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Influence of Weave and Weft Characteristics on Tensile Properties of Fabrics

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Abstract
The breaking strength and elongation at break of a fabric firstly depend on the breaking strength and elongation at break in the testing direction of the used yarn. In our research not only the influence of the weft characteristics and weave on the breaking strength and elongation of woven fabrics was analysed, but also a particular study was devoted to the influence of threads, which were perpendicular to the testing direction. In the first part of our research, the breaking force and elongation of threads at different clamping lengths and extension rates before and after the weaving process were measured. In the second part ,the breaking force and elongation at break and stress-strain curves of woven fabrics were analysed. In order to examine the influence of the weft, fabrics of plain weave with different characteristics of the weft were prepared. Furthermore, different weaves were designed: one group with single weft threads and another with doubled (twisted) weft threads. The results of measurements of the yarn showed only a minimal influence of measuring conditions, but according to the expectations, the important influence of the weaving process on the tensile properties of yarns was also noted. The results of the measurements of the fabric highlighted that not only the raw material, but also the mechanical properties of the perpendicular thread system influence the tensile properties of fabrics in the direction analysed. In comparison with single threads, the use of doubled threads in the weft caused a general improvement in the breaking force and elongation at break by stretching tests in the warp direction.

Key words: *woven fabrics, breaking strength, breaking elongation, weave, weft characteristics.*

Introduction

The final properties of fabrics depend more or less on many various technical and technological parameters, which should already be adjusted during the design phase of a fabric. Only in this way, will production be efficient and the desired final properties of the fabric attained, related to its type and end-use. However, it is impossible to predict precisely all physical properties of fabrics. Many factors influence, directly or indirectly, the final values of the breaking force and elongation at break of a fabric in the warp and weft directions. It is the yarn used (warp and weft), i.e. its mechanical and physical properties (count, breaking force and breaking elongation, fineness, number of twists, raw material composition, after-treatments etc.), which has the most significant effect [1 - 4]. Slightly lower is the effect of the constructional properties of a fabric, such as the weave, warp and weft thread density. There are also other factors which have an indirect influence on final values, such as the conditions in which weaving takes place: temperature, humidity, yarn tension during the weaving process etc.

The aims of the research presented here were the analysis and evaluation of:
- the influence of different clamping lengths on the tensile properties of yarns,
- the influence of the weaving process on the breaking force of warp and weft threads,
- the influence of different warp and weft characteristics (raw material, count, single and doubled yarns) on the shape of the stress-strain curve and the final values of the breaking force of fabrics in the warp and the weft direction,
- the effect of different weaves on th mechanical properties of fabrics.

Theoretical part

Any object, when exposed to external forces, changes its shape, i.e. it undergoes a certain deformation. With regard to the direction of the applied force, we distinguish deformations at stretch and deformations at compression. The investigation of the influence of the weft and weave was focused the deformations, which occur at stretch. At this point the equations presenting relations between the external force, extension, the area of the cross section surface and elasticity modulus or Young's modulus should be accurately taken into consideration [5 - 7].

Tensile properties of yarns and fabrics

The stress-strain curves of yarn (a) and fabric (b) are presented in Figure 1. Zone I represents the Hook's zone or the zone of elastic deformation of both the yarn and the fabric. If the extension occurs inside the Hook's zone, the material recovers to its initial length after relaxation. Zone II represents the zone of viscoelasticity. Viscoelastic deformation is measured after a certain time of relaxation. Zone III represents the zone of permanent deformations, where material does not recover after relaxation [2, 3, 5 - 7].

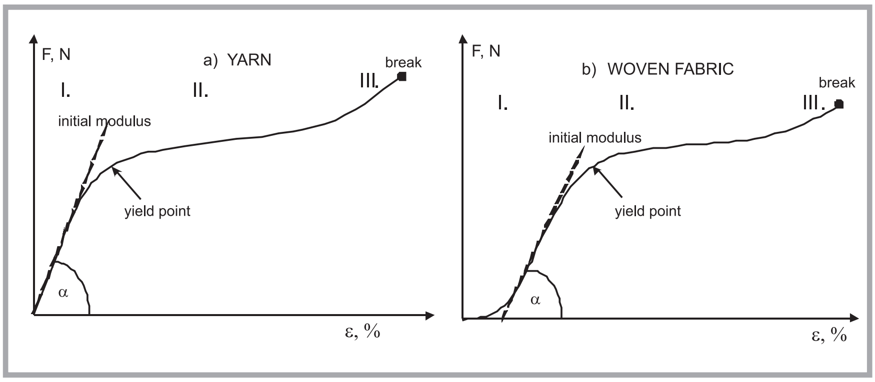


Figure 1. *Stress-strain curves of yarn and fabric.*

A major difference between the shapes of the above curves occurs in the first part of the curve, i.e. in the Hook's zone (I – zone of elastic recovery), where the elongation of the fabric is already increasing under a low force (still before the zone in which Young's modulus is calculated). Here, the crimp is interchanged between the threads of the two systems. Crimp decreases in the direction investigated, but increases in the perpendicular direction. Consequently, the tension of the threads of the system, which is perpendicular to the direction investigated, increases. When a tensile force acts on the threads of one system, the threads of both systems undergo extension. Due to the crimp interchange, the maximum possible elongation of perpendicular threads depends on the fabric geometry. The stationary position of the threads of both systems is important – twisting or deviation of the threads' axes (the height of the arc) from the fabric centre, which depends on the threads count of both systems and tension, i.e. the levelling of tension (relaxation and establishment of the balanced state), to which the threads are exposed during the weaving process.

The breaking force and elongation at break of a fabric are in close relation to the tensile properties of the yarn used. However, the breaking force of such fabric is not equal to the sum of the breaking forces of the threads, because there are several other factors in a fabric which should be taken into account [5, 11, 12].

Experimental part

The tensile properties of yarns with different constructional parameters, and of fabrics woven from these yarns in different weaves were investigated with the use of an Instron 6022 tensile tester, according to Standards SIST EN ISO 13934 - 1:1999 and SIST EN ISO 13934 - 2:1999 [7].

Materials and methods

Table 1 shows basic physical and constructional characteristics, raw materials and the composition of the threads/yarns used as the warp and weft. In all cases, the warp was from 100% cotton 2×8 tex in blue colour. The same yarns were used as weft No. 2 (colored red) and 7 (colored yellow). Weft No. 1 was single yarn from cotton 15 tex and other wefts (No 3, 4, 5, and 6) had a linear density of 20 tex and were made according to the same spinning procedure, but of different blends of raw materials.

In the first part of the experiment, the breaking force and elongation at break of the yarns were tested under the following conditions:

a) the yarns from bobbin under standard testing conditions for yarns (clamping length 500 mm and extension rate 500 mm/min),
b) the yarns taken from fabrics in the warp and weft direction under the same conditions as a) and
c) the yarns from bobbin under standard testing conditions for fabrics (clamping length: 200 mm, and extension rate: 200 mm/min).

The number of measurements of breaking force and elongation of the yarns on the tensile tester was 25. The measurements were statistically analysed (mean value, coefficient of variation) (Table 2). The influence of the weaving process on the

Table 1. *Physical and constructional characteristics of threads/yarns uswd; *CO-cotton, CV1- viscose1, CV2 – viscose 2, PA 66 – polyamide, PET – polyethilenterephtalate.*

Raw material, %	Fines Tt, tex	Raw material, color, %	Single yarn twists, twists/m	Twisted yarn twists, twists/m
Warp	2×8	100 CO (blue)	1000 S	1040 Z
weft 1 (w1)	15	100 CO (white)	950 S	-
weft 2 (w2)	2×8	100 CO (red)	1000 S	1040 Z
weft 3 (w3)	20	87 CO, 10 CV1, 3 CV2 (gray)	660 S	-
weft 4 (w4)	20	85 CO, 15 PA 66 (white)	720 S	-
weft 5 (w5)	20	50 CO, 50 PET (white)	758 S	-
weft 6 (w6)	20	80 CV1, 20 CV2 (gray)	739 S	-
weft 7 (w7)	2×8	100 CO (yellow)	1000 S	1040 Z

Table 2. *Constructional and mechanical properties of warp and weft threads.*

Thread		A								B			
		Yarn taken from bobbin				Yarn taken from fabric				Yarn taken from bobbin			
		F_y, cN	CV_y, %	ε_y, %	CV_y, %	F_y, cN	CV_y, %	ε_y, %	CV_y, %	F_y, cN	CV_y, %	ε_y, %	CV_y, %
Warp	1	297.4	8.2	5.1	6.0	280.8	7.9	5.3	13.9	296.6	9.8	5.1	7.7
Weft	w1	182.1	8.3	5.8	8.4	164.7	13.3	5.6	8.8	179.7	7.8	6.1	10.0
	w2	311.0	5.4	6.1	3.5	284.6	9.8	6.7	7.6	321.6	8.0	6.2	6.6
	w3	300.2	7.7	5.1	9.7	216.8	15.9	5.8	11.9	319.2	6.7	5.2	7.9
	w4	227.8	7.9	4.4	8.8	171.3	10.4	5.0	10.9	228.1	8.2	4.1	13.6
	w5	361.5	8.7	7.6	9.8	334.6	8.4	9.3	7.7	362.6	8.6	8.4	9.3
	w6	321.0	8.1	10.7	12.2	312.9	8.4	12.0	11.0	329.9	8.2	11.2	8.6
	w7	285.2	6.8	5.7	5.4	310.0	10.3	6.6	7.5	302.4	8.4	6.1	6.9

Table 3. *Physical and constructional characteristics of fabrics investigated; * fabrics 1 and 7 are the same, ** fabrics 2 and 12 are the same, w-number of weft (Table 1).*

Fabric	Group	Weft threads, tex	Warp density, ends/cm	Weft density, picks/cm	Weave	Thickness, mm
1	I*	15 (w1)	21.1	21.4	plain	0.255
2	I**	2×8 (w2)	21.1	21.4	plain	0.281
3	I	20 (w3)	21.1	22.4	plain	0.271
4	I	20 (w4)	21.0	21.6	plain	0.289
5	I	20 (w5)	21.2	21.5	plain	0.263
6	I	20 (w6)	21.1	22.2	plain	0.271
7	II*	15 (w1)	21.1	21.4	plain	0.255
8	II	15 (w1)	21.1	21.6	twill 1/2	0.322
9	II	15 (w1)	21.1	21.6	twill 1/3	0.359
10	II	15 (w1)	21.0	21.5	twill 2/2	0.331
11	II	15 (w1)	21.0	21.2	basket 2/2	0.327
12	III**	2×8 (w2)	21.1	21.4	plain	0.281
13	III	2×8 (w7)	21.1	21.6	twill 1/2	0.346
14	III	2×8 (w2)	21.1	21.7	twill 1/3	0.380
15	III	2×8 (w2)	21.1	21.7	twill 2/2	0.386
16	III	2×8 (w2)	21.0	21.3	basket 2/2	0.355

breaking force and elongation at break of the yarns was evaluated by comparing the results of a) and b), whereas the effects testing conditions had on the force/elongation were analysed by comparing the results of a) and c) [2, 3].

In the second part of the investigation, three groups of fabrics (the total of 14 fabrics) with doubled warp thread (fineness $T_t = 2×8$ tex), warp thread density: 20 ends/cm, and weft thread density: 21 picks/cm were designed on a loom. The group index, actual densities, weaves and thickness are shown in Table 3. The group indexes indicate: I - the fabrics of plain weave with different raw materials in the weft system, II - the fabrics of selected weaves with single yarn in the weft system and III - the fabrics of selected weaves with doubled yarn in the weft system.

The stress-strain curves of the fabrics of plain weave with different raw materials (group I) were constructed on the basis of 15 measurements with a constant increase in elongation (a step of 0.125%). The mean value and coefficient of variation of the breaking force was calculated for every step of elongation. This statistical method enabled graphical presentation of all curves of the fabrics with different raw materials in one figure (Figures 3 and 4 see page 48).

The construction of stress-strain curves of the woven fabrics of different weaves with single and doubled yarn (groups II and III) was carried out in the same way as in the case of group I. The stress-strain curves were constructed on the basis of 5 measurements for each group of different woven structures, and contemporary graphical presentation as well as comparison was possible for the different weaves of woven fabrics (Figures 5 and 6).

Besides the measurements of breaking forces, elongation at break and construction of stress-strain curves in the warp and weft directions under standard conditions, the following additional studies were carried out:

a) from the first group of samples (I) - how different the composition of the weft influences the breaking force and elongati at break on of fabrics in the warp direction, and
b) from the comparison of groups two (II) and three (III) - how single or doubled yarn in the weft affects the breaking force and breaking elongation in the warp direction.

Results

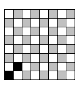
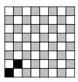
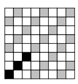
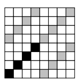
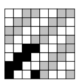
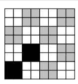
The results of the measurements of mechanical characteristics of yarns: F_y in cN- the mean value of the breaking force, ε_y in per cent – the mean value of the elongation at break and CV_y in per cent – the coefficient of variation, by: A – a clamping length of 500 mm and a speed of stretching of 500 mm/min and B – a clamping length of 200 mm and a speed of stretching of 200 mm/min are presented in Table 3.

The results of the measurements of mechanical characteristics of all the fabrics: F_f, N- the mean value of breaking force, ε_f, % – the mean value of breaking elongation and CV_f, % – the coefficient of variation are presented in Table 4.

The results of statistical analysis of stress-strain curves of plain fabrics with different raw materials (group I) and woven fabrics of different weaves with single and doubled yarn (groups II and III) can be presented with the values of variation coefficients CV, %. As explained in the experimental part, the stress-strain curves (Figures 3, 4, 5 and 6) were constructed on the basis of the mean values of stress measured at constant steps of elongation. Figures 3, 4, 5 and 6 are presented in the next chapter and a statistical explanation of these figures will be presented here. When the stress was applied in the warp direction of group I fabrics (plain fabrics with different raw materials), the mean value of variation coefficient was 17.39%, the minimum value 1.95% (weft 3) and maximum value CV = 44.60% (weft 2). When the stress was applied in the weft direction of group I, the variation coefficient was between 1.76% (weft 1) and 34.14% (weft 3), with the mean value CV = 8.87%.

In the case of groups II and III (woven fabrics of different weaves with single and doubled yarn) the mean value of variation coefficient in the warp direction was 13.52% for the fabrics with single yarn in the weft and 13.99% for the fabrics with doubled yarns (Figure 5). The minimum and maximum values were between 1.53% (basket weave, single yarn) and 40.28% (plain weave, doubled yarn). When stress was applied in the weft direction, the CV values were between 1.20% (twill 2/2, doubled yarn) and 37.05% (twill 1/2, single yarn) with the mean values CV=14.88% for the fabrics with single yarn in the weft and CV=8.48% for the fabrics with doubled yarn in the weft (Figure 6).

Table 4. *Constructional and mechanical properties of fabrics with different wefts from tensile test in warp and weft directions.*

	Weave		Type of weft	Warp direction				Weft direction			
				F_f, N	CV_f, %	ε_f, %	CV_f, %	F_f, N	CV_f, %	ε_f, %	CV_f, %
Analysis of F_f in ε_f of plain weave with different wefts	plain		w1	220.0	3.2	9.5	4.5	168.1	3.6	10.2	3.4
			w2	238.3	4.9	10.0	8.4	215.5	1.3	11.6	3.5
			w3	224.4	3.1	9.9	4.5	231.7	2.4	10.1	5.1
			w4	193.7	3.9	10.5	4.8	188.4	0.8	10.2	3.4
			w5	201.8	3.5	11.0	2.4	295.1	4.1	15.6	4.2
			w6	230.6	5.3	9.3	3.6	287.8	4.3	17.8	2.6
Analysis of F_f in ε_f of different weaves with single-1 and twisted-2,7 yarn	plain		w1	220.0	3.2	9.5	4.5	168.1	3.6	10.2	3.4
			w2	238.3	4.9	10.0	8.4	215.5	1.3	11.6	3.5
	twill 1/2 3-end twill		w1	226.8	2.2	9.1	2.3	170.3	6.5	10.9	3.5
			w7	232.3	3.1	9.6	1.1	259.8	2.6	10.8	3.0
	twill 1/3 4-end twill		w1	203.3	3.6	8.0	6.3	158.4	4.9	10.9	4.7
			w2	200.9	1.4	8.1	3.1	233.3	4.9	11.3	3.9
	twill 2/2 twill 2/2		w1	204.4	3.1	8.0	2.6	163.2	2.5	10.0	3.9
			w2	202.3	8.6	8.1	7.1	235.8	2.3	10.9	0.9
	basket 2/2 4-end basket		w1	160.1	1.7	6.3	4.8	156.9	5.1	9.3	4.6
			w2	172.7	9.3	6.4	3.5	210.0	2.2	10.3	1.6

Discussion

Influence of clamping length and weaving process on the breaking Strength and elongation at break of yarns

The results presented in Table 3 are graphically illustrated in Figure 2. In this figure, single measurements of the breaking force of different threads (warp, weft 1-7) can be graphically compared with the mean value of all breaking force values of the warp and weft threads taken from bobbin and fabrics at different measuring conditions. The three groups of measurements in Figure 2 are: $F_{y\ 500b}$ - a breaking force of 500 mm specimen length and 500 mm/min extension rate from bobbin, $F_{y\ 500f}$ - a breaking force of 500 mm specimen length and 500 mm/min extension rate from fabric, $F_{y\ 200b}$ - a breaking force of 200 mm specimen length and 200 mm/min extension rate from bobbin. The mean breaking force of yarns from bobbin tested under clamping length: 500 mm and extension rate: 500 mm/min was $F_{y\ 500b\text{-}av}$ = 285.8 cN, from fabric after weaving under the same condition $F_{y\ 500f\ \text{-}av}$ = 259.5 cN, and from bobbin under a clamping length of 200 mm and an extension rate of 200 mm/min $F_{y\ 200b\text{-}av}$ =292.5 cN.

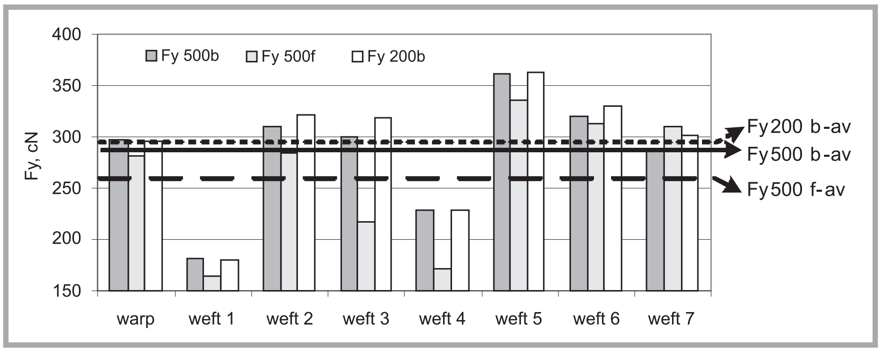


Figure 2. Influence of specimen length and extension rate on the breaking force of yarns used, taken from bobbin and from fabric.

Comparison of the breaking force and elongation at break of the yarns taken from bobbins and those taken from fabrics, which are presented in Table 3, shows, as expected, that the weaving process has a negative effect on the breaking force of warp and weft threads . After weaving, the breaking force of the warp threads decreased by 5.6% and that of the weft threads by 2.5 - 27.8%. The mean decrease in the breaking force was 9.2% ($F_{y\ 500b\text{-}av}$: $F_{y\ 500f\text{-}av}$ = 285.8 cN : 259.5 cN). The elongation at break of the run-in threads increased after weaving by 11% in general – of the warp threads by 3.9% and of the weft threads by 3.4% - 22.4%.

Furthermore, the comparison after changing the clamping length (clamping lengths of 500 mm and 200 mm) shows that the clamping length has only a slight influence on final values. At a shorter clamping length, the breaking force and elongation at break exhibited a minimal general increment, which implies the dependence of the results on the quality, i.e. the uniformity of individual yarns. Namely, when measurements were carried out at shorter clamping lengths, the influences of weak points in the yarn were smaller. The mean force increment at a shorter clamping length was 2.1% and the mean elongation increment was 2.7% for all samples.

Comparison of the breaking force and elongation at break of samples of plain weave with different wefts

Table 4 presents the results of breaking force and elongation at break measurements of the fabrics of plain weave with weft threads made from different raw materials and with different constructional properties. The investigation was focused on the influence of the properties of the thread system, which is perpendicular to the direction of stretching, on the tensile properties of the fabric in the direction of the applied force. The breaking force and elongation at break were monitored in the warp direction of the fabrics of plain weave with different wefts (Figure 3). If the different wefts did not have any influence, the breaking force of the fabrics in the warp direction would be totally or almost equal. In our case, the similarity in the stress-strain curves was evident in the fabrics with wefts 1, 2, 3 and 6, which had similar raw materials: cotton fibres, cotton/viscose blends or viscose blends. The mean breaking force of these fabrics was 228.3 N ± 3.48%.

From Table 4 and Figure 3, it is evident that deviation occurs mainly with the fabrics with wefts 4 and 5, which are composed of cotton and man-made (PA66 and PET) fibres. Their breaking forces are 193.7 N (weft 4 – 85% CO, 15% PA 66) and 201.8 N (weft 5 – 50% CO, 50% PET), which is 13.4% or approximately 30 N lower than the mean breaking force of the other four fabrics. It is also evident in Figure 3 that the fabrics with wefts 4 and 5 have the gentlest initial part of the

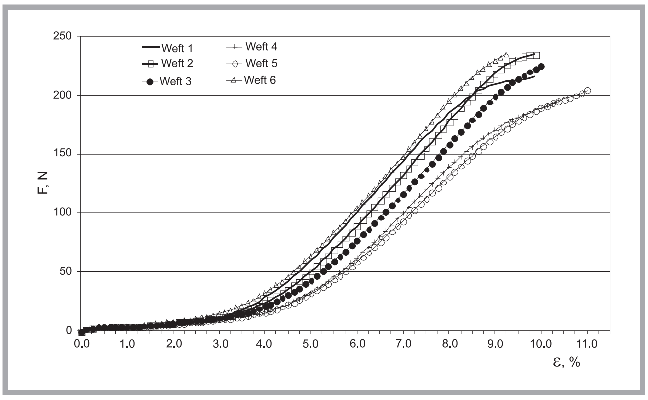


Figure 3. Diagram of stretching curves of fabrics of plain weave with different wefts in warp direction.

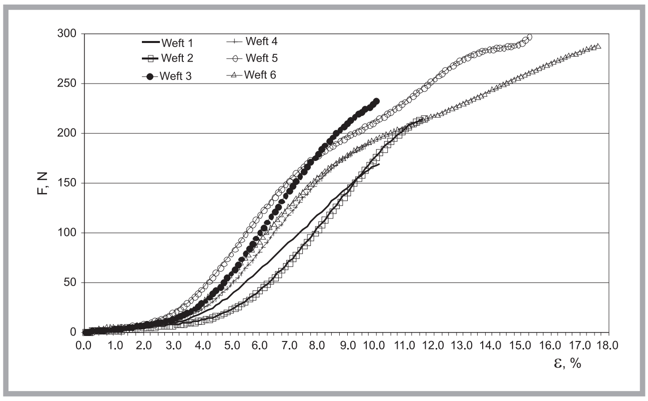


Figure 4. Diagram of stretching curves of fabrics in plain weave with different wefts in weft direction.

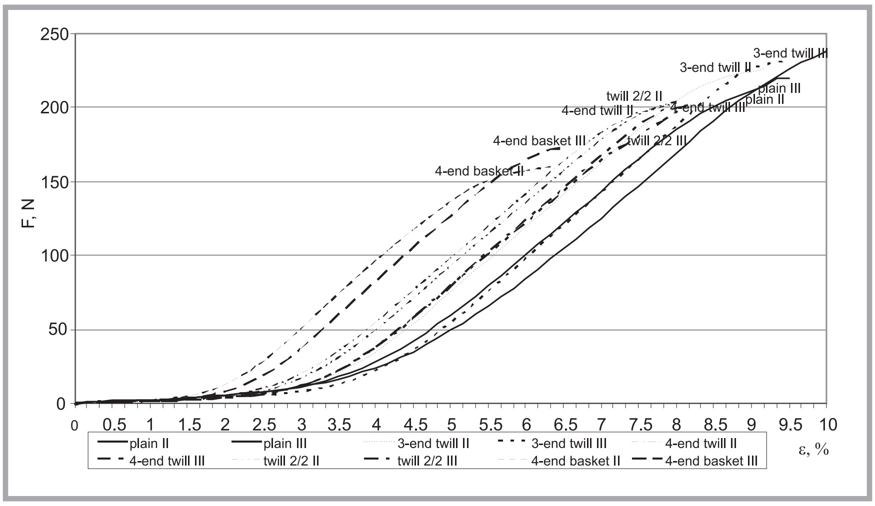


Figure 5. Diagram of stretching curves of fabrics with single spun yarn - II (thin line) and doubled yarn - III (thick line) in warp direction – different weaves.

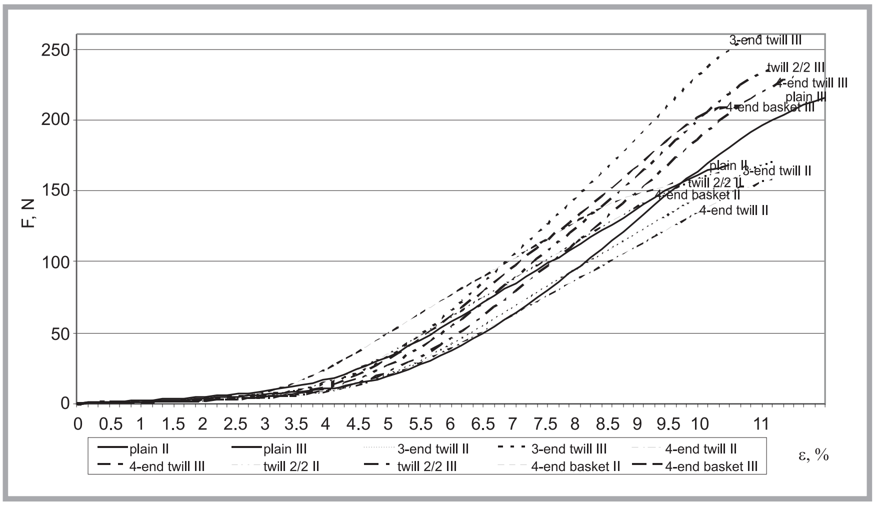


Figure 6. Diagram of stretching curves of fabrics with single spun yarn – II (thin line) and doubled yarn - III (thick line) in weft direction – different weaves.

stress-strain curve and, consequently, the highest values of elongation at a certain stress. It is probably due to the content of man-made fibres in the weft threads, which made their behaviour different and intensified their influence on the yarns of the other thread system when the stress was applied in the warp direction.

Figure 4 presents actual discrepancies between the mechanical properties of the fabrics with different weft threads from 1 to 6 at stretching in the weft direction. In this case, the results were more predictable and the discrepancies between the stress-strain curves and the final values of the breaking force were the consequence of the different properties of the weft threads.

Comparison of the influence of yarn constructional parameters on the tensile properties of fabrics of different weaves

The most interesting part of our research was the comparison of the effects of yarn constructional parameters on the tensile properties of fabrics of different weaves. Figures 5 and 6 present the curves of stretching of the fabrics of five different weaves, whose weft was made from single spun yarn - II (Table 2, fabric 7-11, weft 1) and doubled yarn – III (Table 2, fabric 12-16, weft 2.7). It should be emphasised that the yarns had similar fineness (single yarn: 15 tex and doubled yarn: 16 tex) and raw material composition (100% cotton). Nevertheless, it is evident from Table 1 that yarns of wefts 1 and 2 differ in some other physical and mechanical characteristics (spinning, twists).

Prior to commenting on the results, two irregularities which we think do not affect the general discussion about the results and final conclusions should be mentioned. First, the results of the breaking force and elongation in the warp direction for basket weave will not be considered as regular (they are definitely too low) because of the fabrics slipping from the clamps during measuring. It did not happen with other samples in the same measuring conditions. The second irregularity is presented in Table 4, where it can be seen that 3-end twill samples from doubled yarns do not have the same

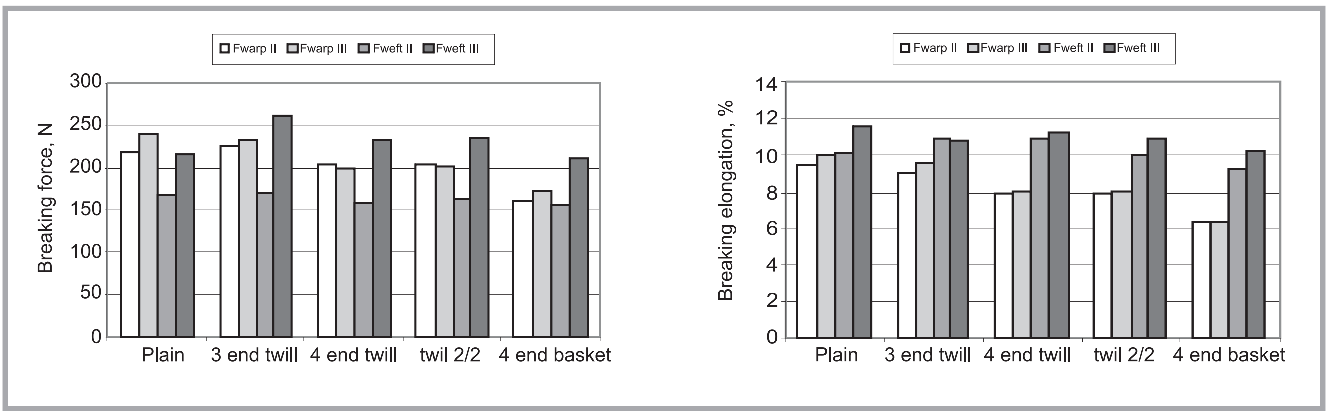


Figure 7. Comparison of breaking force F_f (a) and elongation at break ε_f (b) of fabrics in different weaves with weft from single spun yarn (II) and doubled yarn (III) in warp and weft direction.

weft - yellow as other weaves – red (the influence of different dyeing on the doubled yarn, with the same construction, Table 1). These irregularities did not allow total comparability of the results of groups II and III, but did not ruin the overall conclusions and, moreover, they might initiate some new interesting considerations.

Comparison of the curves of both groups II and III reveals certain differences in the mechanical properties of the fabrics during the tensile test carried out in the warp and weft directions. A quick analysis of Figure 5 could bring us to the conclusion that there is almost no discrepancy in the stress-strain curves of the fabrics of both groups when stress is applied in the warp direction. The fact is that the shapes of the stress-strain curves of groups II and III are really similar, but a precise comparison highlights that in general the warp threads of fabrics II start to take over the applied tension with lower elongation.

Figure 6 shows, according to expectations, a significant difference between the shapes of curves when the stress is applied in the weft direction. Here, a significantly lower increase in the force at a certain elongation can be seen for fabrics containing single spun yarn than for fabrics containing doubled yarn. Therefore, the elasticity modulus of the structures containing doubled yarn is significantly higher because the fabrics containing doubled yarn resist stretching with a much higher force than the fabrics containing single spun yarn.

Furthermore, in Figure 7, comparison of the mean values of breaking force - F (Figure 7.a) and elongation - ε (Figure 7.b) in the warp and weft direction is presented for fabrics with single II and doubled III yarns in the weft. It can be assumed that the characteristics of the threads, which are perpendicular, have a significant influence on the thread system analysed. Thus, with the same weave, a higher breaking strength and elongation in the warp direction (first and second column of each weave in Figure 7.a and 7.b) was, in general, obtained when doubled yarn was used in the weft.

In the case of single spun yarn in the weft (group II), the values of the breaking force in the warp direction ranged from 203.3 N for four-end twill (the results of basket weave were not considered as regular ones) to 226.8 N for three-end twill weave, with a mean value of 213.6 N ± 5.4%. The mean breaking force of the group of samples with doubled yarns in the weft (group III) was approximately 5 N higher with a mean value of 218.45 N ± 8.9%. In this group, four-end twill had the lowest strength, i.e. F_f = 200.9 N, and plain weave the highest, i.e. F_f = 238.3 N. From the results of both groups, we can conclude that, as regards the investigated samples, the weave does not have any significant influence on the final values of the breaking force of fabrics in the warp direction, which is as we expected. The reason probably lies in the very open construction of the fabrics investigated, with practically the same number of yarns in the samples tested (equal thread density). Different weaves actually allow the production of fabrics of different densities, which afterwards contribute more to the different tensile properties of the fabrics.

Different ranges of the elongation at break were stated for the various wefts; namely, plain weave had the highest elongation at break (9.5% with single weft and 10.0% with doubled weft) and twill 4 and twill 2/2 had the lowest elongation at break (8.0% with single weft and 8.1% with doubled weft in both cases) in the warp direction. The sequence of the values of elongations at break follows the frequency of threads interlacing in different weaves, which is the highest with plain weave and the lowest with 4-end twill weave.

When the tensile test was carried out in the weft direction, discrepancies between the two groups were, as expected, more pronounced. Table 4 shows that the mean values of breaking forces in the weft direction of the fabrics with untwisted yarn range from 156.9 N in four-end basket weave to 170.3 N in three-end twill weave, with a mean value of 163.4N ± 3.6%. The values are almost 30% lower than those of fabric with doubled yarn, which ranged from F_f = 210.0 N for four-end basket weave to F_f = 259.8 N for three-end twill, with a mean value of 230.88 N ± 8.5%.

Comparison of the breaking forces and elongation of the samples with doubled yarns in both the warp and weft directions (group III) shows interesting details since the warp and weft threads, which the fabrics were made from (warp, weft 2 and 7 from Table 1), had the same construction before dyeing (fineness, twists). The warp was dyed blue and all weaves, except 3-end twill (yellow weft), had the weft, which was dyed red . The average values for all weaves in the warp direction is 209.3 N and in the weft direction 230.88 N, which is approximately 20 N difference in favour of the results in the weft direction. The same difference remains even if we remove the results of 3-end twill, which was made from weft 7. In this case, the mean values would be 203.55 N in the warp direction against 223.65 N in the weft direction. There are two possible causes, which can explain the differences mentioned above.

a) The higher breaking force of weft 2, which was dyed red rather than blue (a 4.6% higher force of the specimens from bobbin with a 500 mm clamping length, a 7.7% higher force of the specimens from bobbin with a 200 mm clamping length and only 1.4% difference in the fabric samples). The last one was not considered very relevant since the samples for measuring the breaking force of the yarn taken from fabric were only from the samples with plain weave.
b) The Higher average value of the weft density of about 0.5 yarn/cm (Table 2), which is about 2.5% more than the average warp density.

At the same time, comparison of elongations at break shows that the breaking elongation in the weft direction is on average about 2.5% higher, which is probably as a consequence of different tensions of the warp and weft yarns in weaving, and consequently higher shrinkage of the weft yarns.

The interaction between doubled yarn in the warp and single yarn in the weft firstly, and doubled yarn in both directions secondarily can be be defined by the coefficients expresed as the ratios of breaking forces for the different yarns (threads) and fabrics in the direction measured. The ratio could not be calculated for the results in the warp direction because the same warp threads were used in all the fabrics. In the weft direction, the coefficient of the mean breaking forces of single- (F_{y1}) and doubled (F_{y2}) yarns F_{y1}/F_{y2} was 0.58 and the coefficient of the mean breaking forces of fabrics in the weft direction was F_{II}/F_{III} = 0.71. The comparison of both coefficients allows to conclude that warp yarns affect the wefts from single threads less than those from doubled wefts. This is perfectly in accordance with the results, which were obtained in the warp direction.

Conclusions and further research propositions

On the basis of the measurements, it can be confirmed that the tensile properties of fabrics are a highly complex matter, and they do not only depend on the tensile properties of yarn in the direction investigated. There is no doubt that the tensile properties of yarn in the direction investigated are the starting point, but there are also several other factors which have a positive or negative effect.

The summary of the experimental work presented concludes the following.

- A different clamping length does not significantly affect the tensile properties of yarns measured. The mean force increment at a shorter clamping length for all yarns tested was 2.1% and the mean elongation increment 2.7%.
- The experiment presented here confirms the expected results that the weaving process has a significant role in reducing the breaking force of the warp (5.6%) and the weft (2.5 - 22.8%).
- When the yarns used in the warp and weft were of similar characteristics (count, raw materials), the weft had a smaller effect on the shape of the stress-strain curve and on the final values of the breaking force of fabrics in the warp direction. A more significant effect was detected when weft yarns were composed of cotton and man-made fibres (PET and PA). In this case, the warp and weft differed in the raw material composition – various blends of fibres with different rigidity, which caused a decrease in the breaking force in the warp direction by more than 13%.
- The breaking force and elongation in the warp direction were higher when doubled yarns were used as the wefts instead of single threads. The difference in the breaking force was about 5 N.
- Since the samples of different weaves had practically the same thread density, whose structures were open, the effect of the weave on the mechanical properties of the fabrics was not as exposed as it would be in a tight structure, and consequently this effect could not be objectively estimated.
- The research results indicate that there are certain possibilities of continuing the experimental work. One of them is to repeat the investigation on more tight and compact woven structures, where the effect of weaves would certainly be more pronounced. The investigation should be firstly oriented towards the determination of the mechanical properties of woven structures on the basis of known properties of yarns used in the warp and weft. The fact is that it is not only the construction of threads in the direction investigated, which affects the tensile properties of a product, but also the construction of the threads perpendicular to the direction under investigation and their interaction. It would be interesting to precisely analyse the construction of these threads, their count, density and last but not least their floating. The results of such analysis should be incorporated into the design phase of the mechanical properties of any woven product.

References

1. Lord, P. R., Radhakrishnaiah, P.: A comparison of Various Woven Fabrics Containing Friction, Rotor and Ring Spun Cotton Yarn Fillings. Textile Research Journal, Vol. 58, No. 6, pp. 354-362, 1988.
2. Realff, M. L, Seo, M., Boyce, M. C, Schwartz, P., Backer, S.: Mechanical Properties of Fabrics Woven from Yarns Produced by Different Spinning Technologies: Yarn Failure as a Function of Gauge Length. Textile Research Journal, Vol. 61, No. 9, 1991, pp. 517- 530.
3. Seo, M. H, Realff, M. L, Pan, N., Boyce, M., Schwartz, P., Backer, S.: Mechanical Properties of Fabrics Woven from Yarns produced by Different Spinning Technologies: Yarn Failure in Woven Fabric. Textile Research Journal, Vol. 63, No. 3, 1993, pp.123- 134.
4. Frydrych, I., Dziworska, G., Matusiak, M.: Influence of yarn properties on the strength properties of plain fabrics. Fibres and Textiles in Eastern Europe, Vol. 8, No. 2, 2000, pp. 42-45.
5. Černoša, E.: Vpliv vezave in značilnosti votka na pretržne lastnosti tkanin. Diplomsko delo. Ljubljana, 2005, p. 45.
6. Koškin, N. I., Širkevič, M. G.: Priročnik elementarne fizike. Ljubljana: Tehniška založba Slovenije, 1986.
7. Saville, B. P.: Physical testing of textiles. Woodhead Publishing Limited and CRC Press, Cambridge, 2002, p. 310.
8. Gabrijelčič, H., Dimitrovski, K.: Influence of constructional parameters on mechanical properties of woven fabrics. V: Katalinić, B. (Ed.), DAAAM International scientific book 2004, (DAAAM International scientific book). Vienna: DAAAM International, 2004, ch. 20, pp. 189-202.
9. Kisilak, D.: Vpliv cikličnih obremenitev na deformacijo tkanin : doktorska disertacija. Ljubljana: Univerza v Ljubljani, Naravoslovnotehniška fakulteta, Oddelek za tekstilstvo, 1995.
10. Jakšić, D.: Projektiranje in konstrukcija tekstilij. Del 1. Ljubljana: VTOZD Tekstilna tehnologija, 1988, p. 307.
11. Hajdarović, K., Kovačević, S.: Vpliv vezave tkanine in napetosti osnove v procesu tkanja na pretržno silo in pretržni raztezek tkanin. Tekstilec, Vol. 46, No. 3-4, 2003, pp. 73-81.
12. Čakš, M.: Primerjava mehanskofizikalnih in uster lastnosti klasične in kompaktne prstanske preje spredene na prstanskem predilniku firme Reiter: diplomsko delo. Ljubljana, 2004, p. 36.

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