Analysis of Mechanical Properties of Fabrics of Different Raw Material

Aušra ADOMAITIENĖ *, **Eglė KUMPIKAITĖ**

Faculty of Design and Technology, Kaunas University of Technology, Studentu 56, LT-51424 Kaunas, Lithuania

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The study analyzes dependence of mechanical properties (breaking force, elongation at break, static friction force and static friction coefficient) on integrated fabric structure factor φ and raw material density ρ, among the fabrics of different raw material (cotton, wool, polypropylene, polyester and polyacrylnitrile) and woven in different conditions. The received results demonstrate that sometimes strong dependences exist (wool, polypropylene and polyacrylnitrile), whereas in some cases (cotton and polyester) there is no correlation. It was also discovered that the breaking force and elongation at break in the direction of weft increase, when fabric structure becomes more rigid. In the meantime variations of the curves in the direction of warp are insignificant. Regarding static friction force and static friction coefficient (found in two cases, when fabrics were rubbing against leather and materials), it was discovered that consistency of the curves is irregular, i. e. they either increase or decrease, when integrated fabric structure factor φ growth. It was also identified that some dependences are not strong and relationship between explored and analyzed factors does not exist. Variation of all these mechanical properties with respect to material density ρ enables to conclude that increase of material density ρ results in poor dependences or they are whatsoever non-existent.

Keywords: raw material, integrated fabric structure factor φ, material density ρ, breaking force, elongation at break, static friction, friction coefficient.

INTRODUCTION

Technological properties of fabric depend on the fabric structure and they are reflected in fabric weavability, which depends on the raw material and loom construction [1]. This study employs integrated fabric structure factor φ, proposed by Milašius. It depends to Brierley group of the integrated fabric structure factors, reflecting fabric weavability, which remains to be one of the most important technological properties of fabrics, as fabric processability in loom depends on it [1 – 5].

Mechanical properties, like the breaking force and elongation at break, friction force and friction coefficient are very important, though dependence of these properties on the fabric structure are not yet properly explored.

Nikolic et al. [6] proposed fabric strength to estimate as yarn strength, fabric setting and yarn strength coefficient function. They discovered that fabric strength increases together with yarn strength. The best among fabrics is plain weave fabric and it is stiffer in the direction of warp. Frydrych et al. [7] were exploring influence of fabric finishing, weft setting and raw material on the elongation at break. They discovered relationship between the change of friction and the area of warp and weft thread contact. Wang et al. [8] were analyzing mechanical interaction of warp and weft yarns in shearing deformations. They defined theoretical equations, which revealed relationship between shearing rigidity and fabric structure. Kumpikaitė and Sviderskytė [9] explored dependences of PES fabric breaking force and elongation at break on the different weave factors. Received results demonstrate that there is no correlation between fabric breaking force and weave factors, however, the elongation at break depends on these factors, i. e. increase of weave stiffness leads to increase of the elongation at break. They also explored dependences of the breaking force and elongation at break on weft setting. Received results demonstrate that increase of weft setting leads to slight decrease of the breaking force and increase of the elongation at break. Dependence of the breaking force and elongation at break on the integrated fabric structure factors proves that there is no correlation between the breaking force and integrated fabric structure factors, whereas elongation at break is increasing, when fabric structure is stiffening [9]. Kumpikaitė [10] explored 12 different weaves of PES fabrics relationship of the breaking force and elongation at break on weave factor P_1. It was discovered that above factor has no impact on the breaking force, whereas the elongation at break decreases, when weave factor P_1 is increasing. Truncytė and Gutauskas [11] explored dynamic friction force and dynamic friction coefficient among cotton and linen fabrics, washed in 90 ºC temperature and softened afterwards. They made this analysis, employing three surfaces (glass, organic glass and explored material) and discovered that the highest level of friction was achieved when rubbing the fabric against another fabric. Less significant was rubbing of the fabric against glass and least significant – rubbing it against organic glass. This demonstrates that irrespective of surface employed, washing does influence on friction parameters, i. e. the friction coefficient and dynamic friction force always increases. In the other works fabric tear strength [12] and bending stiffness [13] was analysed.

The structure of the fabrics changes, when they are taken from the weaving loom [14]. The aim of this research is to determine if changes of mechanical properties (breaking force, elongation at break, friction coefficient, static friction force) of fabrics after stabilisation of fabric structure are regular.

*Corresponding author. Tel.: +370-37-300218; fax.: +370-37-353989.
E-mail address: *ausra.adomaitiene@gmail.com* (A. Adomaitienė)

METHODS AND MATERIALS

Fabrics of different raw material (cotton, wool, polypropylene, polyester and polyacrylnitrile) were woven in different conditions. Weft setting was chosen to obtain following integrated fabric structure factor φ: 40, 45, 50, 55, 60, 65. Fabrics were also woven in maximal weft settings (maximal fabric structure factor φ). Fabric structure parameters are presented in Table 1.

Universal computer-integrated tension machine "Zwick/Z005" was employed in fabric tension and friction tests, also using software TestXpert Standard in standard weather conditions. Fabrics of two different directions (weft and warp) were chosen for tension tests. Tension speed was 100 mm/min with 200 mm distance between clamps. Tension tests were performed in accordance with standard LST EN ISO 13934-1 [15], whereas friction tests – in accordance with standard LST EN ISO 53375 [16]. Two surfaces (leather and costume half-wool material) were employed in friction tests.

Table 1. Fabric structure parameters

Raw material	Warp and weft linear density, tex	Warp setting S_m, dm^{-1}	Material density ρ, Mg/m^3	Weave	Yarn structure
Cotton	18.5 × 2	260	1.54	Plain	Plaid yarn
PES	29.4	284	1.38	Plain	Multi-thread
PAN	347	63	1.18	Plain	Staple yarn
PP	166.7	59.1	0.91	Plain	Staple yarn
Wool	92.3	177	1.31	Crepe	Spun yarn

EXPERIMENTAL RESULTS

Our research also focused on exploration of how mechanical parameters (breaking force, elongation at break, static friction force and static friction coefficient) in weft and warp direction of the different fabrics are changing on the integrated fabric structure factor φ. As it is known, factor φ evaluate lot of structure parameters (linear densities, weave, material density, settings), so general evaluation of this factor is fabric tightness, because breast beam and back rest position, also initial warp tension and heald cross advance were stable, and in this research only fabric tightness changes. That's why the influence of mentioned fabric structure parameters were not investigated separately. Wang et al. [8] discovered that there is a link between shear stiffness and fabric structure. Thus, Fig. 1 introduces dependences of breaking force *FH* on factor φ, of fabrics of different raw material, stretched in weft direction. Evidently, in all fabrics maximal breaking force *FH* increases with fabric structure becoming more rigid, i. e. integrated fabric structure factor φ increasing. Kumpikaitė [10] discovered that weave factor P_1 makes no impact on the breaking force, but influences elongation at break. Dependences of the breaking force of all materials on the factor φ appear to be very strong and coefficients of determination are almost equal to one. Highest alteration of breaking force *FH* was discovered among PP fabrics (from 530.23 cN/tex to 1171.9 cN/tex), which makes 45.2 %. Margins of error of PP fabrics were 2.37 % ÷ 7.21 %. Least were changes in breaking force of cotton fabric (from 158.78 cN/tex to 408.61 cN/tex), which makes 38.9 %. Margins of error of cotton fabrics were 2.09 % ÷ 4.81 %. Variation coefficient of breaking force *FH* of wool and PES fabrics didn't reach 5 %, whereas PAN fabrics variation coefficient of *FH* was 1.69 % ÷ 7.38 %. Dependence equations of the breaking force and integrated fabric structure factor φ in weft direction, and determination coefficients are introduced in Table 2.

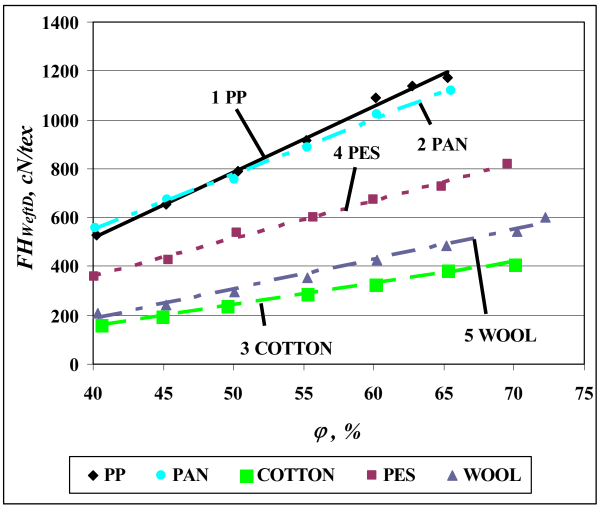

Fig. 1. Dependences of the breaking force *FH* on the integrated fabric structure factor φ, when weaving fabrics of different raw material (weft direction)

Table 2. Equations and determination coefficients of dependences of breaking force on the integrated fabric structure factor φ in weft direction

Graph No	Raw material	Equation	Determination coefficient R^2
1	PP	$FH = 26.832\varphi - 554.94$	0.9951
2	PAN	$FH = 22.636\varphi - 358.86$	0.9963
3	COTTON	$FH = 8.648\varphi - 191.85$	0.9971
4	PES	$FH = 15.52\varphi - 263.83$	0.9943
5	WOOL	$FH = 12.217\varphi - 305.7$	0.9896

Totally different tendencies were traced the change of inclination of curves: in warp direction (Fig. 2). Increase of factor φ leads to increase of *FH* with φ among some raw materials and decrease among others. According to Nikolic et al. [6], strongest among fabrics is plain weave fabric and it is better of warp direction. In this research as it is seen in Table 1 that almost all fabrics were woven in plain weave. Breaking force of cotton, PAN and wool fabrics increases, when fabrics are stiffening, whereas it decreases of PES and PP fabrics, when integrated fabric structure factor φ is growing. Variation coefficient of breaking force *FH* of PAN, cotton and wool fabrics didn't reach 6 %, whereas PP and PES fabrics were 4.02 % ÷ 19.60 %. Dependences are hesitating from low values to high values. Because the aim of this research was to find out if mechanical behaviour of fabric has impact on fabric structure, and if these properties varies regular or irregular, we received that mechanical properties vary irregular, because dependencies in some cases are strong, sometimes poor. Breaking force and integrated fabric structure factor φ, dependence equations and determination coefficients of warp direction are introduced in Table 3. Kumpikaitė and Sviderskytė [9] maintain that there is no correlation between PES fabric breaking force and integrated fabric structure factor φ. We found out similar results. Wang et al. [8] also found out theoretical equations, which revealed relationship between shearing rigidity and fabric structure. We received similar dependences, although we analysed other mechanical properties not shearing rigidity.

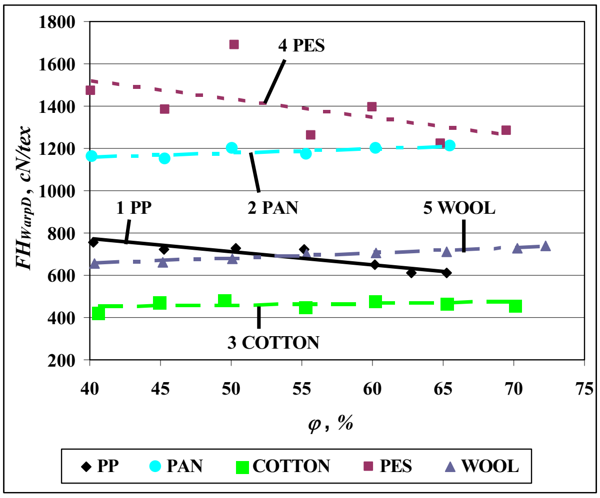

Fig. 2. Dependences of the breaking force *FH* on the integrated fabric structure factor φ, when weaving fabrics of different raw material (warp direction)

Table 3. Equations and determination coefficients of dependences of breaking force on the integrated fabric structure factor φ in warp direction

Graph No	Raw material	Equation	Determination coefficient R^2
1	PP	$FH = -6.0309\varphi + 1012.6$	0.8457
2	PAN	$FH = 1.9544\varphi + 1079.2$	0.6072
3	COTTON	$FH = 0.5899\varphi + 428.5$	0.1041
4	PES	$FH = -8.6433\varphi + 1861.9$	0.3308
5	WOOL	$FH = 2.508\varphi + 554.54$	0.9812

Fig. 3 introduces the dependences of the elongation at break εH in weft direction on the integrated fabric structure factor φ, when weaving fabrics of the different raw material. Fig. 3 shows that increase of factor φ leads to increase of the elongation at break of all fabrics. It also shows that cotton fabrics are least affected by elongation at break (from 21.61 % to 30.28 %). Determination coefficients of PP, PAN and wool fabrics are very high, close to one, which means that there is a strong relationship between explored property and factor φ. It was also discovered that of PES fabric very poor link exists between the integrated fabric structure factor φ and elongation at break, as the curve is almost parallel to horizontal axis, whereas determination coefficient is very low (0.0027). Therefore, it is possible to maintain that elongation at break of PES fabrics is not affected by integrated fabric structure factor φ. It can be explained by the fact that PES is the only multi-thread fabric, whereas the rest of them are woven from spun yarn. Elongation at break εH coefficient of variation of the PES, PP, cotton and PAN fabrics didn't reach 7 %, whereas wool fabrics margins of error was 1.40 % ÷ 11.06 %. Equations and determination coefficients of dependences of elongation at break on integrated fabric structure factor φ in weft direction are introduced in Table 4. Frydrych et al. [7] explored influence of finishing, weft setting and raw material on fabric's elongation at break. They determined that fabrics with cotton weft have no influence of weft density on the elongation at break in the weft direction. In our research we determined that relationship is also poor, that's why we can say, that fabric's elongation at break vary irregular, as breaking force in warp direction.

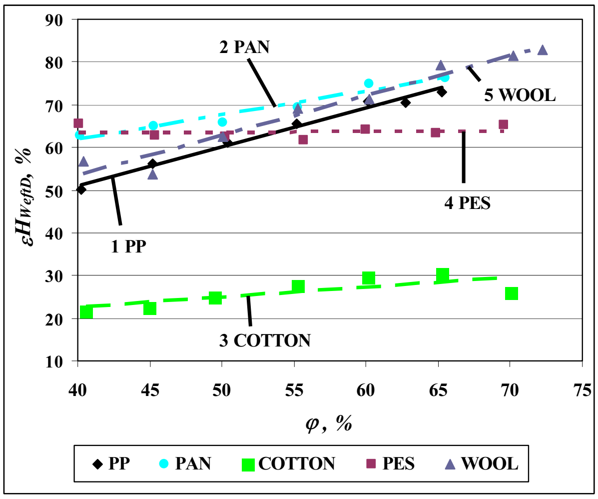

Fig. 3. Dependences of the elongation at break εH on the integrated fabric structure factor φ, when weaving fabrics of different raw material (weft direction)

Table 4. Equations and determination coefficients of dependence of elongation at break εH on the integrated fabric structure factor φ in weft direction

Graph No	Raw material	Equation	Determination coefficient R^2
1	PP	$\varepsilon H = 0.9063\varphi + 14.798$	0.9838
2	PAN	$\varepsilon H = 0.5678\varphi + 39.016$	0.9485
3	COTTON	$\varepsilon H = 0.2397\varphi + 12.799$	0.5952
4	PES	$\varepsilon H = 0.0073\varphi + 63.136$	0.0027
5	WOOL	$\varepsilon H = 0.9345\varphi + 16.006$	0.9572

Elongation at break in warp direction of almost all fabrics (Fig. 4) increases together with increase of factor φ. The same tendency, but of PES fabrics, was traced by Kumpikaitė and Sviderskytė [9]. To the contrary, of PP fabrics this tendency is decreasing, when fabrics are stiffening, though determination coefficient is equal to 0.9654, which means that dependence is very strong. This could be due to different warp tension on warp beam. Dependences of the other fabrics are middling. Elongation at break εH coefficient of variation of the wool, PAN and cotton fabrics didn't reach 5 %, whereas PP and PES fabrics bias reached 18 %. Equations and determination coefficients of dependences of elongation at break on the integrated fabric structure factor φ in warp direction are introduced in Table 5.

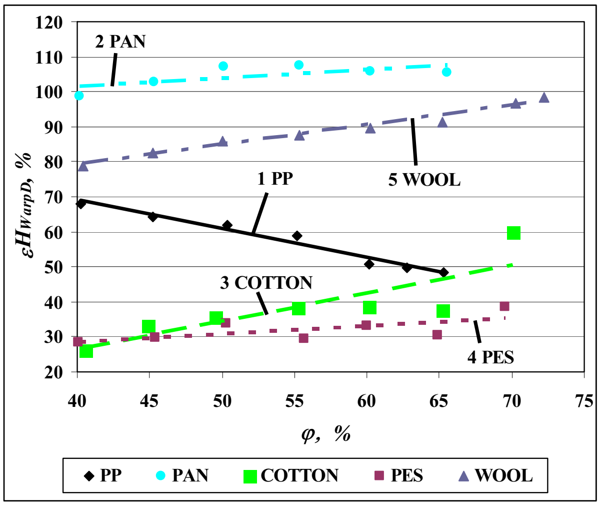

Fig. 4. Dependences of the elongation at break εH on the integrated fabric structure factor φ, when weaving fabrics of different raw material (warp direction)

Table 5. Equations and determination coefficients of dependences of elongation at break εH on the integrated fabric structure factor φ in warp direction

Graph No	Raw material	Equation	Determination coefficient R^2
1	PP	$\varepsilon H = -0.8252\varphi + 102.1$	0.9654
2	PAN	$\varepsilon H = 0.2431\varphi + 91.7$	0.4683
3	COTTON	$\varepsilon H = 0.8071\varphi - 6.023$	0.6989
4	PES	$\varepsilon H = 0.2234\varphi + 19.634$	0.4477
5	WOOL	$\varepsilon H = 0.562\varphi + 56.636$	0.9756

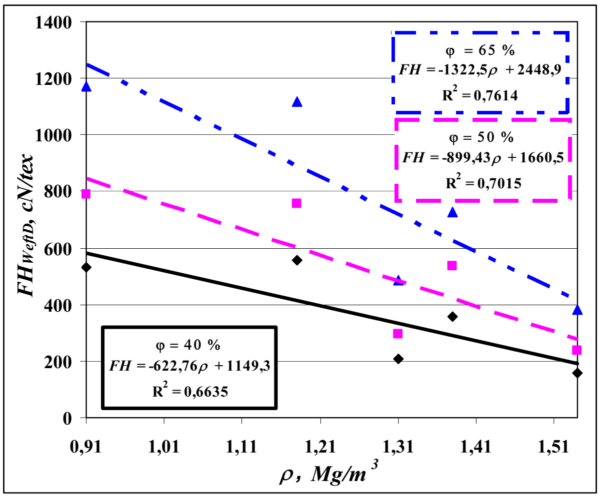

Fig. 5. Dependences of the breaking force FH on the material density ρ, when φ is equal to: ♦ – 40 %, ■ – 50 %, ▲ – 65 % (weft direction)

Fig. 5 introduces the dependences of the breaking force FH in weft direction on the material density ρ, when integrated fabric structure factor φ is equal to 40 %, 50 % and 65 %. Evidently, increase of the material density ρ leads to decrease of the breaking force FH. Determination coefficients are middling (from 0.6635, when $\varphi = 40$ % and 0.7614, when $\varphi = 65$ %). The highest breaking force is characteristic to curves, when integrated fabric structure factor φ is equal to 65 %, whereas the lowest breaking force is characteristic to curves, when φ is equal to 40 %.

In the case of warp direction (Fig. 6) very weak dependences between the breaking force FH and material density ρ are received, which means that there is no relationship between these explored properties, as determination coefficients appear to be very low (0.00004 ÷ 0.0142).

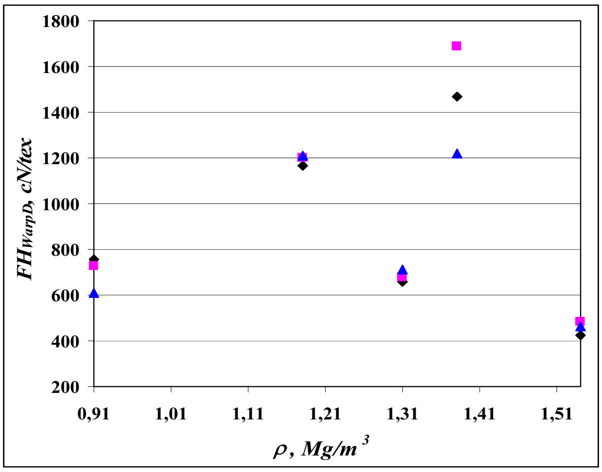

Fig. 6. Dependences of the breaking force FH on the material density ρ, when φ is equal to: ♦ – 40 %, ■ – 50 %, ▲ – 65 % (warp direction)

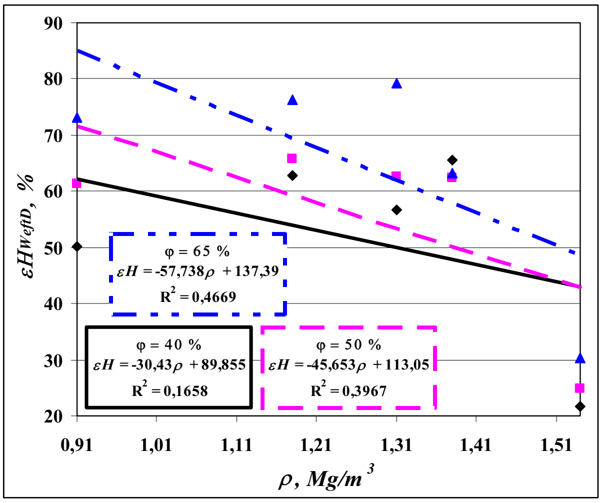

Fig. 7. Dependences of the elongation at break εH on the material density ρ, when φ is equal to: ♦ – 40 %, ■ – 50 %, ▲ – 65 % (weft direction)

Fig. 7 introduces the dependences of the elongation at break εH in weft direction on the material density ρ, when φ is equal to 40 %, 50 % and 65 %. It is discovered that increase of the material density ρ leads to decrease of the elongation at break. The highest elongation at break is that of the curve with integrated fabric structure factor of 65 %, whereas the lowest – of the curve, where φ is equal to 40 %. Dependences appear to be weak or middling. Determination coefficient is amounting to 0.4669, when $\varphi = 65$ %. It amounts to only 0.1658, when $\varphi = 40$ %.

The situation with warp direction (Fig. 8) is different: the curves tend to decrease, when the material density ρ increases. The relationship is weak; however, it is stronger with respect to dependences of the breaking force *FH* of warp direction on the material density ρ. The values of determination coefficients of the elongation at break differ correspondingly: when $\varphi = 40$ %, $R^2 = 0.3662$; when fabrics are more rigid ($\varphi = 50$ %), $R^2 = 0.1927$; finally, fabrics are most rigid ($\varphi = 65$ %), determination coefficient amounts to only 0.061. Values of determination coefficients of the breaking force are even lower and it is possible to maintain that there is no relationship between explored property εH and the material density ρ.

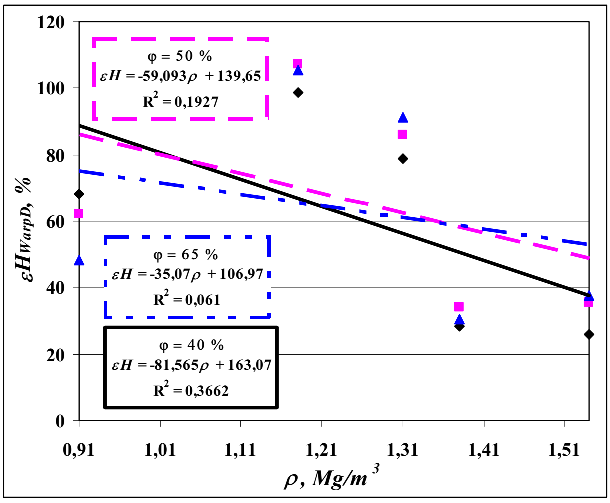

Fig. 8. Dependences of the elongation at break εH on the material density ρ, when φ is equal to: ♦ – 40 %, ■ – 50 %, ▲ – 65 % (warp direction).

Fig. 9 introduces the dependences of the static friction force F_s on the integrated fabric structure factor φ, when rubbing fabrics against the leather. Frydrych et al. [7] discovered relationship between changes of friction and contact interface of warp and weft. Truncytė and Gutauskas [11] explored dynamic friction force and dynamic friction coefficient among cotton and linen fabrics, rubbed against three different surfaces. They determined parallel results as we found. Fig. 9 shows that the static friction force remains to be stable among all fabrics, excepting wool, when fabric structure becomes more rigid, i. e. when factor φ is increasing. It means that there is a weak dependency between explored parameters. Static friction force margins of error of cotton, PES and PAN fabrics didn't reach 6 %, whereas wool and PP fabrics these errors seek 17 % and 15 %. Determination coefficients (Table 6) also point to this link. The static friction force of wool fabric is decreasing, when the integrated fabric structure factor φ is increasing. Exceptional character of wool fabric could be explained by the fact that this material is woven in crepe weave, whereas the rest of them are woven in plain weave. This exceptional phenomenon is because weave is a main property which influences fabric's friction force and the weave of wool fabric is different in comparison with other fabrics. Dependency of this material is the strongest and its determination coefficient amounts to 0.6145. However, alteration of its static friction force is the highest (from 0.53 N to 1.02 N), which makes 92.5 %. The highest static friction force is typical to PAN material (from 1.09 N to 1.18 N). Thus, alteration makes only 8.3 %. The least is alteration of the static friction force of PES material (from 0.32 N to 0.34 N), which makes 6.2 %.

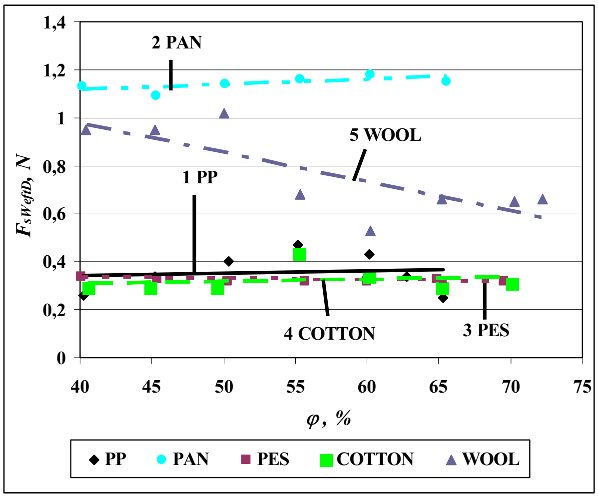

Fig. 9. Dependences of the static friction force F_s on the integrated fabric structure factor φ, when weaving fabrics of different raw material.

Table 6. Equations and determination coefficients of dependences of the static friction force on the integrated fabric structure factor φ

Graph No	Raw material	Equation	Determination coefficient R^2
1	PP	$F_s = 0.0011\varphi + 0.2984$	0.0141
2	PAN	$F_s = 0.0022\varphi + 1.0263$	0.4551
3	COTTON	$F_s = 0.0008\varphi + 0.2749$	0.0289
4	PES	$F_s = -0.0003\varphi + 0.3504$	0.3608
5	WOOL	$F_s = -0.0122\varphi + 1.4632$	0.6014

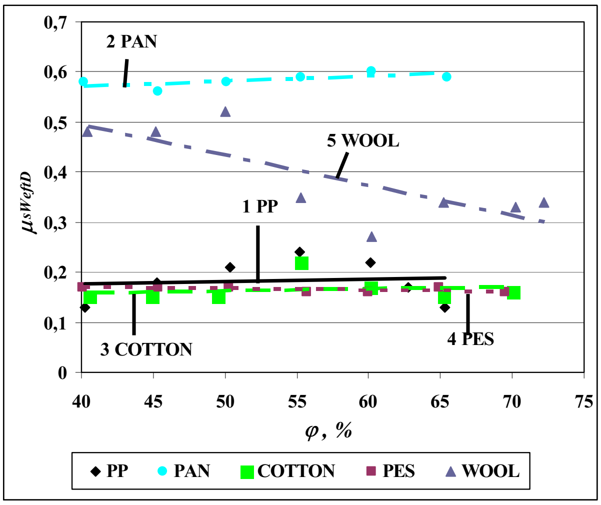

Fig. 10. Dependences of the static friction coefficient μ_s on the integrated fabric structure factor φ, when weaving fabrics of different raw material

Fig. 10 introduces the dependences of the static friction coefficient μ_s of different fabrics on the integrated fabric structure factor φ. Evidently, alteration of all fabrics is similar (excepting wool), curves are almost parallel to horizontal axis, i. e. the static friction coefficient μ_s is almost stable, when fabric structure is becoming more rigid. The highest coefficients of the static friction are those of PAN fabric. Its friction coefficients increase from 0.56 to 0.60, which makes 7.1 %. The biggest changes are those of wool material (from 0.27 to 0.52) and make 92.6 %. It could be explained by the fact that wool fabric's weave are different and it has a significant meaning to the fabric's friction. The curve of wool material tends to decrease, when factor φ is increasing. Dependence equations and determination coefficients of the static friction coefficient μ_s and integrated fabric structure factor φ are introduced in Table 7. Truncytė and Gutauskas [11] discovered that friction coefficient and dynamic friction force is always increasing and it does not depend on employed surface, whereas Frydrych et al. [7] determined that relationship between friction and contact interface exists. We determined similar results.

Table 7. Equations and determination coefficients of dependences of the static friction coefficient on the integrated fabric structure factor φ

Graph No	Raw material	Equation	Determination coefficient R^2
1	PP	$\mu_s = 0.0005\varphi + 0.158$	0.0098
2	PAN	$\mu_s = 0.001\varphi + 0.530$	0.4886
3	COTTON	$\mu_s = 0.0004\varphi + 0.1437$	0.0245
4	PES	$\mu_s = -0.0004\varphi + 0.182$	0.3430
5	WOOL	$\mu_s = -0.006\varphi + 0.7351$	0.6145

CONCLUSIONS

Dependences of the mechanical properties of fabrics of five different raw material on the integrated fabric structure factor φ and material density ρ were explored in this work. It was found that:

- in all fabrics (weft direction) breaking force *FH* and elongation at break εH increases, when fabric structure is stiffening (increasing integrated fabric structure factor φ);
- similar or the same tendency of the breaking force and elongation at break was not traced among fabrics of warp direction, as maximal breaking force *FH* and elongation at break εH of some materials increases or decreases, when factor φ is increasing. In this case minor dependencies with rather low determination coefficients are obtained;
- increase of the material density ρ of some fabrics of weft direction leads to decrease of breaking force *FH* and elongation at break εH;
- there is no relationship between breaking force *FH,* elongation at break εH of some fabrics (warp direction) and material density ρ, as determination coefficients are very low;
- static friction force F_s of all fabrics (excepting wool) is almost stable, when fabric structure is stiffening (factor φ is increasing). Static friction force F_s of wool material is decreasing, when integrated fabric structure factor φ is increasing. Exceptional character of wool fabric could be explained by the fact that it is woven in crepe weave, whereas the rest of them are woven in plain weave;
- curves of other fabrics are almost parallel to horizontal axis and it points to existence of minor dependence between static friction force F_s and integrated fabric structure factor φ;
- alteration of all fabrics, excepting wool, is similar, i. e. stiffening of fabric structure makes almost no impact on static friction coefficient μ_s. The curve of wool material tends to decrease, when factor φ is increasing.
- as in earlier research, where weft setting varies irregular, we received the same tendency in this research, that mechanical properties of fabrics also varies irregular.

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