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PROPERTIES OF PARACHUTE FABRICS FROM POLYAMIDE AND POLYESTER MATERIALS

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ABSTRACT

Traditional parachute fabrics are composed from PA 66 (nylon type) multifilament yarns. They are resistant against high frequency repeat deformation but they are able to absorb water which is not optimal for use in different climatic conditions. Challenge is to create parachute fabrics made of PES multifilament yarns which are more versatile. Main aim of this work is to investigate influence of parachute fabric composition and construction characteristics on real end use properties. The relationships based on the prediction of bulk densities were used to calculate the volume porosity. The morphology of the parachute fabrics was evaluated using scanning electron microscopy. Mechanical and dynamic mechanical properties of parachute fabric Ortex made from multifilament PA 66 and PES yarns by Sky Paragliders company are compared.

KEYWORDS

Parachute fabrics; Morphology; Porosity; Mechanical properties; Calendering.

INTRODUCTION

Parachute textiles are during use exposed to a series of rapid events during the opening of the parachute and handling during descent, which can lead to their frictional and thermal damages which at limit cause to catastrophic failure [1- 4]. In addition to standard textile tests, which are standardized, it is also necessary to develop or to modify tests that better characterize dynamic manifestations, surface structure and resistance to air flow in conditions simulating real conditions during use [5- 6]. The construction of fabrics largely affects the behavior of parachutes, especially with regard to their porosity and resistance to thermal shocks [7].

One of main challenge is the replacement of polyamide (PA 66) multifilament by polyester (PES) one. The problem is that no suitable company was found that produces polyester multifilament of the necessary parameters for other than polyethylene terephthalate (PET) polymers. The produced PET multifilament is therefore not primarily intended for parachute textiles.

A comprehensive evaluation of the structure and properties of polyamide fibers [8] and polyester fibers [9] was published e.g. in the chapters of the book "Handbook of Properties of Textile and Technical Fibers". PA 66 fibers generally have the following advantages compared to PET fibers:

- higher resistance to cyclic stress (better recovery),
- high flexibility (lower stiffness - modulus),
- higher toughness (energy required to break),
- high abrasion resistance,
- lower tendency to accumulate electrostatic charge (higher electrical conductivity),
- lower specific weight (but somewhat larger volume with the same geometry).

These advantages were the main reason for using PA 66 fibers for parachute fabrics. On the other hand, PA 66 are more sensitive to higher humidity (water content 4-5% under standard conditions), have lower resistance to torsion and less resistance to UV radiation than PET fibers. Also, the glass transition temperature and mechanical properties at elevated temperatures are lower. The problem is that the mechanical properties of the fibers vary over a relatively wide range depending on the length of the macromolecular chains, but especially on the conditions of fibers drawing and heat treatment. It is therefore difficult to evaluate the differences between parachute fabrics produced from multifilament prepared specifically for industrial parachute fabrics (PA 66) and parachute fabrics from multifilament produced primarily for other applications (PET).

The research activities described in this contribution are mainly focused on comparing and modifying the properties of parachute textiles made of PA 66

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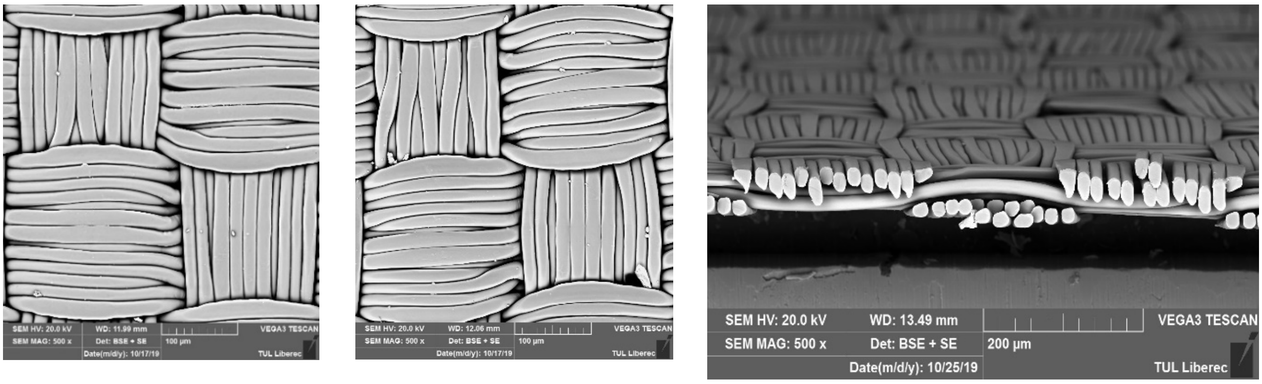

(a) (b) (c)

Figure 1. Sample 1: (a) front side, (b) reverse side, (c) cross section (magnification 500x).

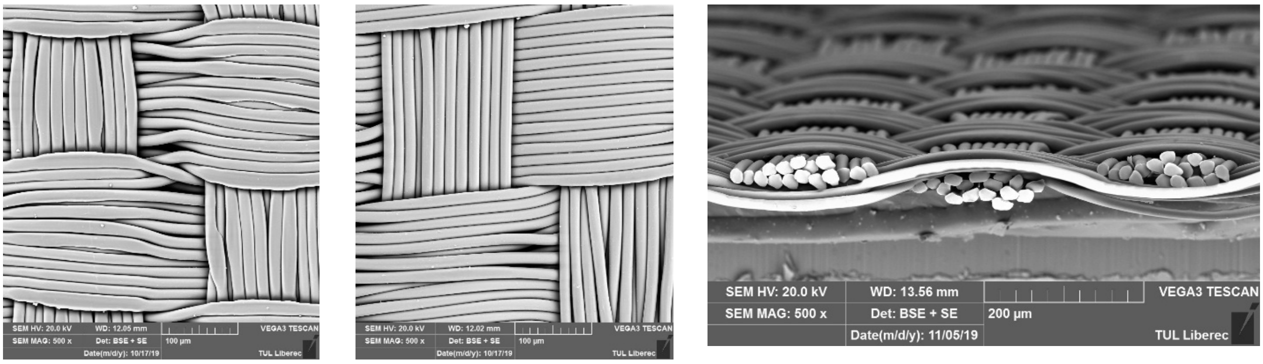

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Figure 2. Sample 2: (a) front side, (b) reverse side, (c) cross section (magnification 500x).

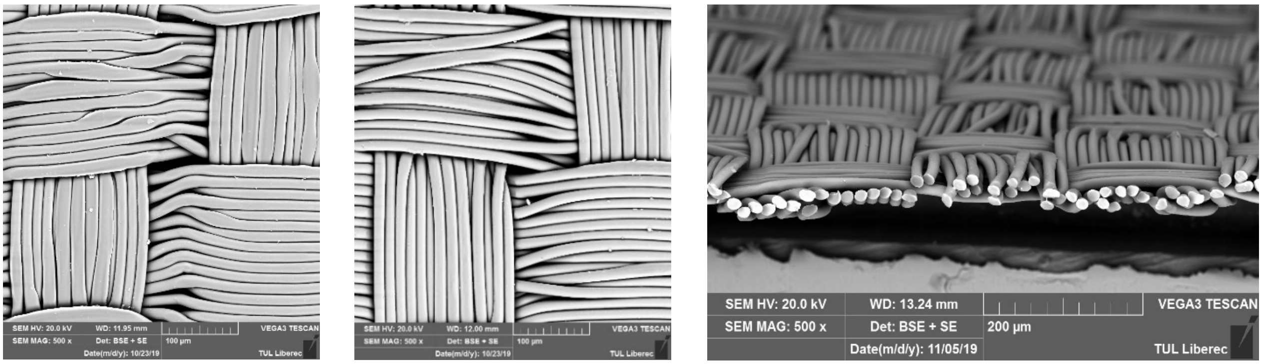

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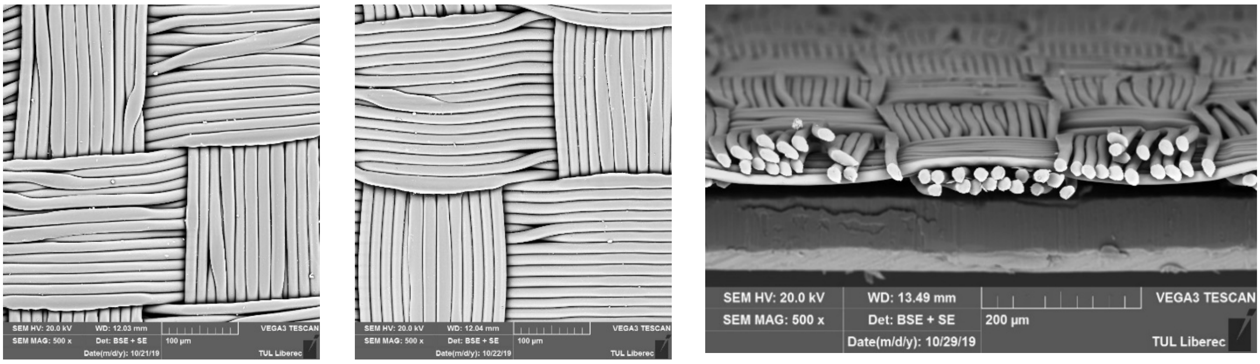
Figure 3. Sample 3: (a) front side, (b) reverse side, (c) cross section (magnification 500x).



(a) (b) (c)

Figure 4. Sample 4: (a) front side, (b) reverse side, (c) cross section (magnification 500x).

Table 1. List of Ortex parachute fabrics (Sky paragliders).

Sample	Composition	Treatment	Ends/cm	Picks/cm
1	PA 66 33dtex/14 fibers	Final fabric	31	30
2	PES 33dtex/16 fibers	Unfinished fabric	45	43
3	PES 33dtex/ 16 fibers	1st calendering (185 °C, 24m/min, 2500 N)	43	42
4	PES 33dtex/16 fibers	2nd calendering (185 °C, 24 m/min, 2500 N)	42	41

Table 2. Morphology of parachute fabrics.

Sample	Areal mass [gm^{-2}]	Thickness [mm]	Density [kgm^{-3}]	Porosity [-]
1	39.2	0.05	784	0.31
2	34.9	0.05	698	0.49
3	34.9	0.05	698	0.49
4	34.7	0.05	694	0.49

(sample 1) and polyester – PET (sample 2: raw, sample 3: after single calendering and sample 4: after two times calendering). The construction of these textiles was examined in more detail.

PARACHUTE FABRICS GEOMETRY AND VOLUMETRIC POROSITY

Ortex parachute fabrics made of PES and PAD multifils were supplied by company Sky Paragliders, see Tab. 1.

Microscopic images of fabric samples were prepared on a Vega Tescan electron microscope. From the microscopic images, the Ripstop weave was identified. Selected images of parachute fabric samples no. 1 to 4 are shown in Fig. 1 to 4.

It is visible that PA 66 fabric was calendered during preparation because the surface filaments are flat. Calendering of PET filaments had very low effect on fabrics surface geometry.

The thickness and areal weight (gsm) of the parachute fabrics were measured and their density (the ratio of areal weight to thickness) was calculated. The ratio of the density of the parachute fabric to the density of the fibers from which it is made is equal to the volume fraction of the fibers in the fabric. The PA 66 fiber density of 1130 kgm-3 and the PES fiber density of 1360 kgm-3 were used for the calculation. The volume porosity of the parachute fabrics was calculated as one minus volume traction. The results are shown in Tab. 2.

According to volume porosity, samples can be divided into 2 groups, sample no. 1from PA 66 has a significantly lower porosity value from 0.31. Samples from PET have porosity value of 0.49 independently of the first and second calendering. In sample from PA 66 are the fibers distributed relatively evenly at the binding points. In the case of PES fabrics, even after the second calendering, it was not possible to evenly distribute the weft fibers, which were apparently clogged under a lower tension. Air pores have been created in the edges of the attachment points, which increase the porosity of PES fabrics.

It was found that volume porosity correlates well with air permeability of parachute fabrics [4].

MECHANICAL CHARACTERISTICS OF PARACHUTE FABRICS

The mechanical properties of these fabrics were evaluated in terms of tensile, bending, tear, bursting strength and dynamical mechanical analysis. Further, the drape coefficient was also evaluated.

Tensile test

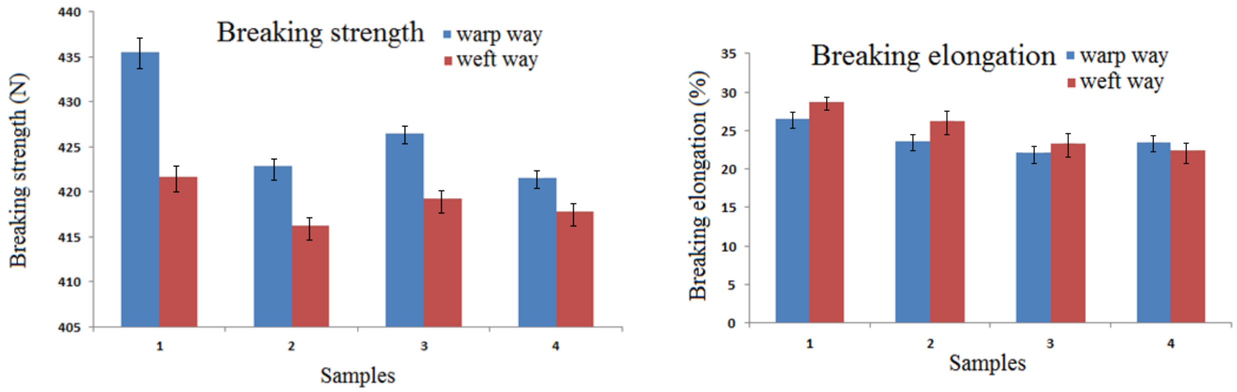
Tensile properties of all fabric samples in warp and weft direction were measured on a TIRA 2300 (LaborTech s.r.o., Opava,Czech Republic) universal testing machine. This test was performed according to standard EN ISO 13934-1 (sample size 5x3 cm rate of deformation 100 mm/min). The tensile strength and elongation at break were measured both in warp and weft directions. The results are given in Tab. 3 and in Fig. 5. The values are average of 5 measurements. In sequel errors bars are equal to end points of 95% confidence intervals.

The breaking strength is higher for sample of PA 66 compared to the PES samples. There is a slight increase of PES fabric strength after 1st calendering. A slight increase in strength after 1st calendering can be due to fusing of filaments which might cause an increase in cohesion and thus slightly higher load bearing capacity. However, after 2nd calendering again the strength decreases. This may be attributed to the degradation/weakening of PES filaments under the thermal treatment and calendering conditions. Overall it can be observed that the tensile strength of PES original fabric as well as calendered fabric is lower than the PA 66 fabric. Warp way strength is always higher than weft way strength due to consolidation of warp yarns and higher weaving tension, which might have caused better orientation of filaments and thus improved mechanical performance. Breaking elongation are given in Fig. 5(b).

Table 3. Tensile properties.

Samples	Breaking strength [N]				Breaking elongation [%]			
	warp		weft		warp		weft	
	Mean	SD*)	Mean	SD*)	Mean	SD*)	Mean	SD*)
1	435.54	19.43	421.64	21.23	26.55	1.19	28.71	0.89
2	422.85	17.23	416.23	18.30	23.63	0.87	26.20	1.02
3	426.51	16.83	419.28	18.33	22.11	1.32	23.23	1.12
4	421.55	17.92	417.82	15.32	23.42	1.09	22.39	1.32

*) SD is abbreviation of standard deviation



(a) (b)

Figure 5. (a) fabric breaking strength [N], (b) fabric breaking elongation [%].

Table 4. Tearing strength.

Samples	Tearing strength [N]			
	warp		weft	
	Mean	SD	Mean	SD
1	32.37	1.37	33.63	1.49
2	26.22	1.27	25.72	1.42
3	22.26	1.32	25.06	1.34
4	23.42	1.09	25.33	1.14

The breaking elongation for PA 66 fabric is higher than PES fabric. The thermal treatment during calendering causes fusing and increased cohesion between filaments, which restricts the tensile deformation. Moreover, the weakening of individual filaments leads to a lower elongation at break. Elongation in the weft direction is slightly higher than elongation in the warp direction. It is due to lower weft tension and higher residual elongation, which is retained in the weft filaments as compared to the warp way filaments.

Tear test

A parachute fabric tears when it is snagged by a sharp object and the immediate small puncture is converted into a long rip by what may be a very small extra effort. It is probably the most common type of strength failure of parachute fabrics in use. It is particularly important in industrial fabrics that are exposed to rough handling in use such as tents and sacks and those where propagation of a tear would be catastrophic such as parachutes. For measurement of tear strength, EN ISO 13937-2 standard is used (rate of deformation 100 mm/min). The tear strength in warp and weft direction is given in Tab. 4. The values are average of 5 measurements.

The tearing strength is a measure of the inter-yarn cohesiveness and friction between adjacent yarns. Tearing warp way needs to break the weft yarns and split them from forming bundles. Similarly tearing in the weft direction involves breakage and rupture of warp filaments. It is observed that the weft way tear strength is higher than warp way tear strength. It is due to relatively stronger warp yarns as compared to weft yarns as well as higher wrap sett compared to weft sett. The PA 66 sample shows higher tearing strength, which is mainly due to stronger filaments as compared to PES filaments. Moreover, the inter-fiber and inter-yarn frictional forces are higher. The calendering rather weakens the PES filaments in the weft and there is slight decrease in the tear strength in warp direction. Weft way tear strength remains almost unchanged.

Bursting strength test

Bursting strength is an alternative method of measuring strength in which the material is stressed in all directions at the same time and is therefore more

Table 5. Bursting strength.

Samples	Bursting strength [kPa]	
	Mean	SD
1	329.12	17.20
2	330.72	13.67
3	326.24	13.23
4	322.30	16.53

Table 6. Drape coefficient.

Samples	Drape coefficient
1	32.37
2	33.79
3	32.82
4	33.19

suitable for parachute materials. These are fabrics, which are simultaneously stressed in all directions during service where it may be important to stress them in a realistic manner. The EN ISO 13938-2 standard is used for measurement of bursting strength. The fabric bursting strength is given in Tab. 5. The values are average of 5 measurements.

The bursting strength shows no significant difference. There is a slight decrease in bursting strength after calendering of PES fabric which may be due to thermal degradation of the filaments.

Drape measurement

Fabric drape can be defined as a description of the deformation of a fabric produced by gravity when only part of it is directly supported. The drape ability of a fabric is quantified into a dimensionless value called ‘drape coefficient’, which is defined as the percentage of the area from an annular ring of the fabric covered by a vertical projection of the draped fabric. The ISO 9073-9:2008 standard is followed for such measurements. Results of drape coefficient calculation are shown in Tab. 6.

There is no significant difference in drape ability of the fabrics. However, the drape coefficient of PES parachute fabrics is slightly higher than the PA 66 fabric. It can be due to higher stiffness of fabrics resulting from stiffer yarns and higher fabric sett. The yarns of PES could be stiffer as they are composed from 16 filaments as compared to 14 filaments in case of PAD yarns. Moreover, the PES fabrics have much higher sett in both warp and weft direction which increases the fabric stiffness. The calendaring does not change the drape too much.

Bending rigidity

The bending rigidity is related to the tensile modulus for a simple body, as in the case of a single fiber; however, this relationship is not so straightforward in the case of a fabric. To measure the fabric bending stiffness, the cantilever method is widely used in practice. The fabric bending length is measured by using cantilever stiffness measurement equipment. The bending rigidity was measured by the standard ASTM test method D-1388.

Bending rigidity or stiffness depends on the rigidity of yarns as well as the fabric sett. The results of stiffness measured in warp and weft direction are given in Tab. 7 and Fig. 6.

The bending rigidity of fabric is dependent on fiber/filament diameter, yarn fineness, number of filaments, the inter-fiber and inter-yarn friction etc. Friction between individual filaments in a yarn is caused by different mechanisms. The filaments on the outer perimeter of the yarn interact with filaments

Table 7. Bending rigidity of fabrics.

Samples	Bending rigidity (N.m^2) x 10^{-6}			
	warp		weft	
	Mean	SD	Mean	SD
1	10.62	0.63	10.53	0.45
2	10.83	0.67	10.78	0.52
3	10.97	0.83	10.88	0.66
4	10.84	0.72	10.68	0.62

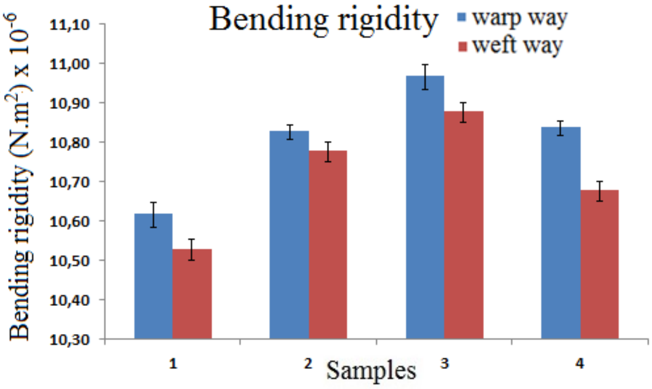
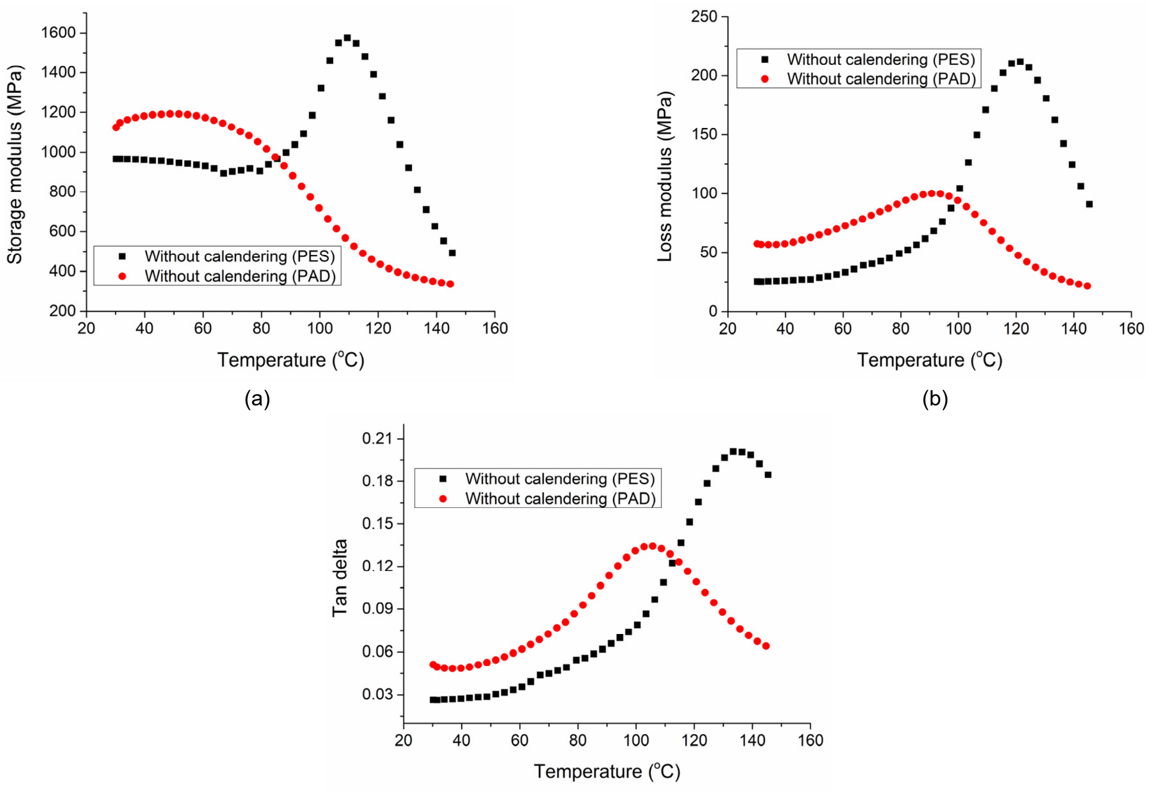


Figure 6. Fabric bending rigidity.



(a)

(b)

(c)

Figure 7. Dynamic mechanical properties of polyester and polyamide parachute fabrics: (a) storage modulus, (b) loss modulus, (c) tan delta.

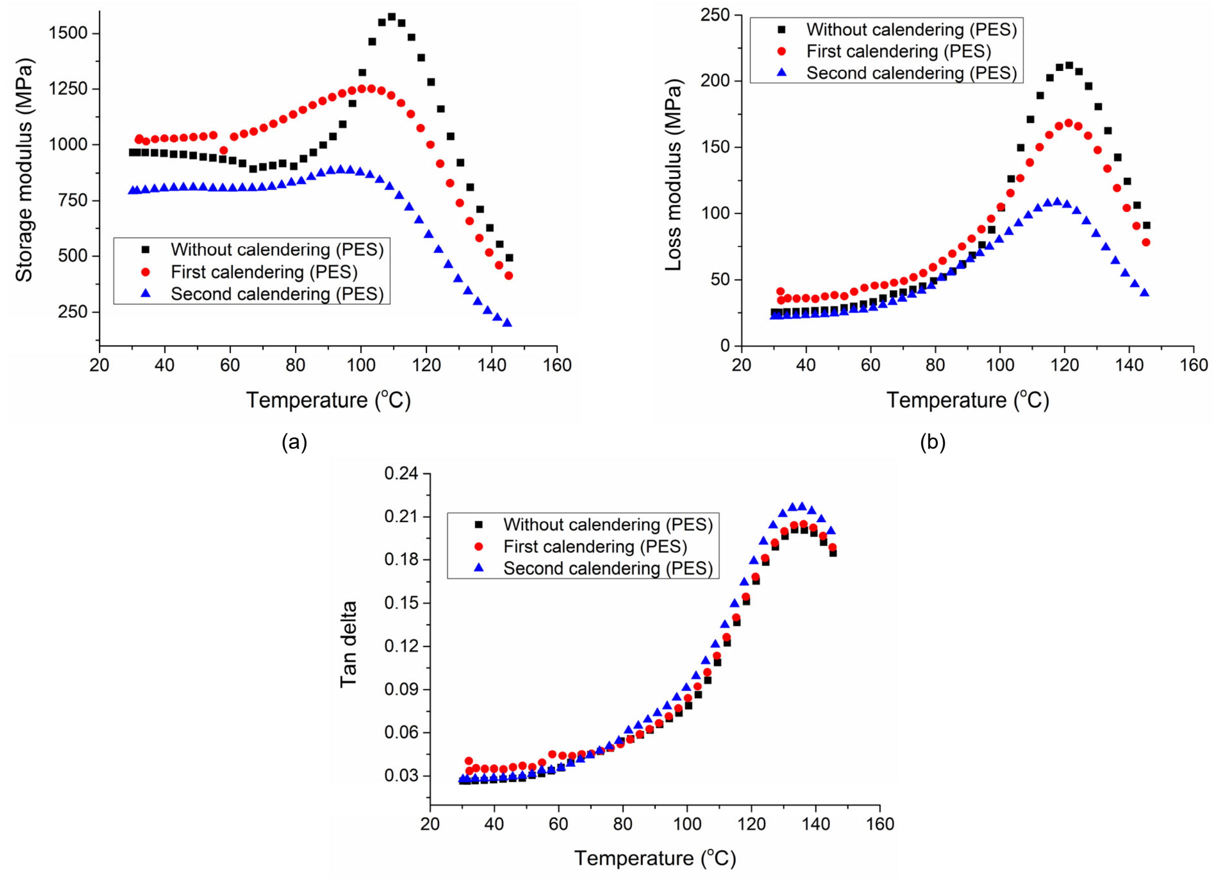
from other yarns due to undulation in fabrics. Filaments within the yarns are often entangled because of fiber migration and length differences due to deformations. A fiber sizing is often applied during production to protect the yarn material and/or improve fiber-matrix bonding. Another factor plays a role in the intra- as well as inter-yarn friction behavior. The effects mentioned above all have influence on the deflection behavior of yarns based on friction mechanisms.

It is clearly visible that warp way rigidity is higher than weft way bending rigidity as the warp yarns are stiffer and there is a higher sett in warp direction. The PES samples have higher rigidity as compared to the PA 66 fabric. It can be due to inherent higher rigidity of the PES filaments as compared to PA 66 filaments. There are higher number of filaments in each yarn thus causing increase in yarn bending rigidity. Further, the sett of the PES fabrics is much higher than the PA 66 fabric. Therefore, the bending stiffness is increased. After 1st calendering, there is probably stiffening and partial sticking of the PES filaments and thus a further increase in stiffness is observed. During 2nd calendering, there is a possibility of filament/fiber weakening which results in a deterioration of mechanical properties. It might cause a loss of rigidity as well. The deterioration of weft yarn seems more severe as compared to the warp yarn.

Dynamic mechanical analysis

The dynamic mechanical properties of PA 66 and PES parachute fabrics were measured in tensile mode using Q800 Dynamic mechanical thermal analysis (DMTA) instrument of TA instruments (New Castle DL, USA). The testing conditions were controlled in the temperature range of 30–150 °C, with a heating rate of 3 °C/min, at frequency of 1 Hz, preload of 0.01 N, amplitude of 15 µm, and force track of 125%. The test was carried out with gauge length and sample width of 30 mm and 10 mm respectively.

The effect of calendaring treatments on change in dynamic mechanical properties of was studied. The storage modulus results depicted the load bearing capacity whereas the tan delta results showed the damping properties of parachute fabrics (see Fig. 7). The PA 66 fabric showed higher storage modulus (i.e.1124 MPa) than the storage modulus of polyester fabric (i.e. 965 MPa) at 30 °C. This increase in storage modulus value can be attributed to the higher stiffness of polyamide fabric structure However, the storage modulus of polyamide fabric dropped at faster rate than polyester fabric with the increase in temperature. At 100 °C, the storage modulus of 713 MPa was observed in case of PA 66 fabric as compared to the storage modulus of 1300 MPa for PES fabric. The significant drop in storage modulus of PA 66 fabric was due to the softening of structure and easier movement of polymeric chains.



(a)

(b)

(c)

Figure 8. Effect of calendaring on dynamic mechanical properties of polyester parachute fabrics: (a) storage modulus, (b) loss modulus, (c) tan delta.

On the other hand, the relatively smaller drop in case of PES fabric was attributed to their restricted segmental motion at higher temperatures. The damping properties of the material give the balance between the elastic phase and viscous phase in a polymeric structure. The ratio of loss modulus to storage modulus is defined as mechanical loss factor or damping factor or tan delta. The damping factor expresses an ability of converting the mechanical energy into heat energy when the material is subjected to an external loading. It was observed that the PA 66 fabric has lower damping factor as compared to PES fabric, which indicates their increment of the loss of energy due to macromolecular friction. Furthermore, the tan delta peak of PES fabric was located at higher temperature (i.e. at 135 °C) as compared to the PA 66 fabric (i.e. at 103 °C).

The curves confirmed that all the properties of the parachute fabrics were greatly affected by calendering treatments across all temperature ranges (see Fig. 8). At 30 °C, the PES fabric with no calendaring treatment showed higher storage modulus (i.e. 965 MPa) than second calendered polyester fabrics (792 MPa). The marginal improvement in storage modulus was shown by first calendared PES fabric (1020 MPa) over non-calendared fabric. This change in load bearing capacity under different calendaring actions is attributed to partial softening of polyester fabrics due to segmental mobility of polymeric chains. With further increase in temperature, the storage modulus of calendared PES fabrics was dropped heavily as compared to non-calendared PES fabrics. The storage moduli of 1135 MPa, 889 MPa and 498 MPa were depicted by PES fabrics of without calendaring, first calendaring and second calendaring actions respectively at 125 °C. The significant drop in storage modulus of polyester fabric at higher temperature was attributed to even higher segmental mobility of polymeric chains than observed at 30 °C. Furthermore, no significant change in damping factor was observed after the calendaring actions on the polyester fabrics.

CONCLUSION

It has been shown that when using PET multifilament of the same fineness and number of fibers as PA 66 multifilament, the PET multifilament has a smaller diameter, and the filaments diameter is also smaller. For these reasons, it is necessary to use a slightly higher level of PET fabric sett than the sett of PA 66 fabric. In calendered parachute fabrics, the multifilament fibers are usually spread evenly so that the flattening is near to one. Due to the higher value of fiber density, PET multifilament fabric achieves slightly higher values of areal weight and total density than PA 66 multifilaments.

It was clearly shown that differences between parachute fabrics from PA 66 (especially prepared for parachutes) and PES (prepared for general use) are not very different. In many cases are common PES fabrics over special PA 66 fabrics. This is great challenge for preparation of special PES fabrics for parachutes with enhanced mechanical properties by use higher polymerization degree higher drawing ratio and proper thermal treatment [2]. It was confirmed that prototype PET fabric gets the similar morphology, mechanical properties and surface behavior than actual PA 66 parachute fabric

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REFERENCES

1. Johari H., Desabrais K.J.: Stiffness scaling for solid cloth parachutes, Journal of Aircraft, 40(4), 2003, pp. 631-638. https://doi.org/10.2514/2.3166
2. Cockrell D.J.: The Aerodynamics of Parachutes, Cambridge: AGARD, 1987.
3. Ericksen R.H.., et al.: Deflection-force measurements and observations on Kevlar 29 parachute fabrics, Textile Research Journal, 62(11), 1992, pp. 628-638. https://doi.org/10.1177/004051759206201102
4. Shi Q., et al.: On the verification and validation of a spring fabric for modeling parachute inflation, Journal of Fluids and Structures, 58, 2015, pp. 20–39. https://doi.org/10.1016/j.jfluidstructs.2015.06.014
5. Kiryukhin S.M., Lazunina Yu.N.: Assessment of strength reliability of polyamide parachute fabrics, Fibre Chemistry, 46, 2014, pp. 56-58. https://doi.org/10.1007/s10692-014-9560-2
6. Citoglu F., Esi B.: Parachute fabric and its manufacturing process, International Journal of Science, Environment and Technology, 6(5), 2017, pp. 3214 – 3224.
7. Baker A., Swallow J. E.: Light transmission and air flow through nylon parachute fabrics, Journal of the Textile Institute Transactions, 47, 1956, T102-T109. https://doi.org/10.1080/19447027.1956.10750380
8. Militký J., Venkataraman M., Mishra R.: The chemistry, manufacture, and tensile behavior of polyamide fibers, In Bunsell A. R. ed.: Handbook of Properties of Textile and Technical Fibres, Elsevier, 2018.
9. Militký J.: Tensile failure of polyester fibers, In Bunsell A. R. ed.: Handbook of Properties of Textile and Technical Fibres, Elsevier, 2018.
10. Kaynak H.K., Babaarslan O.: Polyester microfilament woven fabrics, In Han-Yong J. ed.: Woven Fabrics, Rjeka, 2012.
11. Křemenáková, D. et al.: Air permeability of parachute fabrics, In Preparation.

This work is dedicated to prof. Izabella Krucińska from TU Lodz, who was not only a prominent scientific personality but also our close friend. A tribute to her memory.