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The Influence of Modacrylic and Metal Protective Fibres in the Mixture on the Mechanical Properties of Ring Spun Yarns for Protective Textiles

Vpliv dodanih vlaken MAC in MTF v mešanici na mehanske lastnosti prstanske preje za varovalne tekstilije

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Abstract
The research is focused on the influence of the fire resistant modacrylic (MAC) fibres in the ring-spun yarn mixture with cotton (CO) fibres and of the conductive metal fibres (MTF) in the ring-spun yarn mixture with polyester (PES) fibres on the mechanical properties in the region of lower loads. Analysed yarns are intended for the protective clothing production (fire resistant and electrically conductive clothing). The viscoelastic behavior of yarns in the field of lower loads under the specific stress/extension curve which amounts to 5 cN/tex, reaching the weight of 85 g. The results of the research show that the incorporation of MAC fibres in the yarn from the mixture of 55% MAC/45% CO fibres increases the region of elastic deformations (the stress and extension in the yield point), on the other side the MAC fibres in the yarn mixture decrease the elasticity modulus level. The incorporation of MTF (stainless stell) fibres in the yarn mixture consisting of 75% PES/25% MTF decreases the region of elastic deformations (about 10%), however the region of elastic deformations lies very close to the chosen stress value under the specific stress/extension curve – 5 cN/tex or 85 g.
Keywords: modacrylic fibres, metal fibres, ring-spun yarn, mechanical properties, viscoelastic properties

Izvleček
Raziskava je usmerjena na vpliv ognjevarnih modakrilnih vlaken v prstanski preji iz mešanice modakrilnih in bombažnih vlaken in elektroprevodnih kovinskih vlaken v prstanski preji iz mešanice poliestrskih in kovinskih vlaken na mehanske lastnosti v območju manjših (uporabnih) obremenitev. Analizirane preje so namenjene za izdelavo zaščitnih oblačil (ognjevarnih in elektroprevodnih), tako se raziskava osredinja na viskoelastično območje manjših obremenitev na krivulji napetost/raztezek, tj. pri napetosti 5 cN/tex, kar pomeni obremenitev mase 85 g. Raziskava je pokazala, da ognjevarna modakrilna vlakna (MAC) v mešanici iz 55 % modakrilnih 45 % bombažnih vlaken vplivajo na povečanje elastičnega območja (napetost in raztezek v meji polzišča), na drugi strani pa vplivajo na znižanje modula elastičnosti prstanske preje. Vsebnost MTF (iz nerjavnega jekla) vlaken v mešanici iz 75 % PES in 25 % MTF vlaken vpliva na zmanjšanje elastičnega območja za okrog 10 %, na drugi strani pa se vrednosti elastičnega območja gibljejo v mejah območja manjših (uporabnih) obremenitev na krivulji specifična napetost/raztezek, ki znaša 5 cN/tex oziroma 85 g.
Ključne besede: modakrilna vlakna, kovinska vlakna, prstanska preja, mehanske lstnosti, viskoelastične lastnosti

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1 Introduction

The protection becomes nowadays very important taking into account the industrial developments and the strong need to increase the workwear clothing production, especially in the field of protective clothing. The protective textiles have extraordinary importance for the European textile and clothing industries as well as the end users. Protective textiles show high-tech character and are used mainly in the industrial segments. The expected average increase in Europe in the field of protective textiles production amounts to around 4% [1–3].

Novel developments with complex protection requirements are, apart from the protection against electromagnetic radiation, also directed to the protective clothing for electricians working on energized plants with the risk of exposure to very high arcing flames. The facts presented above have encouraged the direction of the research in regard to the mechanical behavior of the ring-spun yarn from flame resistant and electrically conductive yarn mixtures. Certain authors dealt with the flame retardant properties of yarns and fabrics. In recent years, many researchers are interested also in electrical and conductive properties of fibres and fabrics intended for protective clothing [4–7].

Approximately 90% of global fiber consumption is processed into yarns, with 57% of the entire production consisting of yarns from chemical fibres. About 8% of the yarn production belongs to the organic fibres intended for protective clothing, while inorganic fibres present around 1% of yarn production intended for protective clothing [8].

The number of natural disasters such as floodings, landslides and fires are unfortunately increasing in the last few years. With the increasing of disasters, the need of functional textiles, i. e. the protective clothing for firefighters, rescuers, civil protection, police is also increasing. That is the main reason for choosing the research which deals with so–called protective ring-spun yarn loading behavior.

A growing segment of the industrial textiles industry has therefore been involved in a number of new developments in fibres, fabrics and protective clothing. For heat and flame protection, requirements range from clothing for situations in which the wearers may be subjected to occasional exposure to a moderate level of radiant heat as part of their normal working day, to clothing for prolonged protection, where the wearer is subject to several factors such as radiant and convective heat, to direct flame, for example the firefighter's suit.

The effect of heat on a textile material can produce physical as well as chemical change. In thermoplastic fibres, the physical changes occur at the glass (Tg), and melting temperature (Tm), while the chemical changes take place at pyrolysis temperatures (Tp) at which thermal degradation occurs. Textile combustion is a complex process that involves heating, decomposition leading to gasification (fuel generation), ignition and flame propagation. Fibres with LOI (limiting oxygen index) greater than 25% are flame retardant. For protective clothing, however, there are additional requirements, such as protection against heat by providing insulation, as well as high dimensional stability of the fabrics, so that, upon exposure to the heat fluxes that are expected during the course of the wearer's work, they will neither shrink nor melt [1, 2].

The fibres could be classified into two categories:

- Inherently flame–retardant fibres, such as aramid, modacrylic, polybenzimidazole (PBI), Panox (oxidised acrylic) or semicarbon, phenolic, asbestos, ceramic etc.
- chemically modified fibres and fabrics, for example, flame retardant cotton, wool, viscose and synthetic fibres.

Electromagnetic radiation has become the fourth most serious source of public pollution in addition to noise, water and air. It is claimed that the electromagnetic waves affect human health and the performance of electrical and electronic devices.

Textile materials made with conductive fibres and yarns can shield the large part of the electromagnetic waves and protect health of the humans and animals. Conventional textile fabrics are poor electrical conductors. Conducting yarns are used to produce fabrics for electromagnetic shielding and electrostatic charge dissipation. Such yarns and fabrics are increasingly used in applications where flexibility and conformability are important. Demand for these products has increased rapidly.

Conductive yarns are produced from metal fibres which have high electrical conductivity, such as stainless steel and copper. They are produced by mixing metal fibres with chemical fibres, cotton and viscose fibres; these increase the electrical conductivity of the fabric, thus eliminating electrostatic charges and preventing static loading on the fabric [1–3].

Modacrylic fibres

Modacrylic fibres are chemical fibres which are composed of less than 85% but at least 35% by weight of acrylonitrile units and have excellent chemical, sun light and flame resistance. The modacrylic fibre melts at around 180–185 °C and exhibits a high range of moisture, around 3.0–3.5%. Temperatures exceeding 150 °C will cause modacrylic fibre to turn yellow, nevertheless, the modacrylic fibre has a very good flame resistance and good weathering resistance. The specific stress of modacrylic fibres ranges from 15.9–22.1 cN/tex with 35–40% elongation. Modacrylic fibres have high value of elastic recovery (88% at 4% deformation), while their specific gravity is 1.37 g/cm^3 [10–13].

Metal fibres

Metal fibres are fibres produced from metals, which may be used alone or in combination with other substances. Metal fibres are produced mainly from aluminum, stainless steel and nickel. Their melting point stands at approximately 1426 °C.

Their specific breaking stress stands at around 22.3 cN/tex, with breaking elongation lower than 1% and they are chemical and thermal resistant.

They are also excellent electrical conductors, rather than stainless steel which is poor conductor, and may be used for resistance heating.

Metal fibres have higher melting point and are more heat resistant than ordinary fibres.

In addition, they are flame resistant and are used mainly for protective fabrics, carpets, upholstery, work clothing and protective clothing [10–17].

The research focuses on the influence of the fire resistant modacrylic (MAC) fibres in the mixture of 55% MAC/45% CO (MAC/CO) fibres and the conductive metal fibres (MTF) in the mixture of 75% PES/25% MTF (PES/MTF) fibres on the mechanical and viscoelastic properties of the ring-spun yarn. Since the yarns analysed are intended for the protective clothing production, the research focuses on the mechanical behavior of the yarns analysed. The research focuses on the field of lower loads under the specific stress/extension curve which amounts to 5 cN/tex, wherein the stress presents the weight of around 85 g.

With that purpose the two-plied fire resistant ring-spun yarn from 100% cotton fibres (100% CO fibres) and the mixture of modacrylic and cotton two-plied yarn in the percentage ratio of 55%/45% were analysed in the first part. Furthermore, the research focuses on the ring-spun yarn from the 100% PES fibres and the electrically conductive yarn from mixture of PES and metal fibres with the ratio of 75%/25%. In the experimental part the mechanical properties (specific stress and extension) were analysed and yarn quality (unevenness) such as yarn imperfections (the mass irregularity CV_m, thin and thick areas/1,000 m, neps and yarn hairiness). The yarn quality was measured on the Uster Tester, while the mechanical properties of analysed yarns were measured on Statimat Tester. The viscoelastic properties (elasticity modulus, the yield point) were calculated from the specific stress/extension curve using DINARA® software [9].

2 Materials and methods

In the research, two-plied ring-spun yarn from 100% cotton fibres and the mixture of modacrylic and cotton fibres in the ratio of 55% modacrylic fibres and 45% cotton fibres were analysed in the first part (short MAC/CO). While in the second part, the research concentrates on the single ring-spun yarn from the 100% PES fibres and the yarn from mixture of PES and metal fibres, with percentage ratio of 75% PES/25% MTF (short PES/MTF) fibres.

The yarns analysed were produced in Predilnica Litija from short staple fibres. The fineness of the single- and two-plied yarns amounts to 16.67 tex.

The two-plied yarn from 100% cotton fibres and the mixture of modacrylic and cotton fibres in the ratio of 55% modacrylic fibres and 45% cotton fibres is wound, doubled and twisted with 720 and 660 twist per meter in the S-direction (counterclockwise direction).

The yarn quality and irregularity, yarn imperfections (the mass irregularity CV_m in percents, the number of thin and thick areas/1000 m, the number of neps) and yarn hairiness were measured on the Uster Tester, while the mechanical properties (stress and extension) were measured on Statimat tester.

On the Uster Tester the yarn is passed through the electric field of a measuring capacitor. Mass variation of the yarn causes the disturbance of the electric field which is converted into electric signal.

The capacitive sensor of Uster Tester is not able to measure the irregularity of special yarns containing electrically conductive material such a metallic fibres, etc.

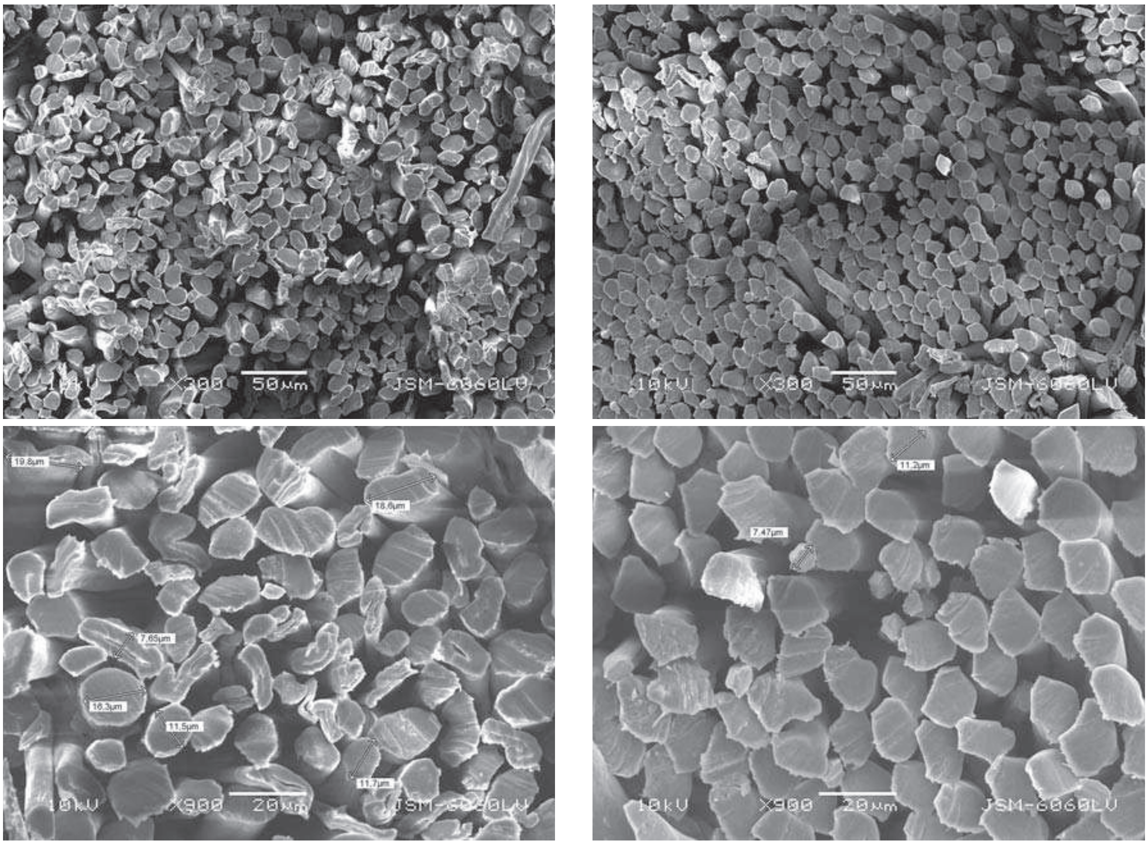
The viscoelastic properties such as elasticity modulus and the yield point were calculated using DINARA® software [9].

The scanning electron microscope (SEM) view of analysed ring-spun yarns from the mixture of MAC/CO and the mixture of PES/MTF fibres is presented in the Figure 1.

Table 1 presents the basic properties of raw material (fibres), while Table 2 presents the basic properties of yarns. The irregularity (quality) of yarn is measured on the Uster Tester (Table 3).

Table 1: The basic properties of fibres

Type of fibre	Diameter (μm)	Fineness (dtex)	Length (mm)	Specific breaking stress (cN/tex)	Breaking extension (%)	LOI index (%)
Stainless steel	8.4	2.7	60	22.3	<1	100
Modacrylic	13.7	1.7	38	24.8	33.2	33–34
Cotton	15.6	1.7	34	43.9	10	18–20
Polyester	12.6	1.5	38	60	18	20–22



a b

Figure 1: The scanning electron microscope view (cross-sectional) of the ring-spun yarns from the mixture of MAC/CO (a) and the mixture of PES/MTF fibres (b)

Table 2: The basic properties of yarn's samples

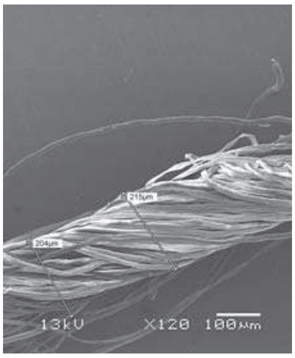
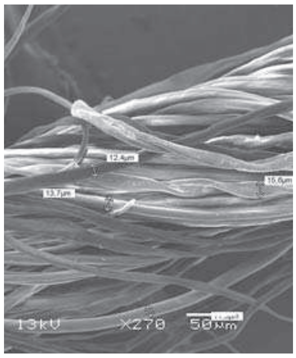
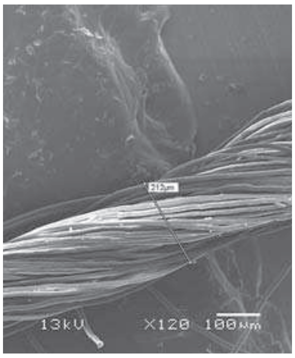
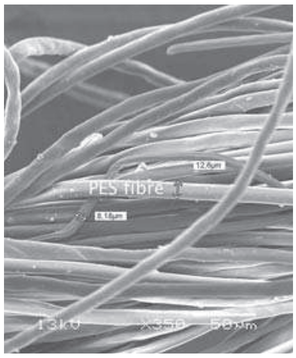
Sample	Fineness (tex)	Yarn type	Turns per meter	Twist direction	Scanning electron microscope view at magnification	
					× 120	× 270 × 350
CO 100%	16.67	Two-plied ring-spun	660	S		
MAC/ CO	16.67		720			
PES 100%	16.67	Single ring-spun	770			
PES/ MTF	16.67		930			

Table 3: The mechanical and physical properties of analysed ring-spun yarn

Sample	Raw material								
	Specific breaking stress [cN/tex]	CV of spec. breaking stress [%]	Breaking extension [%]	CV of breaking extension [%]	The mass irregularity CV_m [%]	Thin places/ 1000m	Thick places/ 1000m	Neps/ 1000m	Hairiness/ 1000m
CO 100%	23.0	4.0	5.9	7.2	8.8	0	1	2	7.3
MAC 100 %	15.8	6.3	18,7	5.7	9.7	0	0	0	7.8
MAC/CO 55%/45%	13.3	5.8	5.9	9.8	9.8	2	17	29	6.4
PES 100%	34.5	9.7	11.4	8.6	11.8	2	5	14	5.8
PES/MTF	21.8	11.6	12.6	10.3	–	–	–	–	–

* The mass irregularity, thin places, thick places, neps and hairiness of analysed ring-spun yarn were determined on the Uster Tester (capacitive sensor method) only for non-conductive yarns such are CO, MAC, MAC/CO and PES yarn.

3 Results and discussion

3.1 The results of specific breaking stress and extension

The results of specific breaking stress and extension of analysed fibres (MAC, CO, PES and MTF) and yarns (MAC/CO, 100% MAC, 100% CO, PES/MTF and 100% PES yarn) are listed in Table 4.

Table 4: The results of specific breaking stress and breaking extension analysed fibres and yarns

Type of fibres/yarn		Property	
		Specific breaking stress [cN/tex]	Breaking extension [%]
Fibres	MAC	24.8	33.2
	CO	43.9	10.0
	PES	60.0	18.0
	MTF	22.3	1.0
Yarns	MAC/CO	13.3	5.8
	100% MAC	15.8	18.7
	100% CO	23.0	5.9
	PES/MTF	21.8	12.6
	100% PES	34.5	11.4

The analysis of specific breaking stress (Table 4) of the yarn from the mixture of MAC/CO fibres has the lowest value which amounts to 13.3 cN/tex. The specific breaking stresses of the 100% MAC and the 100% cotton yarns are higher (15.8 cN/tex and 23.0 cN/tex).

The yarn from the mixture of MAC/CO fibres has the lowest specific breaking stress (13.3 cN/tex) mainly due to the very high difference between the specific breaking stresses of cotton fibres (43.9 cN/tex) and modacrylic fibres (24.8 cN/tex). That results in the specific breaking stress level decrease of the MAC/CO yarn, from 23.0 cN/tex (100% cotton yarn) and 15.8 cN/tex (100% MAC yarn) to 13.3 cN/tex (MAC/CO yarn).

The MAC/CO yarn has the breaking extension of 5.8% and similar values are measured with the 100% CO yarn, while the breaking extension is the highest with the 100% MAC yarn (18.7%).

Since the fire protection of the MAC/CO yarn is dominant, MAC fibres exert the LOI index between 33–34% (the limit of flame resistant fibres of LOI index is 25%) and ensure fire and heat resistance of the protective clothing produced from that yarn. The specific breaking stress of MAC/CO yarn is only about 2% lower than with 100% MAC yarn, but the incorporation of cotton fibres in the yarn (45% of cotton fibres in the mixture) is very important from the point of view of comfort properties (water vapor permeability, air permeability, thermal conduction, etc.) of the yarn intended for the protective clothing.

On the other hand, the results of the mechanical and physical properties of yarn (coefficient of the variation of mass, thick and thin areas/1000 m, neps, hairiness) which are listed in Table 3, show that the variation in mass per unit length along the yarn (CV_m) is similar and amounts to 9.7% (100% MAC yarn) and 9.8% (MAC/CO yarn). The number of thick and thin areas increases from zero (100% MAC yarn) and one (100% cotton yarn) to 17 (thick areas/1,000 m) and 29 (neps/1,000 m) of MAC/CO yarn, meaning the yarn from the mixture is non-uniform. The irregularity of yarn has a profound influence on the appearance of yarn and fabric. In contrast, the yarn from the mixture of MAC/CO fibres is less hairy (hairiness of 100% MAC yarn is 7.8, while the hairiness of the MAC/CO yarn is 6.4). The main reason of low hairiness lies in the different lengths of the MAC fibres (38 mm) and cotton fibres (34 mm). The percentage of longer MAC fibres in the yarn mixture is higher (55%) and prevents the transport of shorter cotton fibres from the inner to the upper (sheath) side of the yarn. On the other hand, lower hairiness of the MAC/CO yarn affects the higher abrasion resistance and better appearance of the yarn.

The second part of the research is directed to the mechanical properties of protective single PES/MTF yarn (Table 4) with MTFs which are fire resistant, heat resistant and have high conductivity. The results of the specific breaking stress show that the PES/MTF yarn has lower specific breaking stress (21.8 cN/tex) than the 100% PES yarn (34.5 cN/tex). The metal fibres (stainless steel) are coarser (2.7 dtex), longer (60 mm) and thinner (7 µm) than the PES fibres (fineness 1.5 dtex, length 38 mm and diameter 12.6 μm). Metal fibres have also lower specific breaking stress (22.3 cN/tex) in comparison with the specific breaking stress of the PES fibres (60 cN/tex), see Table 1. Consequently, the specific breaking stress of the PES/MTF yarn is lower.

The results of the yarn quality (coefficient of the variation of mass, thick and thin areas/1000 m, neps, hairiness) are measured with the 100% PES yarn (Table 3). The results of the yarn quality show that the variation in mass per unit length along the yarn (CV_m) amounts to 11.8 and is higher than with the 100% MAC yarn, 100% cotton yarn and MAC/CO yarn, however the number of thick and thin areas/1000 m and hairiness are lower than with the MAC/CO yarn.

3.2 The results of mechanical behavior of yarns with loading

The results of specific breaking stress and extension curve of fibres and yarns from the 100% cotton, the 100% MAC and MAC/CO yarns are shown in Figure 2. Figure 3 shows the specific stress/extension curve of the MAC/CO yarn with the 1st, 2nd and 3rd derivatives of the specific stress/extension curve. The results of the specific breaking stress and extension curve of fibres and yarns from the 100% PES and the PES/MTF yarn are figured in Figure 4. Figure 5 presents the specific stress/extension curve of the PES/MTF yarn with the 1st, 2nd and 3rd derivatives of the specific stress/extension curve.

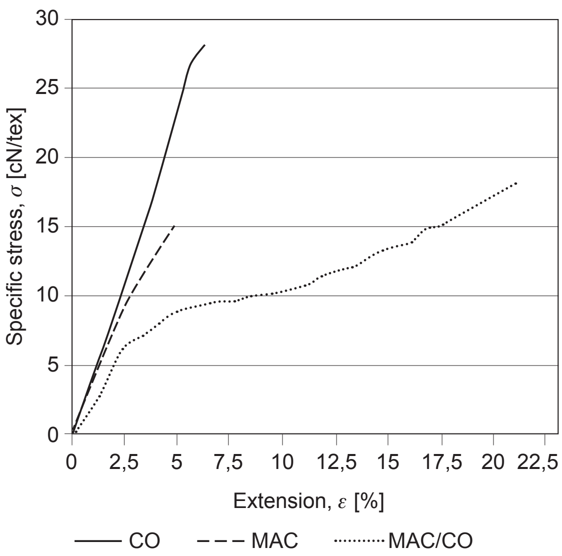


Figure 2: The specific stress/extension curve of the 100% CO, 100% MAC and MAC/CO yarn

The MAC/CO yarn demonstrates the lowest specific breaking stress (13.3 cN/tex) and breaking extension (5.8%). The reason lies in the high difference between the specific breaking stresses and breaking extensions of the 100% CO and the 100% MAC yarn (see Figure 2). In other words, the specific breaking stress decreases from 23.0 cN/tex (100% CO yarn) and 15.8 cN/tex (100% MAC yarn) to 13.3 cN/tex (MAC/CO yarn) (see Figure 2).

The straight-shaped MAC/CO yarn specific stress/extension curve represents the yarn with high modulus. The MAC/CO yarn has a high resistance to loading in comparison with the 100% MAC yarn. The high resistance of the MAC/CO yarn to loading reflects in the lower breaking extension. The 100% cotton yarn proves lower breaking extension, while the 100% MAC yarn, which has the highest breaking extension, consequently proves the lowest modulus.

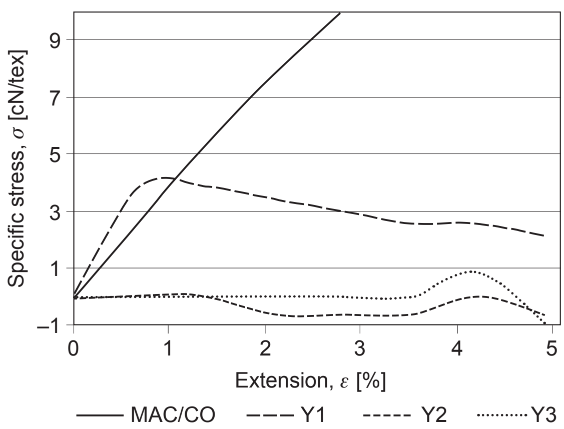


Figure 3: The specific stress/extension curve of MAC/CO yarn with the 1st (Y1), 2nd (Y2) and 3rd (Y3) derivatives

The first derivative of the specific stress/extension curve of MAC/CO yarn shows lower value of elasticity modulus (3.9 cN/tex) than 100% cotton yarn (4.3 cN/tex) (see Figure 3). The resistance of yarn on loading in the elastic region – the field of elastic deformations of the MAC /CO yarn – is about 10% lower. The first deformations in the yarn cause the moving of the fibres in the sheath. That deformations are completely recoverable until they reach the yield point, which presents the limit of elastic region. The yield point is calculated from the 2nd and the 3rd derivative of the specific stress/extension curve in the point where the 2nd derivative is minimal or maximal and 3rd derivative is zero. The specific stress in the yield point of the MAC/CO yarn is 7.83 cN/tex, while the extension in the yield point amounts to 2.1%. On the other hand, the specific stress in the yield point of the 100% cotton yarn is 5.42 cN/tex, while the extension in the yield point amounts to 1.4%.

The results of viscoelastic parameters of the MAC/CO yarn in comparison with results of 100% cotton yarn show that the incorporation of MAC fibres in the yarn mixture decreases the elasticity modulus of the MAC/CO yarn by about 10%. On the other hand, the incorporation of MAC fibres increases the yield point level by about 45%, consequently also increasing the field of elastic deformations. The specific stress in the yield point of the MAC/CO yarn is 7.83 cN/tex, thus being higher than the so-called stress value of 5 cN/tex (85 g), which was selected by this research.

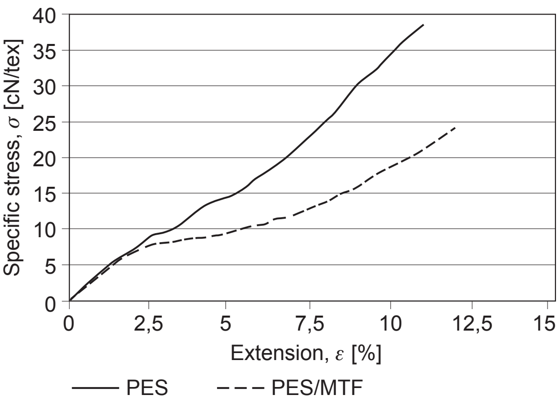


Figure 4: The specific stress/extension curve of the 100% PES and PES/MTF yarn

The PES/MTF yarn has lower modulus and offers lower resistance to loading than the 100% PES yarn (see Figure 4). The reason lies in the specific breaking stress level which is the consequence of the type of raw material and is lower with the PES/MTF yarn (21.8 cN/tex) than with the 100% PES yarn (34.5 cN/tex). The metal fibres (stainless steel) are coarser (2.7 dtex) and longer (60 mm) than the PES fibres (fineness 1.5 dtex and length 38 mm). On the other hand, the MTFs are also thinner and have lower breaking extension (only 1%) than PES fibres (18%) – see Table 2. The MTFs in the PES/MTF yarn break first (they have the lowest breaking extension, 1%) and influence the specific breaking stress level decrease of the PES/MTF yarn. Consequently, the PES/MTF yarn has higher breaking extension than the 100% PES yarn. The PES/MTF yarn shows lower elasticity modulus in comparison with the 100% PES yarn.

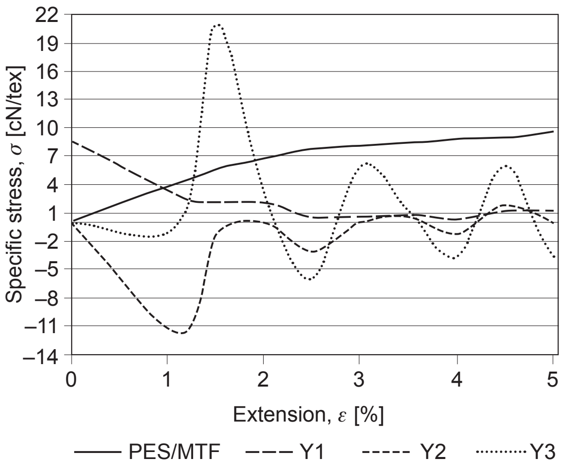


Figure 5: The specific stress/extension curve of the PES/MTF yarn with the 1st (Y1), 2nd (Y2) and 3rd (Y3) derivatives

The first derivative of the specific stress/extension curve of the PES/MTF yarn (see Figure 5) shows higher value of elasticity modulus (8.67 cN/tex) than the MAC/CO yarn (3.9 cN/tex). This would suggest that the PES/MTF yarn ensures higher resistance to loading in the elastic region – in the field of elastic deformations (see Figure 5). The elasticity modulus of the 100% PES yarn is even higher – 9.64 cN/tex, which is about 10% higher than the elasticity modulus of the PES/MTF yarn. The specific stress in the yield point of the PES/MTF yarn is 4.33 cN/tex, while the extension in the yield point amounts to 1.5%. The specific stress and extension in the yield point of the 100% PES yarn amounts to 4.81 cN/tex and 1.5%. The both yield point levels are a little bit lower than 5 cN/tex (80 g) which represents the amount chosen as the limit of elastic extension by this research.

The results of the viscoelastic parameters (the elasticity modulus and the yield point) show that the elasticity modulus of the PES/MTF yarn is about 10% lower than with the 100% PES yarn. On the other hand, the limit of elastic region (the specific stress and extension in the yield point) for the PES/MTF yarn is about 10% lower than with the 100% PES yarn. The MTFs prove very low breaking extension (1%) and only slight influence on the yield point decrease. Under the yield point, which presents the numerical limit of elastic deformations, the first movements of fibres in the sheath appear. Above the yield point, the first movements of the fibres in the yarn core appear and consequently also the viscoelastic deformation (time-dependent deformations). The specific stress/extension curve changes its shape.

From the Figure 4 it can be deduced, that the PES/MTF yarn has a lower field of elastic deformations (under the yield point) than the 100% PES yarn. The field of viscoelastic region of the PES/MTF yarn is wider and finally reaches higher breaking extension (12.6%) than the 100% PES yarn (11.4%).

4 Conclusions

In regard to the research of the influence of the fire resistant modacrylic fibres in the MAC/CO yarn and the conductive metal fibres in the PES/MTF yarn on the mechanical and viscoelastic properties in the field of lower loads (5 cN/tex), the following conclusions were drawn:

- The incorporation of fire resistant MAC fibres in the MAC/CO yarn decreases the specific breaking stress level (13.3 cN/tex) – the specific breaking stress of the 100% cotton yarn amounts to 23.0 cN/tex, while the changes of breaking extension are only minor and unimportant. The CO fibres (5.9%) in the MAC/CO yarn break first (they have lower breaking extension than MAC fibres – 18.7%) and influence the breaking extension level decrease of the MAC/CO (5.8%) yarn in comparison with the breaking extension of MAC fibres – 18.7%.
- The incorporation of conductive MTFs decreases the specific breaking stress of the PES/MTF yarn (21.8 cN/tex) – the specific breaking stress of the 100% PES yarn is 34.5 cN/tex, while the breaking extension of the PES/MTF yarn is somewhat higher (12.6%).
- The incorporation of fire resistant MAC fibres in the MAC/CO yarn decreases the elasticity modulus by about 10% (3.9 cN/tex), which means that the resistance of MAC/CO yarn in the field of lower loads is lower than with the 100% CO yarn (4.3 cN/tex).
- On the other hand, the specific stress in the yield point of the MAC/CO yarn increases (7.83 cN/tex) by about 45%, while the specific stress in the yield point of the 100% CO yarn is 5.42 cN/tex, meaning that the field of elastic deformations of the MAC/CO yarn is wider.
- The incorporation of conductive MTFs decreases the elasticity modulus of the PES/MTF yarn by about 10% (8.6 cN/tex). The elasticity modulus of the 100% PES yarn amounts to 9.64 cN/tex.
- The incorporation of conductive MTFs also decreases the specific stress in the yield point (4.33 cN/tex) of the PES/MTF yarn, while the specific stress in the yield point of the 100% PES yarn amounts to 4.81 cN/tex. The region of elastic deformations of the PES/MTF yarn is about 11% narrower.
- Based upon the facts presented above, it could be claimed that the incorporation of MAC (modacrylic) fibres, which are fire and heat resistant and intended for protective clothing, mostly increase the region of elastic deformations as well as the superior elastic properties of the MAC/CO yarn, as was predicted. On the other hand, the incorporation of MAC fibres in the yarn decreases the elasticity modulus and increases the deformation level.
- The incorporation of MTFs (metal-stainless steel fibres), which are heat resistant and conductive, in the PES/MTF yarn mostly decreases the region of elastic deformations (about 10%). On the other hand, the region of elastic deformations lies very close to the field of lower loads under the specific stress/extension curve which amounts to 5 cN/tex or 85 g.

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