Study of cotton woven fabrics with added polybutylene terephthalate yarns

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The aim of this work is the development of new products, i.e. cotton like woven fabrics with increased extensibility, using textured multifilament polybutylene terephthalate (PBT) yarn in the weft direction and a proper finishing procedure. For the research purpose, a set of referential samples of woven fabrics containing PBT was made. The fabrics differed in the sequences of cotton and PBT yarns in the weft direction. In some samples a doubled PBT yarn is inserted in as one weft, simulating double linear density. The influence of the textured PBT yarn quantity on the elastic properties of cotton/PBT woven fabrics, developed after the treatment in boiling water for 30 minutes, was studied. The contraction in warp and weft directions that affect warp and weft density, thickness, mass per unit area and tensile properties were measured using standardised methods. The quantity of PBT mainly influenced the elasticity in weft direction. The highest elasticity correlated well with the highest quantity of PBT. Furthermore, a minimum portion of PBT effectively improved the tensile properties of treated fabrics in both directions, this being important in such cases, as the fabrics mostly keep their cotton character. The use of PBT and proper finishing procedure for developing the required increased elastic properties of woven fabrics for any purposes could be of significant advantage concerning the price (compared to Lycra®) and production time (preparation for weaving and speed of weaving).
Key words: *woven fabrics, PBT in the weft, finishing-boiling, tensile properties*

1. Introduction

The trend is producing fabrics with increased elasticity, which is comfortable and easy to maintain with a nice handle. There are several problems, how to produce that kind of fabrics with low costs. The so-called stretch fabrics are usually made from different materials. At least one of them must have highly elastic properties. The most frequently used is Lycra®, which can be expensive and cause problems in the maintenance since to retain the elasticity, it cannot be washed at temperatures higher than 40 °C. Lately, there have been new, more reasonably priced materials with elastic properties. One of such materials is polybutylene terephthalate (PBT). The price of PBT is higher than the most frequently used polyester polyethylene terephthalate (PET), but cheaper than elastane and cotton yarns. We expect that their use in an optimal portion can improve the tensile properties (increase the extensibility) of cotton fabrics and consequently, make fabrics less expensive and less complex for the production at the same time.

Study has been conducted on the mechanisms of PBT yarn incorporated in the structure of cotton fabric. The interaction between yarn properties and weave geometry had a strong influence on physical and mechanical characteristics before and after the thermal treatment.

2. Theoretical part

It is known that elastic fibres can greatly improve characteristics of woven fabric made from natural cotton fibres. Used is multi filament textured PBT yarn Elite® produced by Nylstar and can be used for product: ready-to-wear, knitwear, jeans, casualwear, sportswear, as well as in specialized and medical fields [1]. PBT textured yarn has latent elastic properties that become obvious after the thermal treatment, e.g. dying, PBT is dyed at temperature 100 °C [2].

The construction of the fabric, as well as finishing procedures applied, should be pre-programmed, when adding Lycra® [3]. Elastane yarn can be replaced with chemically and thermally more stable highly elastic fibres with over 100 % elastic elongation, e.g. bicomponent elastomultiester (EME), elastolefin (CEF) triexta fibres and polyester PBT [4].

Textured yarns are characterised by highly elastic properties with elastic elongation over 100 % that develop after a high-temperature treatment process, where two dimensional crimps change into three dimensional ones [5]. These latent elastic properties of textured PBT yarn were explained by the changes in the crystal structure of fibres [6].

Stretch properties are very important physical properties of woven fabrics, where about 10–30 % reversible deformation is required for the clothing comfort. About 2–5 % of elastane fibres are usually added into denim 3,3 % to 6,6 % into woollen fabrics [7] and into cotton shirting fabrics to achieve an adequate stretch ability.

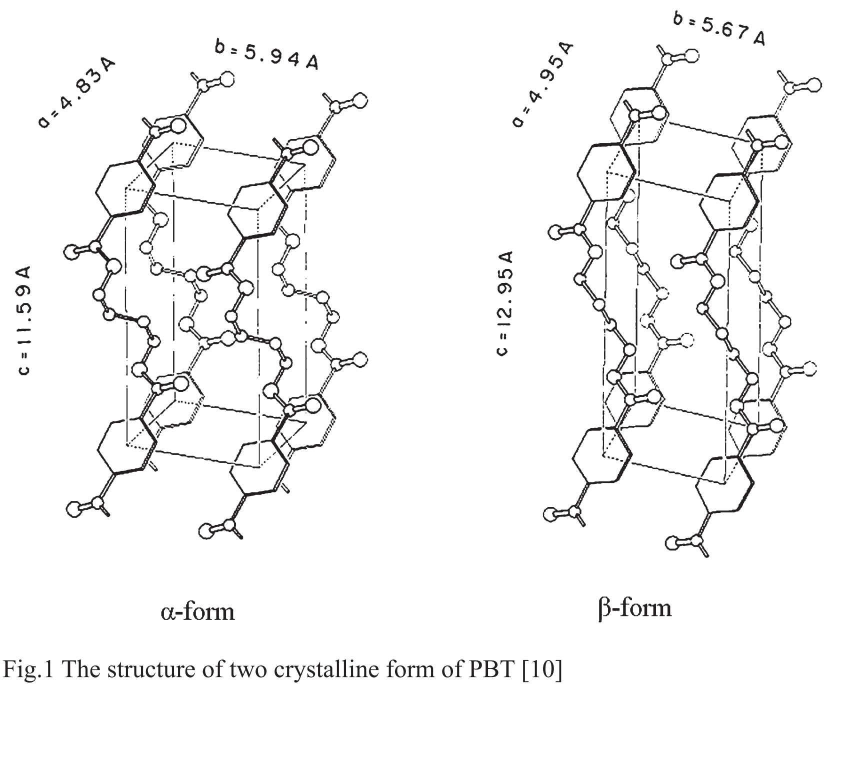
PBT polymer has been known since 1968. The molecular weight of a repeated unit is 220 g/mol and the average polymerisation degree is 100-200 [8]. The used material for increasing the extensibility was polyester PBT, which has four methylene groups in its structural formula, i.e. two methylene groups more than the most frequently used polyester PET. The melting point of PBT is 221 °C and its glass transition temperature is 20–40 °C [9]. Two different crystalline forms are designated as the α and β forms [10]. The crystal structure of PBT transforms into β-form with a hot stretch treatment and into α-form with relaxation [9, 11, 12]. In the β-form, the chain axis c of the crystal unit is 1.295 nm and is longer than in the α-form, where it equals 1.159 nm [13]. Both structures of the PBT crystalline form are given in Fig.1.

Raw PBT yarn poses more of extended β-form that transform to the α-form with the thermal treatment, which causes the shrinkage of fabrics dependably on the PBT yarn quantity and fabric structure.

3. Experimental part

3.1. Materials

To investigate the changes in the characteristics due to incorporated PBT yarns before and after their thermal treatment, several referenced samples were produced. Woven fabrics contained 100 % cotton yarns 17 × 2 tex as warp, and the same cotton yarns combined with PBT yarns 7.8 tex f 24 as weft in a different proportion. The samples started with 100 % PBT as the weft, then changing the proportion of PBT : cotton as the weft in the following order: 2 : 1, 1 : 1, 1 : 2, 1 : 3. All samples were produced in plain weave with the same density of warp and weft. Additionally, we produced a few more samples with single PBT weft yarns and lower weft density in the proportion of PBT : cotton 1 : 2 and 1 : 3, and with 2PBT weft yarns (two PBT 7.8 tex textured yarns inserted as one in the weaving process). In this way, we wanted to know how the increased quantity of PBT yarn in the same and in a more open construction (lower weft density) influences the changes of physical and mechanical characteristics. The labelled samples with their construction parameters are shown in Tab.1. Samples 1-5 differ in the PBT content (22.5 g/m², 14.7 g/m², 9.9 g/m², 6.7 g/m² and 5.2 g/m²), while keeping the weft density the same. Treated samples 1-5 contains 26 g/m², 16.6 g/m², 11.9 g/m², 7.6 g/m² and 5.6 g/m² of PBT in the fabric.



α-form β-form

Fig.1 The structure of two crystalline form of PBT [10]

Tab.1 Construction parameters of produced woven fabrics

Sample number No.	Weft proportion	Warp density ends/cm	Weft density picks/cm
1	PBT	20	20
2	PBT : Cotton = 2 : 1	20	20
3	PBT : Cotton = 1 : 1	20	20
4	PBT : Cotton = 1 : 2	20	20
4a	2PBT : Cotton = 1 : 2	20	20
5	PBT : Cotton = 1 : 3	20	20
5a	2PBT : Cotton = 1 : 3	20	20
6	PBT : Cotton = 1 : 3	20	15
6a	2PBT : Cotton = 1 : 3	20	15

3.2. Methods

The thermal treatment of PBT textured multifilament yarn was made in the boiling distillate water at bath ratio 1:20. The PBT yarn was put in the boiling bath and taken out, after 30 minutes of boiling, to dry on air in a free-relaxation state.

The fabric samples were produced on a laboratory weaving machine with the working speed 100 picks/min. After the woven fabrics were produced, they were thermally treated at the same condition as PBT yarn. The physical and mechanical characteristics of samples were examined using standard analysing methods. Warp and weft densities were measured according to SIST EN 1049-2-1999 standard, thickness according to ISO 5084 and mass per the unit area according to EN 12127.

The measurements of mechanical properties of woven fabrics were made on 50 mm wide strips and gage length of 200 mm at the strain rate 100 mm/min. The measurements were made on the tensile testing machine Instron 6022® according to EN ISO 13934-1:1999 standard. For each woven fabric sample, five measurements were done in, warp and weft, directions.

4. Results and discussion

The measured properties of the textured PBT yarn and cotton twisted yarn are shown in Tab.2.

The mean values of the measurement made on woven fabrics are presented in the follow Tab.3 and 4.

The measured mechanical characteristics of samples are shown numerically in Tab.4, and graphically in Fig.2 and 3.

4.1. Changes in characteristics of samples 1–5

The relationships between the warp and weft densities and the quantity of PBT yarns in the weft are shown in Fig.4.

It is very well seen that due to the stretching in the weft direction, the density of warp yarn decreases by decreasing the quantity of PBT in weft following the polynomial equation with the coefficient of determination R^2 = 0.9912. On the other hand, the changes in weft density are very small and almost linear with the coefficient of determination of R^2 = 0.9312. It is important to know that the set densities were 20 ends/picks

Tab.2 The mechanical properties of the yarns used in the study samples

Properties	Method	PBT yarn		CO yarn	
		Untreated	Treated	Untreated	Treated
Linear density (dtex)	DIN 53 830	77.3	87.5	333.8	338.4
Twist (1/m)	EN ISO 2061	-	-	341.3	332.9
Breaking force (cN)	ISO 2062	205.44	160.74	822.89	912.33
Tenacity (cN/tex)	ISO 2062	26.57	18.37	24.20	26.96
Breaking elongation (%)	ISO 2062	28.5	80.0	5.1	5.6

Tab.3 The measured values of structural and physical characteristics of samples before and after the thermal treatment

No.	Contraction (%)		Warp density (ends/cm)		Weft density (picks/cm)		Thickness (mm)		Mass per u.a. (g/cm^2)	
	warp	weft	before	after	before	after	before	after	before	after
1	2.5	26.4	24	33	21	23	0.34	0.41	110.0	142.9
2	2.5	13.9	22.5	26	23	23.5	0.37	0.45	125.5	146.2
3	3.8	10.4	21.5	25	22	23.5	0.34	0.43	132.1	155.0
4	4.4	6.3	22.5	23	22.5	24	0.36	0.42	147.0	161.5
4a	4.5	8.0	21.5	24	21.5	22.5	0.40	0.52	143.5	162.9
5	5.8	5.3	22	23	23	24	0.35	0.42	148.0	166.2
5a	8.0	8.2	21.5	24	21.5	23	0.42	0.51	146.1	163.3
6	6.8	7.8	20	23	15	16	0.44	0.56	119.3	131.6
6a	10.0	7.4	21	24	15	16	0.41	0.62	123.8	141.5

Tab.4 The mean values of breaking force and breaking elongation in the warp and weft direction before and after the thermal treatment

No.	Breaking force				Breaking elongation			
	Warp direction		Weft direction		Warp direction		Weft direction	
	before	after	before	after	before	after	before	after
	(N)	(N)	(N)	(N)	(%)	(%)	(%)	(%)
1	922.69	1360.50	215.66	187.60	7.40	11.23	53.9	101.2
2	862.81	956.15	316.07	315.04	10.5	13.02	25.4	41.35
3	793.61	972.76	459.85	453.25	10.9	15.02	19.5	30.74
4	805.34	926.15	591.60	603.81	13.9	18.22	18.3	25.44
4a	805.39	929.57	577.16	608.37	13.8	18.32	16.62	24.63
5	831.43	897.40	615.38	693.40	14.6	19.23	14.9	23.78
5a	839.46	913.42	597.03	668.34	14.7	19.53	15.42	20.36
6	752.17	750.93	361.05	442.07	11.2	18.69	10.72	16.90
6a	765.01	824.30	374.35	436.35	11.7	19.53	11.22	22.53

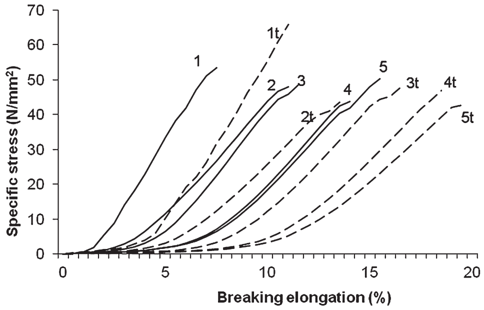


Fig.2 Specific stress – breaking elongation curves of woven fabrics in the warp direction

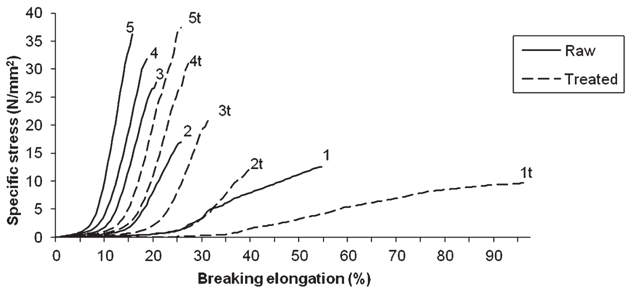


Fig.3 Specific stress – breaking elongation curves of woven fabrics in the weft direction

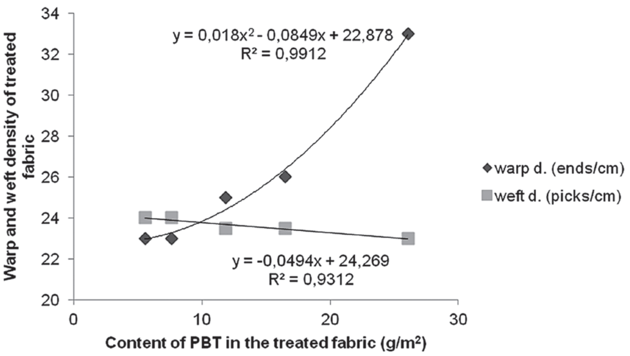


Fig.4 Changes of the warp and weft densities of treated samples 1–5 in dependably on the quantity of PBT in the weft direction

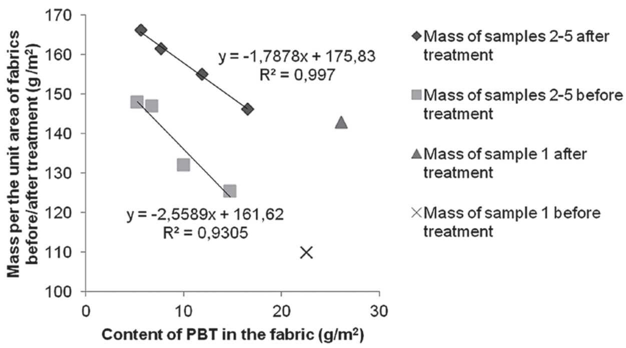


Fig.5 Changes of mass per square meter of samples 1–5 before and after the thermal treatment

per cm and after the treatment, the density of warp changed from 15 % (samples 4 and 5) to 65 % (sample 1), and the density of weft only from 10 % (sample 1) to 20 % (sample 4 and 5), mainly due to a higher number of thicker cotton yarn.

It is obvious that due to the streching, mass per the unit area rises in all samples from by about 30 g (sample 1) to by about 20 g (sample 5). The mass increases with diminishing the quantity of PBT in the weft almost linearly. The latter is expectable, since for samples 2–5, the number of heavier cotton weft increases, which coresponds to the higher mass per unit area of samples. Fig.5 also shows the values for mass per the unit area of sample 1 before and after the treatment which were not taken into account, when the determination coefficient was being calculated. In the case of untreated samples, the mass per unit area could fit well enough with the trend of linearity of samples 2–5, which is not the case with the mass of the treated sample1. The finer PBT yarns should contribute to smaller than the measured mass, whereas due to a high level of streching, mass per the unit area is bigger and does not fit with a linearity of samples 2–5.

The thickness of samples increased 0.34–0.37 mm (untreated samples) to 0.41–0.45 mm. The thinnest was the sample 1 (before and after treatment) due to 100 % PBT weft content; whereas the thickest was the sample 2 due to the combination of mixed PBT/cotton 2 : 1 and second highest stretching (highest mass of PBT in weft among PBT/cotton weft in samples).

The changes in breaking force and breaking elongation before and after the treatment are also shown in Fig.6 and 7.

It is evident that the highest breaking force in the warp direction characterises sample 1 (922.69 N) with only 100 % PBT in weft. A complete opposite situation is in the weft direction, where one PBT yarn had 2.22 N breaking force, what get slightly more than 200 N breaking force of the fabric. The breaking force in the warp direction is so high due to the high breaking force of cotton warp yarn (7.79 N) and high elasticity of PBT yarns, which do not put much pressure on the warp cotton yarns within their interaction. The thermal treatment causes an increase of the breaking forces values in the warp direction of all samples mostly on the account of shrinkage in the weft direction caused by the shrinkage of PBT yarns, resulting in the higher warp density of samples. Additionally, the increased elasticity of treated PBT yarns contributes to the higher breaking force in the warp direction; especially, in samples with double PBT content in the weft.

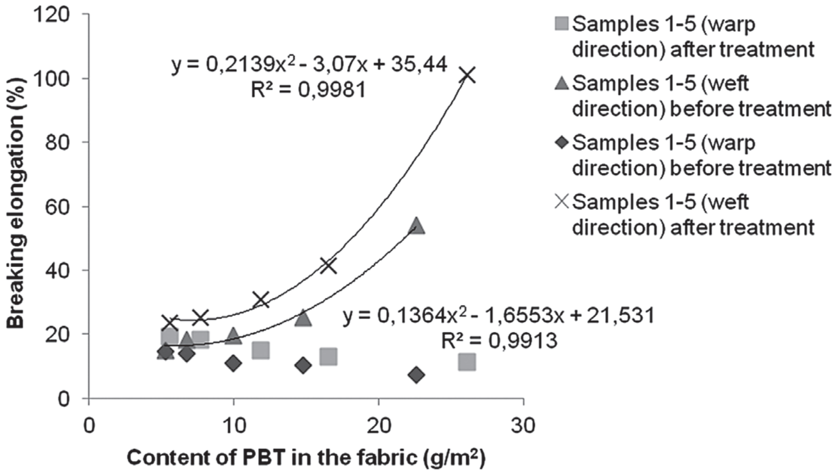


Fig.7 Breaking elongation of samples in the warp and weft direction before and after the treatment

The breaking forces of untreated samples in the weft direction arise from samples 1–5, which is expectable, since the samples have more and more cotton yarns in weft in the fabric structure, this dominantly contributing to the breaking forces of samples. PBT yarns contribute very little to the breaking forces in the weft direction, which is obvious from the fact that if the breaking force is calculated in the weft direction, taking into account the breaking forces of cotton yarns only on 5 cm specimen width and the real density of weft cotton yarns, the results will be very close to the measured values shown in the fourth column of Tab.4. The explanation for that phenomenon lies in extensibility and lower tenacity of PBT yarns compared to that of cotton yarns. At the beginning of the test, PBT yarns contribute very little to breaking force, which is a consequence to extensibility. After the breakage of cotton yarns, which have smaller extensibility the whole force loads to the weaker PBT yarns, which break almost immediately.

The breaking elongation of samples in the weft direction increased with the mass of PBT in the weft. After the treatment, the breaking elongation additionally increased about one third (from 25 % to 41 % – sample 5) about one half (from 53 % to 101 % – sample 1). On the contrary the breaking elongation in the warp direction deceased with an increase of PBT mass in the weft (from 14.6 % for sample 5 to 7.39 % for sample 1). After the treatmant, the figures for breaking elongation increased almost linearly to 19.23 % (sample 5) and 11.23 % (sample 1). However, samples 4 and 5 got after the treatment very similar and satisfactory results regarding the breaking elongation in both direc-

Fig.6 Breaking force of samples in the warp and weft direction before and after the treatment

tions, which was the aim of the research: sample 4 with 18.22 % in the warp and 25.44 % in the weft direction after the treatment, and sample 5 with 19.23 % in the warp direction and 23.78 % in the weft direction.

4.2. Changes in the modified sample characteristics

Additionally were produced samples 4a and 5a introducing 2PBT yarns as one, while the construction parameters were the same of samples 4 and 5. The results were slightly surprising and not easy to explain in details. An introduction of thicker, stronger and more rigid yarn into the fabric construction resulted in a different interaction among PBT/cotton weft, and cotton warp yarns, which have the lower warp and weft densities, smaller mass per the unit area and bigger thickness of untreated samples compared to samples 4 and 5. According to the expectations after the treatment, the modified samples 4a and 5a stretched more than samples 4 and 5, especially in the weft direction. After the treatment, the warp densities of samples 4a and 5a increased more than of samples 4 and 5, while the densities of wefts still remained lower. Consequently, the mass per unit area came very close to samples 4 and 5. The thickness of sample 4a increased almost twice as much compared to the increase of sample 4; nevertheless, the increase in the thickness of sample 5a did not differ much from the thickness of sample 5. This can be caused by the fact that samples 5 and 5a have the smaller quantity of PBT, than samples 4 and 4a and additionally they are differently positioned in the weft. In samples 4 and 4a, the positioning of PBT yarn changes in each fabric repeat, which means that PBT yarns interact with every warp from both sides.

The mechanical characteristics of samples 4, 4a, 5 and 5a (breaking force and breaking elongation in the warp and weft directions) before and after the treatment do not differ significantly. This leads to the conclusion that the use of 2PBT as one weft instead of one single does not contribute to improving the characteristics of these samples. From Fig. 8, it can be seen that the structure of samples 4, 5 and modified 4a, 5a is closed too much to allow greater changes after the treatment. Practically, the whole stretching caused by 2PBT yarn resulted in the higher thickness of samples, while other characteristics remained almost the same.

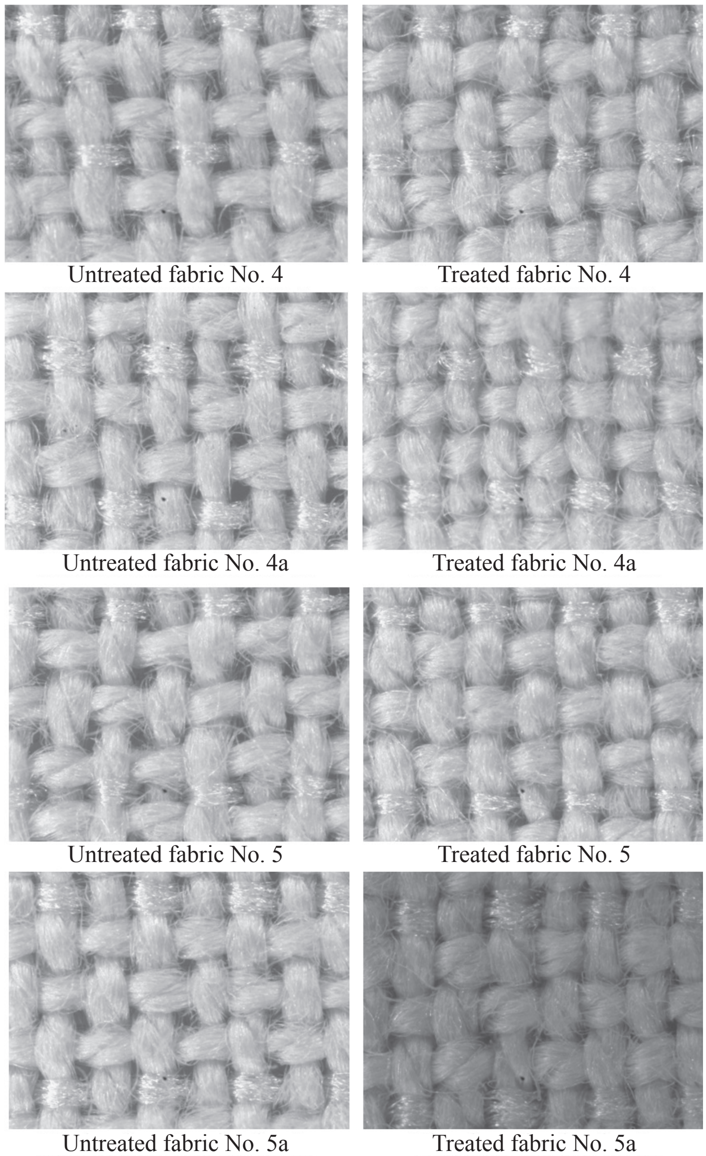


Fig.8 The surface morphology of woven fabrics with different PBT quantity

For that reason, samples 6 and 6a, which differ from samples 5 and 5a only in the weft density, i.e. 15 picks/cm, were investigated. A different, more open structure caused higher density in the warp direction than less open structure, when doubled PBT and equal density of weft was used before the treatment. The treatment caused an increase in the warp density by 15 % in sample 6 and by 20 % in sample 6a, and an increase per one pick in both cases in the weft direction (from set 15 to 16 picks/cm). This resulted in the bigger mass per the unit area and lower thickness of the untreated sample 6a than the treated sample 6a. The treatment caused much greater changes in the characteristics of sample 6a compared to sample 6. The mass per the unit area increased in sample 6a by almost 20 g/m² and thickness-by almost one third (0.2 mm). A comparison of the characteristics of sample 6a with those of samples 4, 4a, 5 and 5a shows significantly smaller mass per unit area, i.e. about 20 g/m², which results in the differences of breaking forces. The breaking force in the warp direction is by 50–80 N and in weft direction by 150–200 N smaller than in samples 4, 4a, 5 and 5a. At the same time the breaking elongation of sample 6a after the treatment became almost identical to those of samples 4 and 5, in spite of by 25 % lower weft density. This leads to the conclusion that for using bulky PBT yarn, it is necessary to leave more room in the fabric construction, if we want to obtain bigger changes in the characteristics and more satisfactory results.

5. Conclusion

A cotton-based fabric with increased extensibility in both directions with the minimum PBT yarn added in the weft direction, according to Fig.4, were samples 4 and 5. In both cases, we can get more than 19 % breaking elongation in the warp direction and more than 23% of breaking elongation in the weft direction. At the same time, the elongation of sample 5 under 5 N of force would be 3.8 % and 5.3 % in the warp and weft directions; and successively 5.0 and 7.3 % under 10 N of force. Actually even a small portion of PBT incorporated in the fabric can contribute to the elastic properties primarily in the incorporated direction. It allows for almost a quarter of the breaking elongation at less than 2 % of the breaking force in warp and weft direction. It does not influence much the elastic properties in the opposite direction. They can be reached with a careful construction of a fabric, and are more or less limited. For getting more extensibility in the warp direction, PBT yarns should be incorporated into the fabric also in this direction. This is of great importance, since producers do not want to put stretchable yarns in the warp due to the difficulties in the weaving process ability in and the diminished productivity. PBT is an ideal material for being also put in warp direction, as its characteristics before the treatment do not differ much from other polyester yarns.

Moreover, other mechanical (breaking force) and physical characteristics (thickness and mass per the unit area) of samples that have a portion of PBT in the weft direction are approximately the best or do not differ much from the best reached. This justifies the use of PBT in the structure of woven fabrics that retains their cotton character, and at the same time increases extensibility and improves other useful characteristics or nears them to the best characteristics possible.

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