MEASURING OF FABRIC RUPTURE PROPERTIES IN ARBITRARY DIRECTIONS

Radko KOVÁŘ, Mehdi Kamali DOLATABADI
Technical University of Liberec, Faculty of Textile Engineering, Department of Textile Technologies, Liberec, Czech Republic
E-mail of the Presenting Author: radko.kovar@tul.cz

Abstract
Standard EN ISO 13934-1 (strip test) does not allow correct testing of materials with great lateral contraction, because tension concentration at jaws results in the break sooner than breaking tension in sample central part is reached. A new method (Czech patent No. 301 314, granted on 02.12.2009) reduces sample tension near the jaws by capstan friction and enables, for example, measuring of woven fabric tensile properties in arbitrary direction. In the paper the new method is described and results of chosen experiments are presented. The sample strength, measured by the new method, is for some cases even three or more times greater than the strength measured in accordance with standard.
Key words: Rupture properties, woven fabric, arbitrary direction, capstan friction

1. Introduction

Prediction and measuring of woven fabric tensile properties in arbitrary direction is still problem and main load directions (i.e. warp or weft) are preferred by researches [1, 2], by testing standards [3] etc. Nevertheless load in other directions is as well important with the respect to practical fabric usage. Where the sources of problems, accompanied with weaves rupture properties measuring at uniaxial load in any direction, are? It is, in brief:

a) Great fabric lateral contraction that results in uneven stress distribution and tension concentration, mainly at sample corners if fast jaws are used.

b) Cut ends of yarns imposed load in the sample. It results in existence of the two strips at sample margins where utilization of the yarn strength is ineffective because yarn tensile stress cannot reach yarn strength (tensile stress at the cut end is zero). The effect is that sample width influences fabric relative strength [4].

c) Existing critical angles of load direction, when just only 1 or small number of yarns is clamped simultaneously by upper and bottom jaws and all other yarns have one free (cut) end. These yarn/yarns break first (its breaking elongations are smaller), later breakage of neighboring yarns follows and the break spreads along the fabric grip.

d) Yarn jamming can improve utilization of fibers strength, namely at load angles near 45 º.

In this paper an analysis of possibilities of solving these problems are described with the stress to be put on sample stress reduction towards both pairs of jaws by capstan friction.

2. Principles of experiments

The two standard methods are often used, called 'strip' test (EN ISO 13934-1) [3] and 'grab' test (EN ISO 13934-2). The second one is not described as it imposed the sample too complex load. The sample, used at strip test, is shown in Fig. 1 a (before) and b (after elongation). The circles mark the places with upmost tension concentration where breaks usually start. Experiments prove that for non-principal directions the breaks can occur even at about one third of real fabric strength.

Better results can be obtained with the use of the sample, narrowed in its central part by 1/3, Fig. 1 c [5]. Similar method is used in an old Czechoslovak standard [6], recommended for knitted fabric, Figs. 1 d, e. Nevertheless these methods are connected with uneven stress distribution anyway and so the results are better but not perfect.

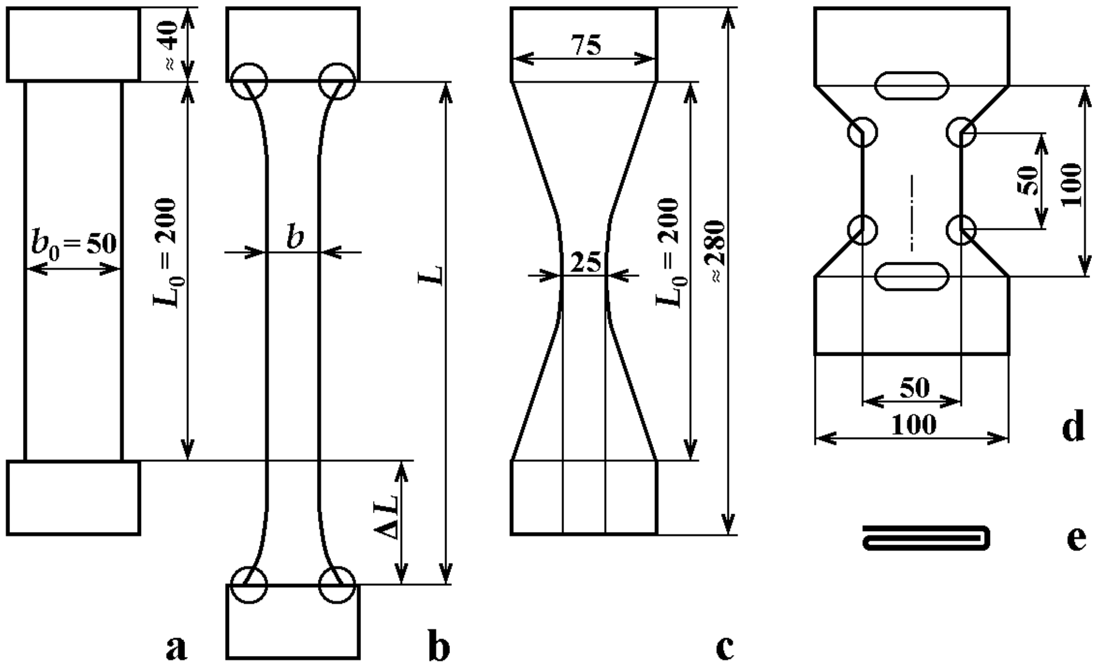

Figure 1. The main principles of measuring of fabric rupture properties

3. Reduction of sample stress by capstan friction

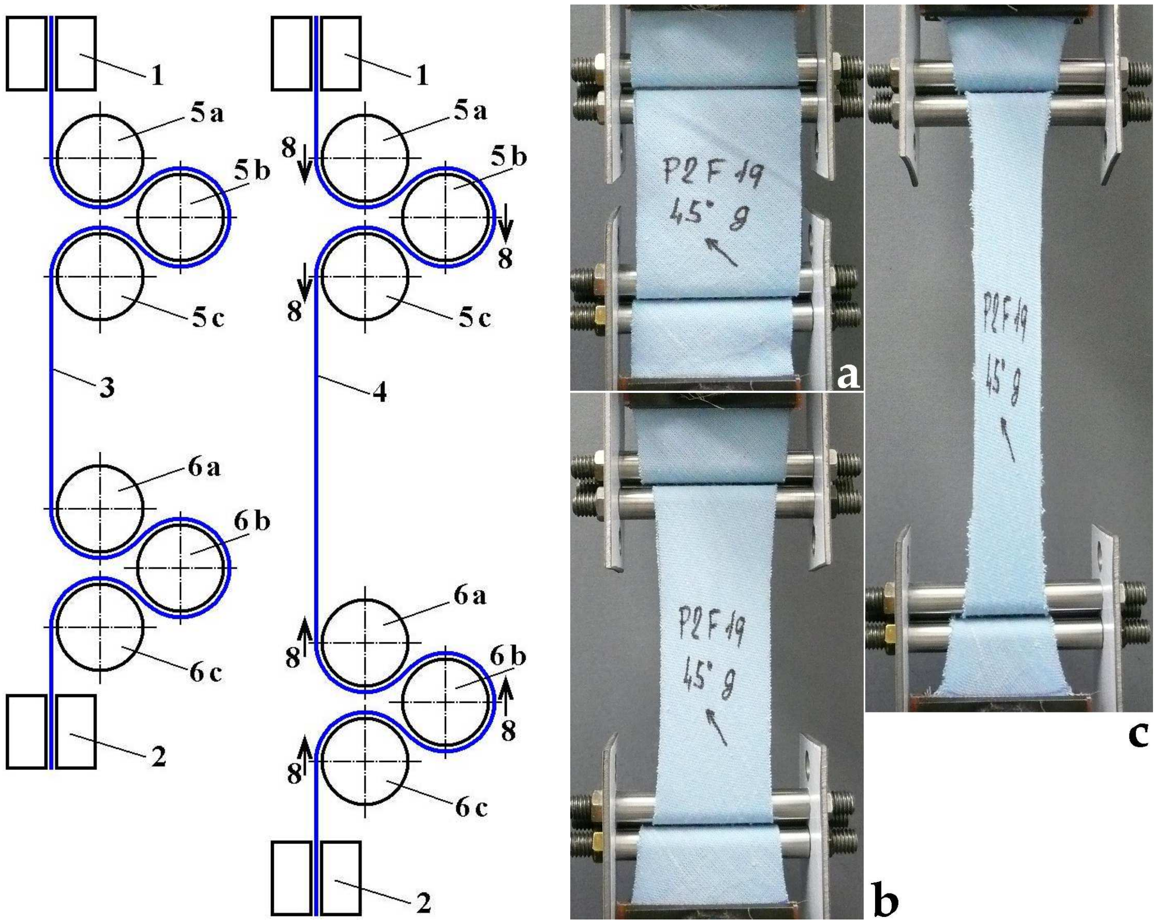

Figure 2. The principle of tensile properties measuring with the use of capstan friction

A new method, that uses capstan friction [7], provides the best results. The principle is introduced in Fig. 2; a set of fast rollers 5, 6, connected with each pair of jaws, reduce by capstan friction sample stress at the grip, so that the chance of break inside the sample rapidly increases. In arrangement, shown in the Fig. 2, is angle of contact 8.03 π (460 º) an so for friction coefficient f = 0.17 (this is low value of f, valid for fabric to steel friction at high load near the sample break [8]) the relation of tensile stresses F_c (in sample central part) and F_j (near the jaws) is

$$\frac{F_c}{F_j} = e^{\alpha \cdot f} \approx 3.9 \qquad (1)$$

4. Examples of experimental results

Till now lots of experiments, comparing different methods were done and others are in progress. Now only several examples would illustrate the differences between used ways of measurements for woven and knitted fabrics.

4.1 Narrowed samples vs. strip test

Fabric specification: plane weave from single cotton rotor spun yarn 33 tex (warp and weft), warp sett 2400, weft sett 2000 yarns per meter. Load direction, called 1:1, means structural diagonal – along diagonal cross-over elements of the plain weave [5].
Fig. 3 shows average results of breaking stress and strain for next shapes of samples: (a) oblong of 25 mm width, (b) oblong of 50 mm width [3], Fig. 1 a, (c) sample narrowed from 50 to 25 mm, (d) sample narrowed from 75 to 25 mm (Fig. 1 c). Breaking strains (left) are for all sample shapes similar, but differences in relative breaking stresses (right) are enormous.

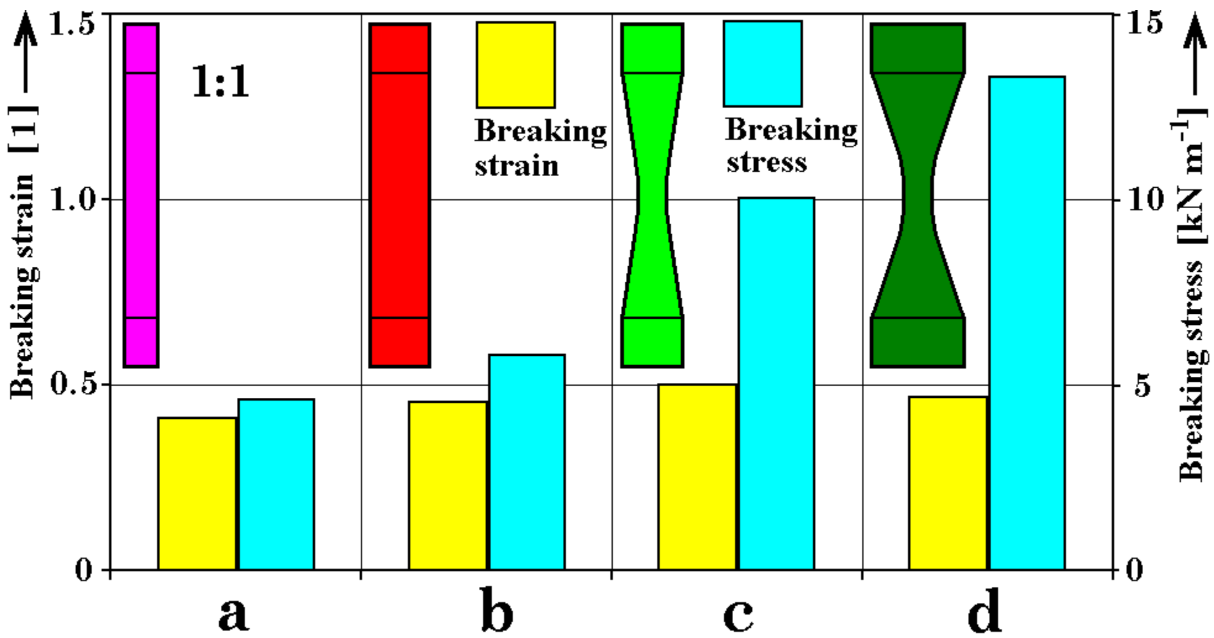

Figure 3. Influence of sample shapes on breaking stress and strain

In figure 4 are shown examples of average stress-strain curves for the same experiments. The test with zero pretension starts at 0-0 point and the gradient in the first part is very low (yarn de-crimping).

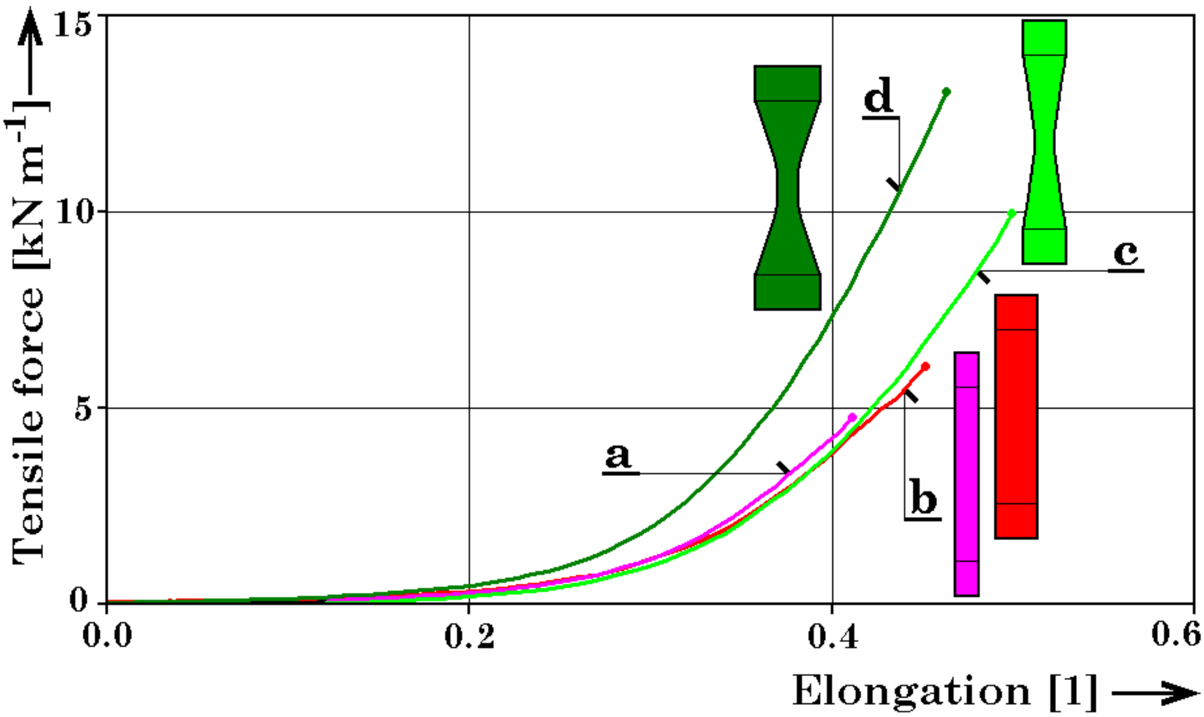

Figure 4. Examples average of stress-strain curves

4.2 Frictional accessory on dynamometer vs. strip test

Now we shall compare chosen experimental results of standard “strip” test [3] marked **S** and new patented method [7] marked **F** (friction). The loads directions were 0, 15, 30 45, 60 and 75 ° towards direction of warp yarns, 90 ° means load in direction of weft yarns.

Fabric P-1 is polypropylene 100 %, P-2 is blend polypropylene 65 % and cotton 35 %, other parameters are the same: yarn linear density 29.5 tex (warp and weft), warp sett 2360, weft sett 1860 ends/m.

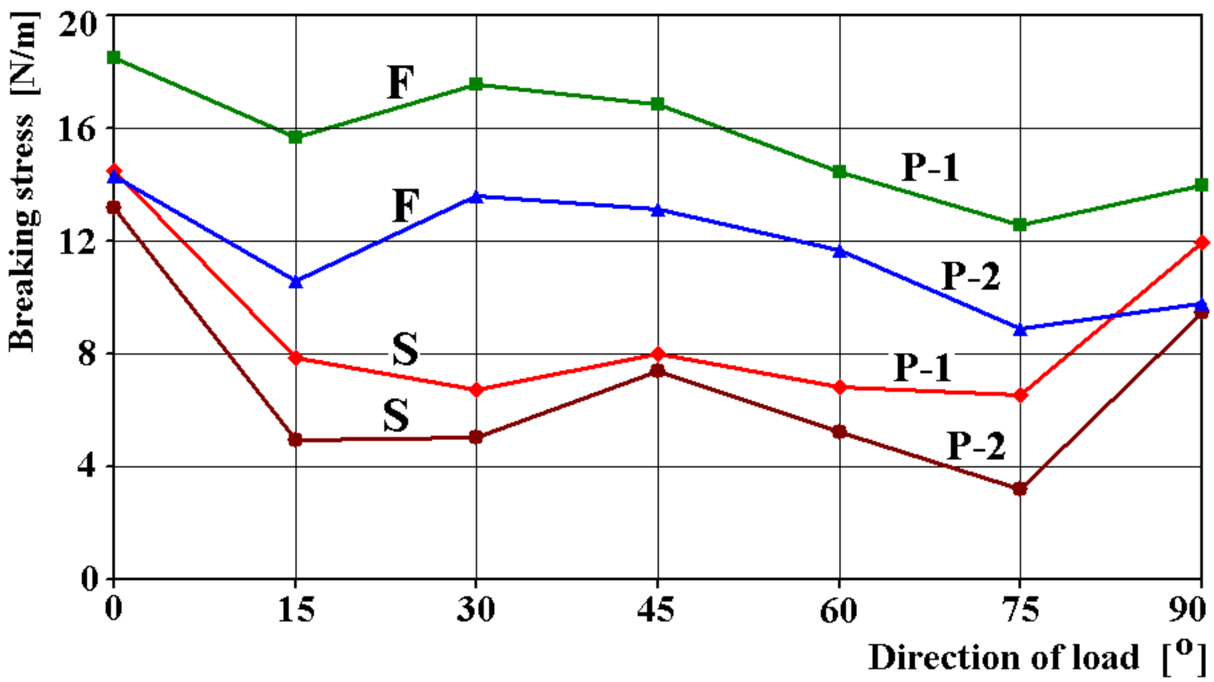

Figure 5. Anisotropy in tensile properties (fabrics P-1 and P-2)

The results are introduced in Figure 5. One can see that decreasing of the load at the jaws by capstan friction (F) results in substantively higher measured relative breaking stress; method [7] gives similar results for the load in main directions, but greater strength for other directions. Relative increase of measured strength F/S is from 178 to 278 %.

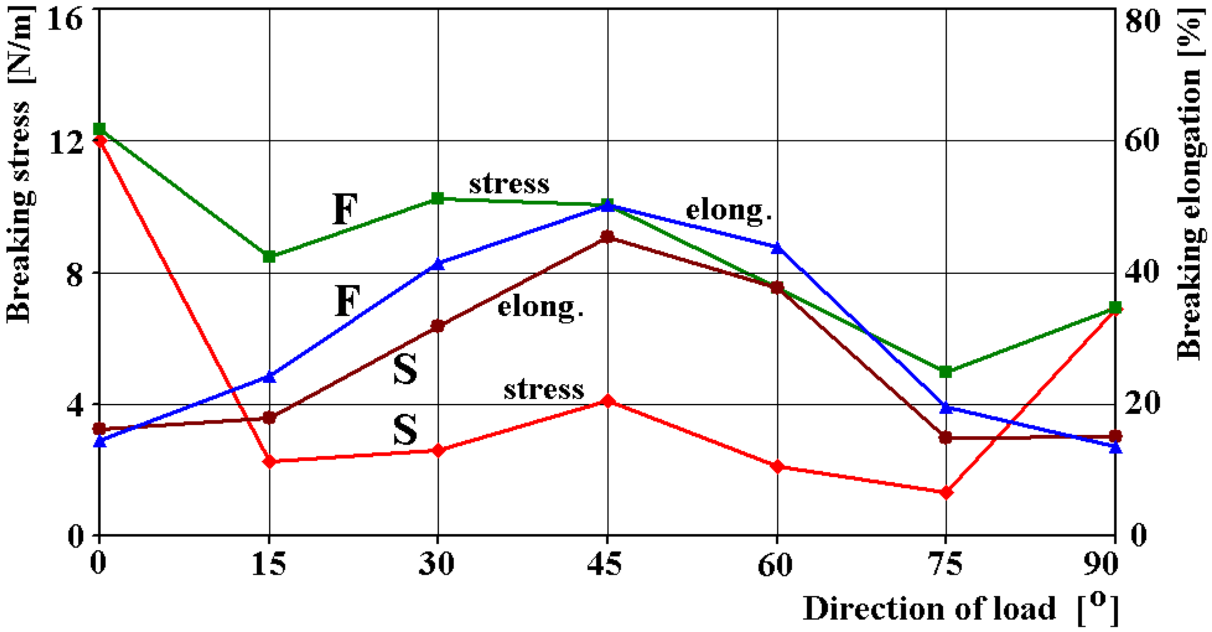

Figure 6. Breaking stresses and strains, polypropylene 35 % and cotton 65 % blend

Next tested fabric is polypropylene 35 % and cotton 65 % blend, warp and weft yarns linear density 29.5 tex and different pitch of yarns; warp sett 2360 and weft sett only 1380 ends/m. In Fig. 6 are shown not only breaking stresses with the use of two methods S and F, but also relevant breaking elongations. Maximum increase of breaking stress (F/S) is 395 % for direction 30 ° (it corresponds with equation 1), whereas changes in breaking strains are small (it can be explain by great stress-strain curve gradient near the break point).

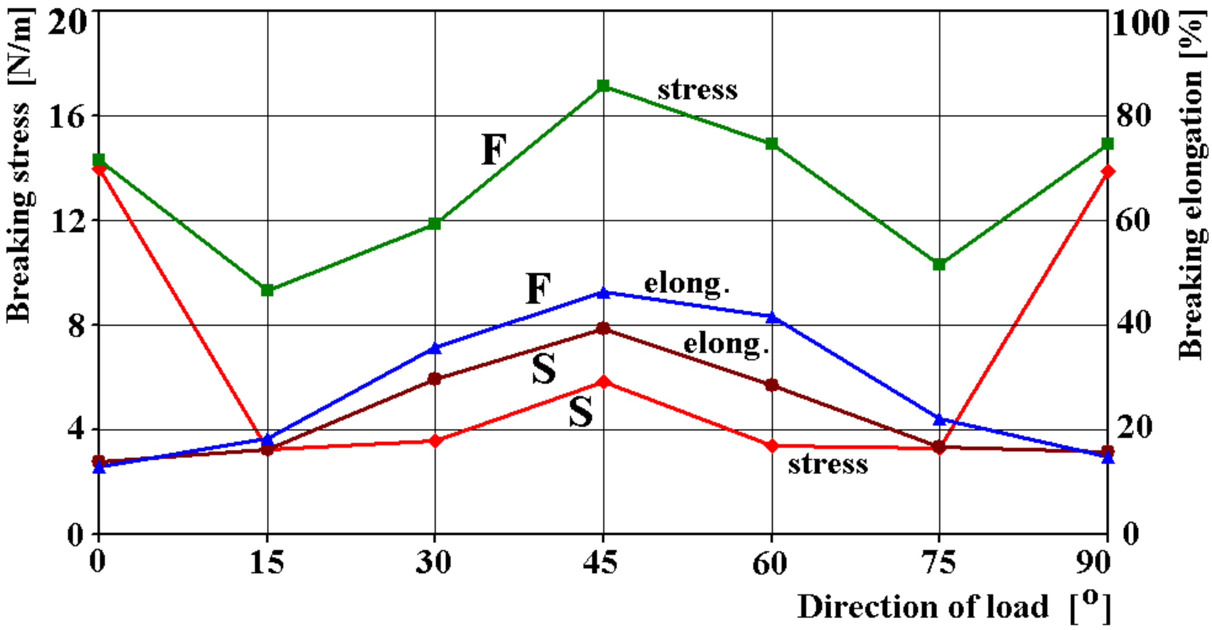

Figure 7. Breaking stresses and strains, pure cotton, gray fabric

Following fabric is cotton 100 %, linear density 29.5 tex (warp and weft), warp sett 2360, weft sett 2320 ends/m. This is approximately square fabric, what results in approximately symmetrical breaking stresses and strains (see Figure 7).

All the previous fabrics were grey; the last one will be pure cotton finished fabric (including dressing with DUVILAX), warp and weft yarns linear density 35.5 tex, warp sett 2600 and weft sett only 2500 ends/m. Breaking elongations are practically identical, maximum strength increase (F/S) is not so great as at grey fabrics – only 209 %, Fig. 8. This is due to finishing (first of all dressing) that improves evenness of stress distribution in the sample area.

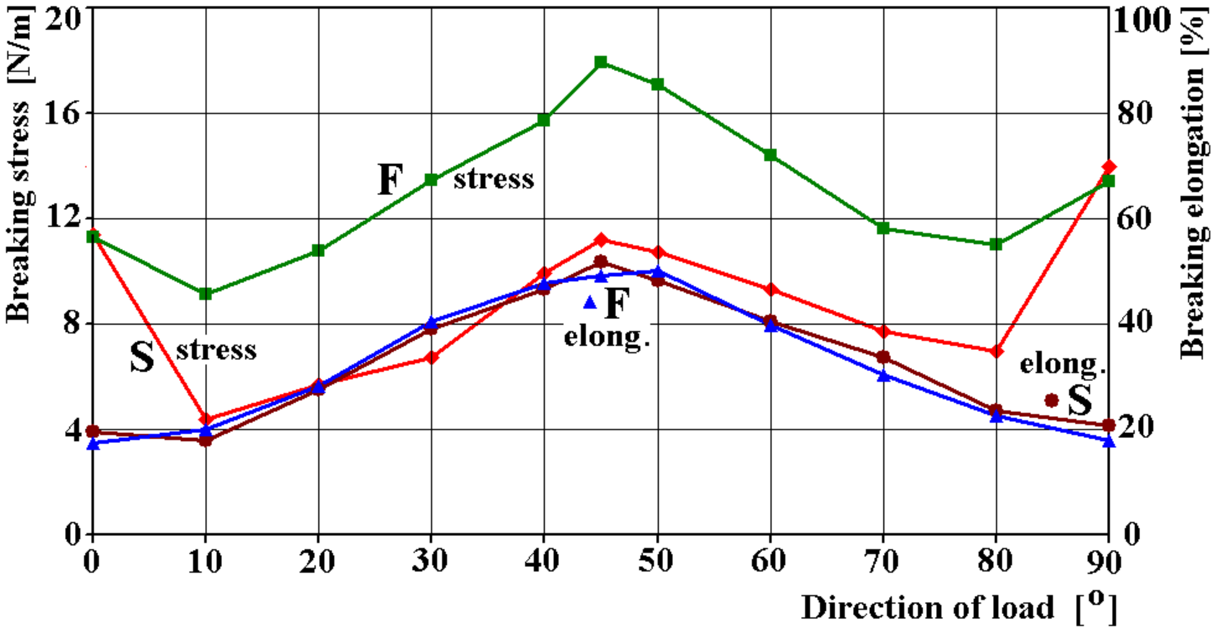

Figure 8. Breaking stresses and strains, pure cotton, finished fabric

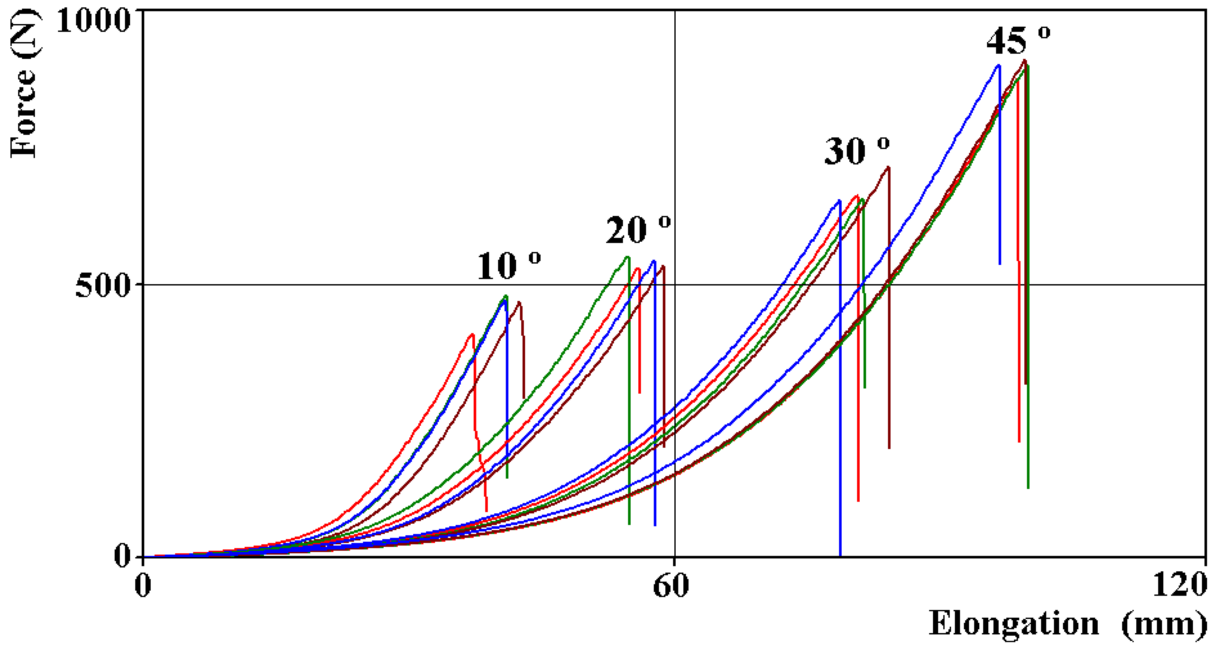

Figure 9. Examples of stress-strain curves – F (friction) tests

In Figurers 9 (F test) and 10 (S test) are shown examples of stress-strain curves of the same fabric for angles of load 10, 20, 30 and 45 º, four curves for each case. The appearance of all lines is typical – small gradient at the beginning corresponds with de-crimp of yarns, greater curve modulus near the break point represents first of all yarns axial elongation and cross-section change (flattening of yarns). Gradual breaks, observed in S test for load direction 10 º, can be explained by breaks starting in the two opposite sample corners and spreading gradually across the sample width.

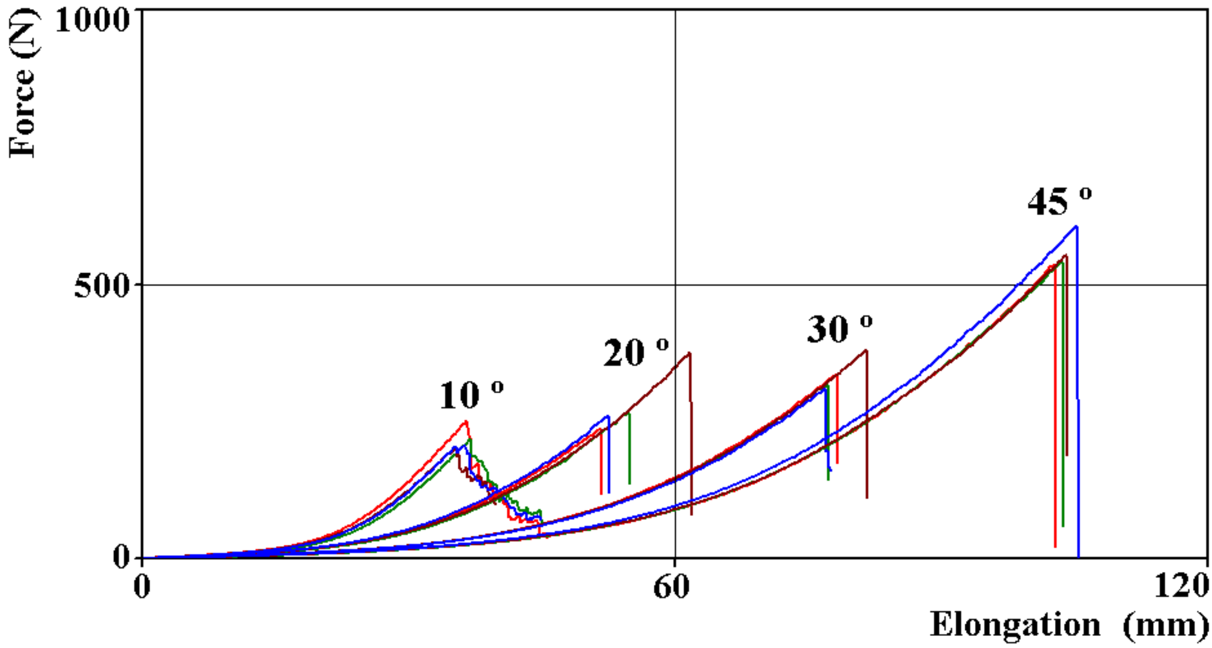

Figure 10. Examples of stress-strain curves – S (strip) tests

5. Conclusion

At all the results one can observe that there is an important minimum in breaking stress near the critical angle, at which is only one yarn clamped in the two pairs of the jaws, all the other yarns have one end free. For critical angle α_c it is valid that tan α_c = 50/200 and so α_c = 14.04 º or 75.96 º (for warp and weft yarns). In the results the minimum is near 15 º and 75 º.

Although the stress distribution in the sample area in the new method [7] is not ideally even, the measured strengths are substantively greater and nearer to real strengths of tested fabrics; it can be stated, that standard strip test is not acceptable for woven fabric rupture properties measuring as errors in breaking stresses reach many tens of percents.

Differences in breaking elongations are small as there are two opposite tendencies: (a) the tensile stress is, in the F test, several times smaller in important area of the sample as it is reduced by friction (it should result in smaller breaking strains) and (b) tensile stress at break in sample central part is in the F test greater.

Similar experiments were carried on knitted fabrics [9] with slightly different results. The effect of diagonal (45 º) direction is not as important as it was for weaves; on the contrary breaking strain strongly depends on direction of wales or courses. In Fig. 11 is an example. Fabric description: plain interlock fabric, density of wales 1100+1100 m^{-1} (1100 face and 1100 back wales) and of courses 1100+1100 m^{-1} (1100 courses of one and the same of second interlock sub-structures), material used viscose spun yarn of T = 21 tex and polyamide multifil T = 4.5 tex. Fig. 11 a shows absolute results of breaking stresses (sample width was 50 mm), influenced by the number of yarns in sample lateral section. In Fig. b are shown relative stresses recounted on 1 yarn. The line Y is in the position of average strength of one yarn. One can see that yarns strength utilization is better for direction of wales and courses then for direction of 45 °.

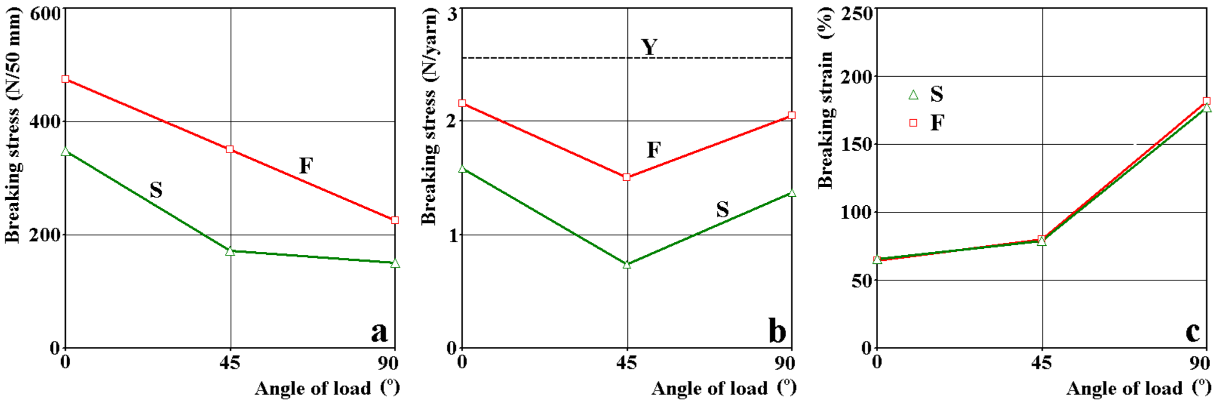

Figure 11. Example of breaking stresses and strains for knitted interlock fabric

Why is the difference between F and S tests smaller than it was for woven fabrics? It can be explained by evener distribution of tensile stress in each yarn; in knitted fabric one yarn bears loads in different directions, yarn lengths redistribution is enabled and yarn tensile load in any direction is changed only by friction in the yarn crossing elements. The differences in breaking strains are for the two methods very small.

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