parameters of cotton woven fabrics on their air permeability*. IOP Conference Series: Materials Science and Engineering, 2017. **254**: p. 1-4.
18. Ozgen, B. and S. Altas, *Evaluation of air permeability of fabrics woven with slub yarns*. Tekstil ve Konfeksiyon, 2017. **27**(2): p. 126-130.
19. Nielson K.J., *Interior textiles: fabrics, application, and historic style.* 2007, USA: Wiley&Sons.
20. Ozdemir, H., B.M. Icten and A. Doğan, *Experimental investigation of the tensile and impact properties of twill and twill derivative woven fabric reinforced composites.* Tekstil ve Konfeksiyon, 2018. **28**(4): p. 258-272.
21. Turhan, Y. and R. Eren, *Dokunabilirlik sınırıyla ilgili deneysel çalışmaların değerlendirilmesi.* Pamukkale Mühendislik Bilimleri Dergisi, 2005. **11**(2): p. 205-218.
22. Galuszynski, S., *Structure and tightness of woven fabrics.* Indian Journal of Textile Research, 1987. **12**: p. 71-77.
23. Kim, H.A. And S.J. Kim, *Simulation of the weave structural design of synthetic woven fabrics.* Fibers and Polymers, 2010. **11**(6): p. 905-910.
24. Dobrik Dubrovski, P., *Woven fabric engineering*. 2010, Croatia: Books on Demand.
25. Ebrahem, H.A.A., *Single woven fabric characterization in terms of yarn diameter and average float: Theoretical considerations and test results.* Mansoura Engineering Journal, 2009. **43**(2): p. 24-32.
26. Sekerden, F., *PES/VİS/LYCRA® içerikli atkı elastan dokumalarda çeşitli dokuma faktörlerinin kumaşın fiziksel ve mekanik özelliklerine etkisinin incelenmesi, in: Textile Engineering2009*, Çukurova University: Turkey. p.193.
27. Sirkova, B.K., *Description of fabric thickness and roughness on the basis of fabric structure parameters,* AUTEX Research Journal, 2012. **12**(2): p. 40-43.
28. Cherif, C., *Textile materials for lightweight constructions: technologies-methods-materials-properties*, 2015, Germany: Springer-Verlag Berlin Heidelberg.
29. Mohammad, G.A. *Comparative study of air permeability of polyester/metallic blended woven fabrics*. Life Science Journal, 2015. **12**(6): p. 78-82.
30. Abou-Nassif, G.A., *Predicting the tensile and air permeability properties of woven fabrics using artificial neural network and linear regression models.* Journal of Textile Science and Engineering, 2015. **5**(5): p. 209-215.
31. Ogulata, R.T., *Air permeability of woven fabrics.* Journal of textile and apparel, technology and Management, 2006. **5**(2): p. 1-10.
32. Umair, M., T. Hussain, K. Shaker, Y. Nawab, M. Maqsood and M. Jabbar, *Effect of woven fabric structure on the air permeability and moisture management properties*. The Journal of The Textile Institute, 2016. **107**(5): p. 596-605.
33. Kullman, R.M.H., C.O. Graham and G.F. Ruppenicker, *Air permeability of fabrics made from unique and conventional yarns. Textile Research Journal*, 1981. **51:** p. 781-786.
34. Sekerden F., *Effect of fabric weave and weft types on the characteristics of bamboo/cotton woven fabrics.* Fibres & Textiles in Eastern Europe, 2011. **19-6** (89): p. 47-52.
35. Fan, J. and L. Hunter, *Engineering apparel fabrics and garments*. 2009, USA: CRC Press.
36. Kaynak, H.K. and M. Topalbekiroglu, *Influence of fabric pattern on the abrasion resistance property of woven fabrics.* Fibres & Textiles in Eastern Europe, 2008. **16**(1): p. 54-56.
37. Kawabata, S., M. Niwa and H. Kawai, *The finite-deformation theory of plain-weave fabrics part- I: the biaxial-deformation theory.* Journal of Textile Institution, 1973. **64**(1): p. 21-26.
38. Realff, M.L., M.C. Boyce and S. Backer, *A micromechanical model of the tensile behavior of woven fabric.* Textile Research Journal, 1997. **67**(6): p. 445-459.
39. Wu, J. and N. Pan, *Grab and strip tensile strengths for woven fabrics: an experimental verification.* Textile Research Journal, 2005. **75**(11): p. 789–796.
40. Ferdousa, N., S. Rahman, R. Kabir and A.E. Ahmed, *A comparative study on tensile strength of different weave structures,* International Journal of Scientific Research Engineering & Technology, 2014. **3**(9): p. 1307-1313.
41. Fatahi, I.I. and A. Alamdar Yazdi, *Assessment of the relationship between air permeability of woven fabrics and its mechanical properties.* Fibres & Textiles in Eastern Europe, 2010. **18**(83): p. 68-71.
42. Ogulata, R.T. and F.D. Kadem, *Prediction of regression analyses of fabric tensile strength of 100% cotton fabrics with yarn dyed in different constructions.* Textile and Confection, 2008. **18**(3): p. 185-190.
43. Unal, P. and C. Taskın, *%100 poliester kumaşlarda dokunun ve sıklıkların kopma mukavemetine etkisi*, Tekstil ve Konfeksiyon, 2007. **17**(2): p. 115-118.
44. Ozdemir, H. and E. Mert, *The effects of fabric structural parameters on the breaking, bursting and impact strengths of diced woven fabrics.* Textile and Confection, 2013. **23**(2): p. 113-123.
45. Kurtca, E., *Atkı ipliği özellikleri, sıklık ve örgü tipinin kumaş mekanik özellikleri üzerine etkisi, in Textile Engineering2001*, Istanbul Technical University: Turkey. p. 74.
46. Yılmaz Akyurek, B., *Şardonlamanın bi-elastik dokuma kumaşlarda mekanik özellikler üzerine etkisinin deneysel belirlenmesi.* Tekstil ve Mühendis, 2016. **23**(101): p. 1-11.