(REFEREED RESEARCH)

INFLUENCE OF WARP TENSION ON BREAKING STRENGTH AND STRAIN OF WOVEN FABRICS

ÇÖZGÜ GERGİNLİĞİNİN DOKUMA KUMAŞLARIN KOPMA MUKAVEMETİ VE UZAMASI ÜZERİNE ETKİSİ

Mine AKGÜN
Uludağ University
Textile Engineering Department
e-mail: akgunm@uludag.edu.tr

Gülcan SÜLE
Uludağ University
Textile Engineering Department

Halil Rifat ALPAY
Uludağ University
Textile Engineering Department

Recep EREN
Uludağ University
Textile Engineering Department

ABSTRACT

This paper assesses the influence of warp tension on the breaking strength and strain of plain woven fabrics. Different fabric constructions were woven by changing weft yarn count, weft density and warp tension. Twisted polyester warp yarn and textured polyester weft yarns are used in weaving fabrics. Warp tension was changed up to four different values for each fabric and their breaking strength and strain were measured. Experimental results showed that as the warp tension increased the fabric's breaking strength in warp direction decreased with thinner weft yarns, slightly increased with thicker weft yarns. There was no significant effect of warp tension on the fabric's breaking strength in weft direction. As warp tension increased the fabric's breaking strain in warp direction decreased in the fabrics with higher warp crimp. As the warp tension increased the fabric's breaking strain in weft direction increased with thinner weft yarns, slightly decreased or remained almost constant with thicker weft yarns.

Key Words: Fabric's breaking strength, Fabric's breaking strain, Weaving, Warp tension, Crimp.

ÖZET

Bu makalede, çözgü gerginliğinin bezayağı dokuma kumaşların kopma mukavemeti ve uzaması üzerine etkisi arştırılmaktadır. Farklı kumaş konstrüksiyonları atkı ipliği numarası, atkı sıklığı ve çözgü gerginliği değiştirilerek dokunmuştur. Dokuma kumaşlarda polyester bükümlü çözgü iplikleri ile tekstüre atkı iplikleri kullanılmıştır. Dört farklı çözgü gerginliği ile dokunan kumaşların kopma mukavemeti ve kopma uzaması değerleri ölçülmüştür. Deneysel sonuçlar, çözgü gerginliği arttıkça kumaşın çözgü yönündeki kopma mukavemetinin ince atkı iplikleriyle dokunan kumaşlarda azaldığını, kalın atkı iplikleriyle dokunan kumaşlarda hafif bir şekilde arttığını göstermiştir. Çözgü gerginliğinin kumaşın atkı yönündeki kopma mukavemetine önemli bir etkisi olmamıştır. Çözgü gerginliği arttıkça daha yüksek çözgü kıvrımına sahip dokuma kumaşlarının çözgü yönündeki uzaması azalmıştır. Çözgü gerginliği arttıkça kumaşın atkı yönündeki uzaması ince atkı iplikleri ile dokunan kumaşlarda artarken, kalın atkı iplikleri ile dokunan kumaşlarda hafif bir azalma göstermiş ya da yaklaşık sabit kalmıştır.

Anahtar Kelimeler: Kumaşın kopma mukavemeti, Kumaşın kopma uzaması, Dokuma, Çözgü gerginliği, Kıvrım.

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1. INTRODUCTION

Breaking strength is the maximum tensile force recorded in extending a test piece to breaking point. It is generally referred to as strength. The force at which a specimen breaks is directly proportional to its cross-sectional area, therefore when comparing the strengths of different fibers, yarns and fabrics allowances have to be made for this. The tensile force recorded at the moment of rupture is sometimes referred to as the tensile strength at break (1).

The breaking load of a fabric in either the warp or weft direction is primarily determined by the strength of the yarn. The other important fabric variables effecting strength of woven fabrics are fiber properties, yarn properties, warp and weft densities, fabric weave, crimp and finishing process. Fabric strength tends to increase as the thread densities in both directions increase (2-7). An increase in the weft density or warp density also leads to an increase in crimp. This has detrimental effect on fabric strength because, as the crimp increases, the yarn lies more obliquely in relation to the plane of the fabric. Thus a greater force is required in the yarn to balance a load applied in that plane (2).

The breaking extension is the sum of the extension due to crimp interchange and the extension of the yarn itself.

Thus the overall breaking extension of the fabric will be dependent on crimp (2). The more crimp there is in the yarn, the more extensible is the fabric. Therefore, the longer the float, the less extensible is the fabric (8). Mansour et al. thought crimp to be an important variable and investigated the relationship between fabric extension and crimp. It was established that fabric extension increased with an increase in crimp for plain weave fabrics (4).

There seems no doubt that tension during weaving has an important effect on the quality of the fabric. The effect of weft tension on mechanical properties of woven fabrics has been researched by Adanur et al. They established that fabric tensile strength decreased as weft tension increased (9).

To summarize, many studies have been performed on breaking strength and strain of woven fabrics, but the change of these properties depending on warp tension has scarcely been investigated. In this research, woven fabric's breaking strength and strain and their relationship with the warp tension and the effect of weft density, weft yarn count on this relationship are investigated.

2. MATERIALS AND METHODS

The breaking strength and strain of plain woven fabrics were investigated experimentally for different warp tension values. Different fabric constructions were woven by changing weft yarn count, weft density and warp tension in a Picanol OMNI air jet loom. Type of warp and weft yarn, warp density and warp yarn count (150 denier / 36 filaments) remained the same. Twisted polyester (yarn twist of 350 turns / metre in the Z direction) warp yarn and textured polyester weft yarns are used in weaving fabrics. Warp tension was changed up to four different values for each fabric construction. Warp tension is a parameter which represents the tension of all ends measured by loom tension sensor. This parameter was entered from machine computer and used to adjust warp tension by the tension control system of the air jet loom. The values of parameters changed for weaving different fabric constructions are presented in Table 1.

Table 1. Construction parameters of the woven fabrics

Weft Count (denier / filaments)	Warp Tension (kN)	Weft Density (thread / cm)	Warp Density (thread / cm)
100/35	0,9	18-22-28	34
	1,25	18-22-28	34
	1,5	18-22-28	34
	1,75	18-22-28	34
150/96	0,9	18-22-28	34
	1,25	18-22-28	34
	1,5	18-22-28	34
	1,75	18-22-28	34
300/70	0,9	18-22	34
	1,25	18-22	34
	1,5	18-22	34
	1,75	18-22	34

The fabric's breaking strength and strain values were measured according to standard ASTMD 1682-64 (10) for grey woven fabrics. Before experiments, the samples were conditioned under laboratuary conditions (25 ^{o}C, 65 %RH) . The experiments were performed with a tensile tester Instron 4301, the distance between the jaws was 200 mm, and the gauge speed of the Instron was 100 mm/min. Tests were performed in warp and weft directions and five samples were taken from both directions of each type of fabric.

It is well known that yarn crimp in a woven fabric is an important parameter which affects most of its physical properties. The crimp is dependent on many factors such as yarn count, yarn properties (yarn bulk, bending stiffness), fabric density, fabric weave as well as the levels of tensions applied in weaving and finishing. Therefore, while we were investigating the effect of warp tension on fabric tensile properties, we also investigated the effect of warp tension on warp and weft crimps. Warp and weft crimps in grey fabrics were measured according to ASTM D3883-04 standart after the fabrics were conditioned under laboratuary conditions.

ANOVA was used to evaluate the influence of warp tension, weft yarn count and weft density on fabric's breaking strength and strain in warp and weft directions respectively. The p-values associated with F-tests for a three way Anova completely randomized analysis of variance are presented in Tables 2 and 3.

3. RESULTS AND DISCUSSION

3.1. The effect of warp tension on fabric's breaking strength in warp direction

The effect of warp tension on fabric's breaking strength in warp direction is presented in Figure 1. The fabric strength in warp direction shows a decreasing trend with respect to increasing warp tension in the fabrics woven with 100 denier weft yarn at lower weft densities (18 and 22 weft densities) as shown in Figure 1. This is probably due to the decrease in warp yarn's breaking strength during weaving process. It is known that a weaving warp consists of several warp threads having cyclic tension variation during weaving. Variation in warp tension during a weaving cycle is the result of shedding, beat up, take- up and let off motions. This repetition of warp tension variation damages the warp yarn and decreases warp yarn strength (11).

Warp yarns were taken out from the woven fabric samples and their breaking strength were measured to determine whether or not the weaving process caused some strength losses in

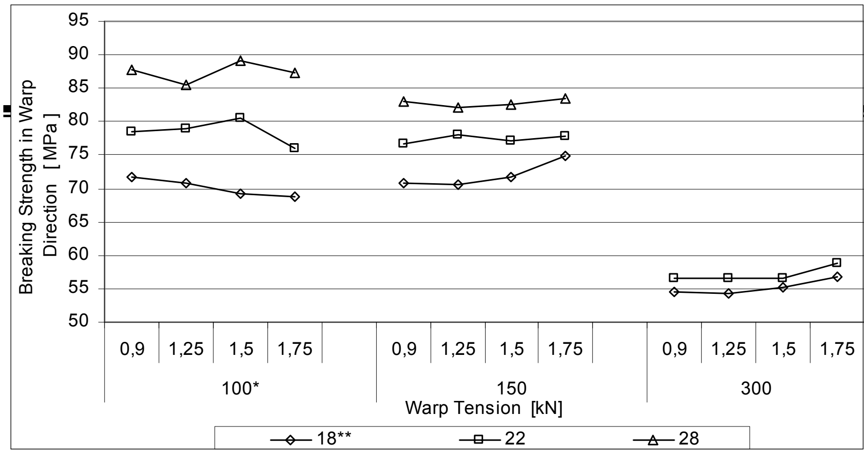

Figure 1. The effect of warp tension on fabric's breaking strength in warp direction (*weft yarn count, **weft density)

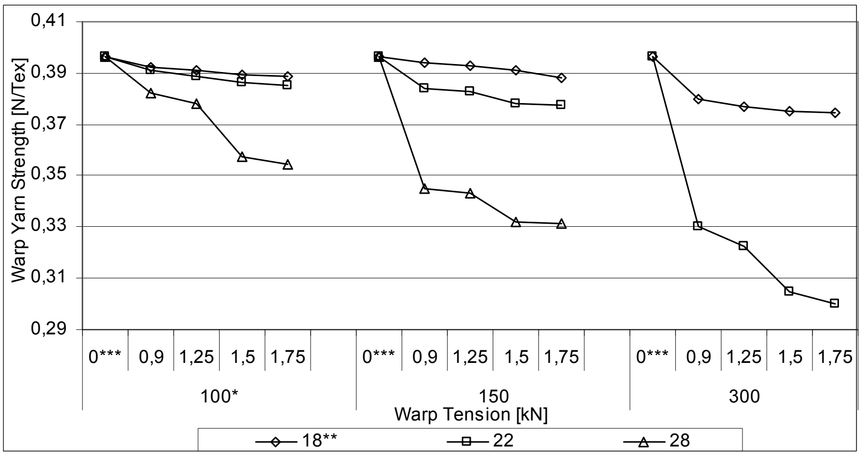

Figure 2. The breaking strength of warp yarn's dependence on warp tension, weft yarn count and weft density (*weft yarn count, **weft density and 0***denotes warp yarns strength on warp beam)

warp yarns. Also, the breaking strength of warp yarns before weaving were measured by taking samples from the warp beam.

As shown in Figure 2, the breaking strength of warp yarns taken out from the woven fabrics are lower compared to the breaking strength of unwoven warp yarn. The warp yarn's breaking strength in the fabrics woven with 100 denier weft yarn at 18 and 22 densities shows a decreasing trend with respect to the increase in warp tension. This is thought to be the reason for the decrease in the fabric's breaking strength in warp direction. In the case of the breaking strength of warp yarn taken out from the fabric woven with 100 denier at 28 weft density decreases steeper as the warp tension increases. The breaking strength of warp yarns taken out from the fabrics woven with 150 and 300 denier decreases very significantly with the increase in weft density and warp tension. This is thought to be higher beat up force required for high weft cover factor fabrics. In weaving such fabrics, cloth fell position moves towards the back of the loom. The reed meets the cloth fell before its most forward position and moves together for some distance. Greenwood et al. (12) investigated mathematical analysis of beat-up process and established the relation between the rate of take-up, the position of the cloth fell, and pickspacing according to excess tension theory. As weft yarn gets thicker and/or weft density increases weaving resistance increases. Increase in required in beat-up force is provided by displacement of the cloth fell away from the weaver. Thus, warp tension increases, fabric tension decreases during beat-up. This happens in a very short period of time in each loom revolution and damages the warp yarn. Decrease in warp yarn's breaking strength becomes higher with thicker weft yarns and higher weft density due to more increasing warp tension during beat-up process. This can be the reason why fabric's breaking strength in warp direction decreases as weft yarn gets thicker in Figure 1. Despite the fact that warp yarn's breaking strength decreases more with increasing weft density as the warp tension increases as seen in Figure 2, the fabric's breaking strength in warp direction increases as shown in Figure 1. To be able to explain this case, the effect of weft density and warp yarn's breaking strength (warp yarns were taken from the fabrics taken out from the fabrics woven with four different warp tension) on the fabric's breaking strength in warp direction was examined. The results of variance analysis are presented in Table 2. The effect of weft density on the fabric's breaking strength in warp direction has been found more pronounced than the warp yarn's breaking strength in the fabrics woven with 100, 150 and 300 denier weft yarns.

The number of interlacing points between warp and weft yarns per unit area of the fabric increases with increasing weft density and this increases frictional forces and therefore the fabric's breaking strength in warp direction increases. But, after a weft density value, some decreases may be observed in the fabric's breaking strength in warp direction with increasing weft density due to the increase in warp crimp (2). According to these results, the decrease in the breaking strength of warp yarn taken out from the fabrics increases with the effect of warp tension as the weft density increases. Despite this, as the weft density is more decisive on the fabric's breaking strength than the warp yarn's breaking strength, the fabric's breaking strength in warp direction increases with the increase in weft density.

Table 2. Analysis of variance p-values for fabric's breaking strength in warp direction (* and *** denotes the significance of the effect of the parameters on fabric's breaking strength in warp direction; ns indicates that the factor is not significant, α=0,05)

	ANOVA p-value fabric's breaking strength in warp direction		
	100 denier	150 denier	300 denier
Main Effects			
Warp Yarn's Breaking Strength for Four Warp Tension	0.0012**	0.0018**	0.0186*
Weft Density	0.0000***	0.0000***	0.0003***
Interaction			
Warp Yarn's Breaking Strength For Four Warp Tension x Weft Density	0.0006***	0.0137*	0.4527 ns

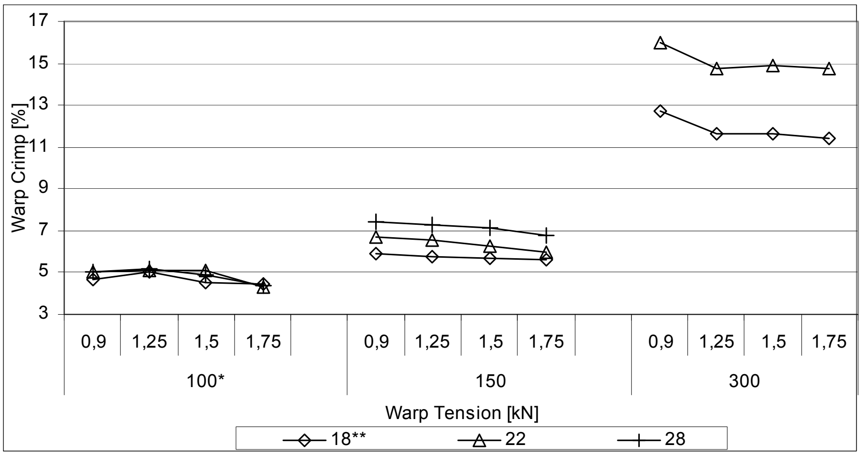

Figure 3. The effect of warp tension on warp crimp (*weft yarn count, **weft density)

As shown in Figure 2, the breaking strength of warp yarn decreases significantly during weaving process with respect to increase in warp tension as the weft density increases and weft yarn gets thicker in fabrics woven with 100 denier weft yarn at 28 weft density and with 150 and 300 denier weft yarns at all weft densities. Despite this, the fabric's breaking strength in warp direction increases slightly with respect to warp tension (Figure 1). This can be explained by warp crimp-warp tension relation. Warp crimp-warp tension relation with four different warp tension values for 100, 150 and 300 denier weft yarns are presented in Figure 3 respectively. Figure 3 shows that in general warp crimp decreases with an increase in warp tension. When warp tension changes from 0.9 kN to 1.75 kN, 4.3 % and 5.1 % warp crimp decrease is observed in the fabric woven with 100 denier weft yarn, 18 weft density and 150 denier weft yarn, 18 weft density, respectively. When warp tension changes from 0.9 kN to 1.75 kN, 11.6 % and 14.4 % warp crimp decrease is observed in the fabric woven with 100 denier weft yarn, 22 weft density and 150 denier weft yarn, 22 weft density, respectively. These results show that warp crimp reduction becomes more pronounced with increasing warp tension as weft yarn gets thicker and/or weft density increases. Greenwood (2) considered that as the crimp increases, the yarn lies more obliquely in relation to the plane of the fabric; thus a greater force is required in the yarn to balance a load applied in that plane. In this paper, warp crimp decrease with warp tension increase becomes higher with 150 and 300 denier weft yarns. Although warp yarn's breaking strength decreases as warp tension increases with 150 and 300 denier weft yarns, the warp crimp decrease with warp tension increase becomes higher with 150 and 300 denier weft yarns. Therefore, fabric's breaking strength in warp direction increases due to more decreasing warp crimp in these fabrics. This can be the reason why the strength in warp direction does not show a decreasing trend in the fabrics woven with 100 denier weft yarns at 28 weft density because the warp crimp in this fabric is higher than the warp crimp in the fabrics woven with 100 denier weft yarn at 18 and 22 densities.

3.2. The effect of warp tension on fabric's breaking strength in weft direction

The effect of warp tension on fabric's breaking strength in weft direction is presented in Figure 4. In Figure 4, there is no significant effect of warp tension on the fabric's breaking strength in weft direction. As the weft yarn count and weft density increase, the fabric's breaking strength in weft direction increases as expected. This is due to the increase in number of weft yarn and increase in the strength of thicker weft yarn.

Analysis of variance p-values for fabric's breaking strength in warp and weft direction is presented in Table 3. According to the statistical analysis, weft count and weft density have a significant effect on fabric's breaking strength in warp and weft directions, while the effect of the warp tension on fabric's breaking strength in warp and weft directions is insignificant.

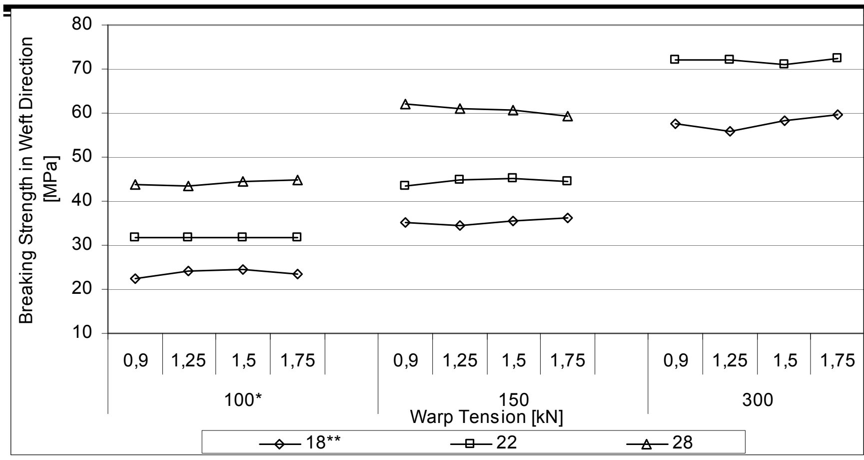

Figure 4. The effect of warp tensions on fabric's breaking strength in weft direction (*weft yarn count, **weft density)

Table 3. Analysis of variance p-values for fabric's breaking strength in warp and weft direction (* and *** denotes the significance of the effect of the parameters on fabric's breaking strength in warp and weft direction; ns indicates that the factor is not significant, α=0,05)

	ANOVA p-value	
	Fabric's breaking strength in warp direction	Fabric's breaking strength in weft direction
Main Effects		
Warp Tension	0.6092 ns	0.5856 ns
Weft Count	0.0000 ***	0.0000 ***
Weft Density	0.0000 ***	0.0000 ***
Interaction		
Warp Tension x Weft Count	0.1033 ns	0.3806 ns
Warp Tension x Weft Density	0.9164 ns	0.3409 ns
Weft Count x Weft Density	0.0150 *	0.0000 ***
Warp Tension x Weft Count xWeft Density	0.8259 ns	0.6471 ns

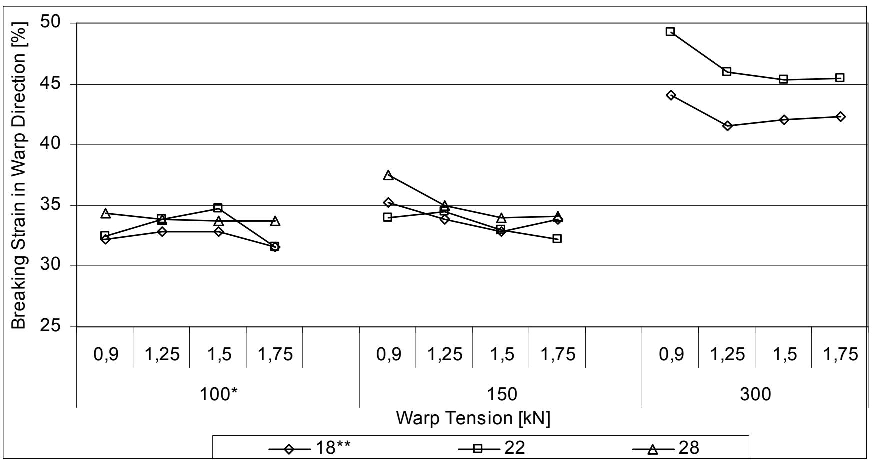

Figure 5. The effect of warp tension on fabric strain in warp direction (*weft yarn count, **weft density)

3.3. The effect of warp tension on fabric's breaking strain in warp direction

The effect of warp tension on fabric's breaking strain in warp direction is presented in Figure 5. It can be seen that fabric's breaking strain in warp direction becomes higher with thicker weft yarns. This is because these fabrics have higher warp crimp values. Figure 5 also shows that fabric's breaking strain in warp direction decreases as warp tension increases in some fabrics (in the fabrics woven with 100 denier weft yarn and 28 weft density, with 150 denier weft yarn and 22, 28 weft densities, with 300 denier weft yarn and 18, 22 weft densities). A close examination shows that all these fabrics have higher warp crimp values. The increase in warp tension causes a decrease in the breaking strain in warp direction in the fabrics where warp crimp is higher. This is because an increase in warp tension decreases warp crimp. There is an increase in warp crimp reduction with increasing warp tension as weft yarn gets thicker and weft density increases. As a result of this, the decrease in warp crimp causes a decrease in the breaking strain of the fabric in warp direction.

3.4. The effect of warp tension on fabric's breaking strain in weft direction

The effect of warp tension on fabric's breaking strain in weft direction is presented in Figure 6. Figure 6 shows that fabric's breaking strain in weft direction increases with increasing warp tension values for 100 denier weft yarn. But, as warp tension increases fabric's breaking strain in weft direction slightly decreases or remained almost constant for 150 and 300 denier weft yarns. This is expressed well enough by the relation between warp tension and weft crimp which is presented in Figure 7. Figure 7 shows that in general weft crimp increases with an increase in warp tension.When warp tension changes from 0,9 kN to 1.75 kN, 9.2 % and 3.1 % weft crimp increase is observed in the fabric woven with 100 denier weft yarn, 18 weft density and 300 denier weft yarn, 18 weft density,

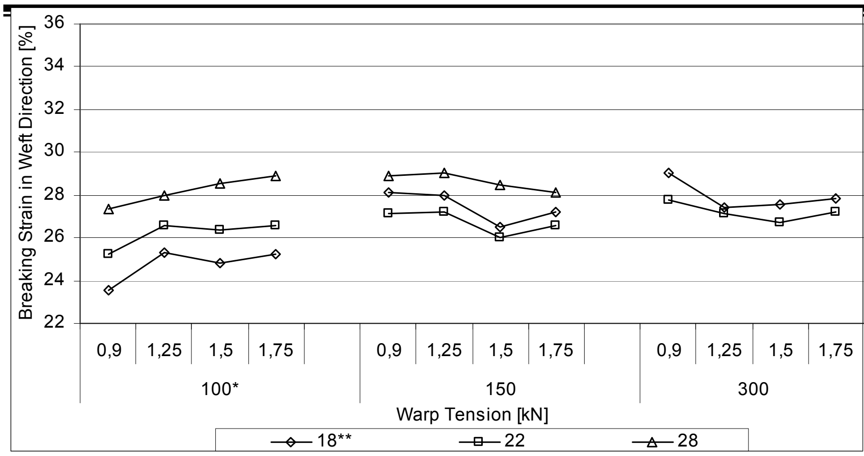

Figure 6. The effect of warp tension on fabric strain in weft direction (*weft yarn count, **weft density)

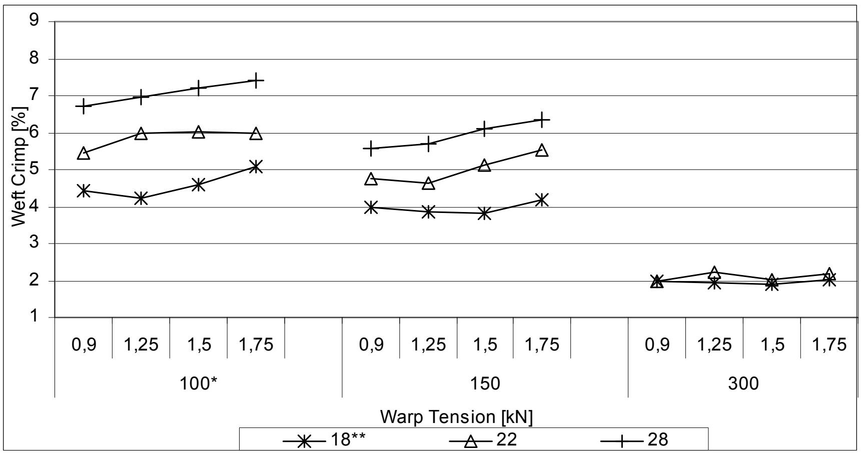

Figure 7. The effect of warp tension on weft crimp (*weft yarn count, **weft density)

Table 4. Analysis of variance p-values for fabric strain in warp and weft direction (*, ** and *** denotes the significance of the effect of the parameters on fabric strain in warp and weft direction; ns indicates that the factor is not significant, α=0,05)

	ANOVA p-value	
	Fabric strain in warp direction	Fabric strain in weft direction
Main Effects		
Warp Tension	0.0004 ***	0.2469 ns
Weft Count	0.0000 ***	0.0000 ***
Weft Density	0.0307 *	0.0018 **
Interaction		
Warp Tension x Weft Count	0.0184 *	0.1451 ns
Warp Tension x Weft Density	0.4523 ns	0.6448 ns
Weft Count x Weft Density	0.0000 ***	0.0002 ***
Warp Tension x Weft Count xWeft Density	0.8247 ns	0.9314 ns

respectively. When warp tension changes from 0.9 kN to 1.75 kN, 15.4 % and 11.2 % weft crimp increase is observed in the fabric woven with 100 denier weft yarn, 22 weft density and 300 denier weft yarn, 22 weft density, respectively. These results show that weft crimp increase becomes more pronounced with increasing warp tension as weft yarn gets thinner and/or weft density increases. As the weft crimp increases, the fabric's breaking strain in weft direction increases as expected. Therefore, fabric's breaking strain increase in weft direction with warp tension increase becomes higher as weft yarn crimp increases with weft yarn getting thinner.

Analysis of variance p-values for fabric's breaking strain in warp and weft directions is presented in Table 4. According to statistical analysis, warp tension, weft count and weft density have a significant effect on fabric's breaking strain in warp direction. Weft count and weft density have a significant effect on fabric's breaking strain in weft direction while the effect of the warp tension on fabric's breaking strain in weft direction is insignificant.

4. CONCLUSION

We investigated experimentally the effect of warp tension on breaking strength and strain of plain woven fabrics in this paper. As the warp tension increased the fabric's breaking strength in warp direction decreased with 100 denier weft yarn at lower weft densities. This was probably due to the decreasing warp yarn's breaking strength during weaving process. As the warp tension applied in weaving increases, the decrease in warp yarn's breaking strength also increases. But, the fabric's breaking strength in warp direction increases with 150 denier and 300 denier weft yarns. This was probably due to the warp crimp-warp tension relation. Fabric's breaking strength in warp direction decreases as weft yarn count increases. This was because decrease in warp yarn's breaking strength becomes higher with thicker weft yarns and higher weft density due to more increasing warp tension during beat-up process. Also fabric's breaking strength in warp direction increases as weft density increases as expected.

The effect of warp tension on fabric's breaking strength in weft direction was investigated. There was no significant effect of warp tension on the fabric's breaking strength in weft direction and as the weft yarn count and weft density increased the fabric's breaking strength in weft direction also increased as expected.

The effect of warp tension on fabric's breaking strain in warp direction was investigated. Fabric's breaking strain in warp direction increased as weft yarn count increased. This was because warp crimp increased as weft yarn count increased. As warp tension increased fabric's breaking strain in warp direction decreased in the fabrics with higher warp crimp. This was because an increase in warp tension decreased warp crimp.

The effect of warp tension on fabric's breaking strain in weft direction was investigated. Fabric's breaking strain in weft direction increased with increasing warp tension values for 100 denier weft yarn. But, as warp tension increased fabric strain in weft direction slightly decreased or remained almost constant for 150 and 300 denier weft yarns.

Experimental results show that warp tension has an effect on breaking strength and strain of plain woven fabrics. To obtain a fabric having same tensile properties warp tension control system of a weaving machine should not cause any deviation in warp tension between full and empty beam. When weaving the same fabric on different looms, necessary care should be given that warp tension on looms to be equal.

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