



# Fibres and Textiles (1) 2010

## Vlákna a textil (1) 2010

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## MECHANICAL AND THERMAL PROPERTIES OF LDPE/GLUCURONOXylan BLENDS

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**Abstract:** The great application of polysaccharides, especially starch, cellulose, xylans and their derivatives in the polymers field are as a component in polymer blends. Most of the applications are focused on polyethylene, which is widely used as packaging material. This work deals with blends preparation low density polyethylene and glucuronoxylan laurate (LaCOLX) with DS= 1.9 in four different amounts (1, 3, 5 and 10 wt.%) with and without compatibilizer EAA in three different amounts: 10, 25 and 50 wt.% in respect of polysaccharide. The compatibility of the prepared blends LDPE/LaCOLX has been studied using light microscopy. The presence of filler LaCOLX and the effect of compatibilizer have been studied through the mechanical properties (tensile strength, elongation at break and Young's Modulus) of blends. The prepared blends of LDPE/LaCOLX containing 25 wt.% and 50 wt.% of EAA have showed the good mechanical properties. Increasing amount of LaCOLX and presence of compatibilizer had positive effect on thermal stability of LDPE/LaCOLX blends.

**Keywords:** blends, glucuronoxylan, mechanical properties, thermal stability, polyethylene

### 1. INTRODUCTION

The continuous growth of utilization of non-degradable and environment-unfriendly polymeric materials stimulates further research in the field of application. It is estimated that 2% of all plastic eventually reach the environment extensively contributing to the currently acute ecological problem. On this account, research has been concentrated on preparation of degradable either natural or synthetic polymers or their blends recently [1, 2, 3].

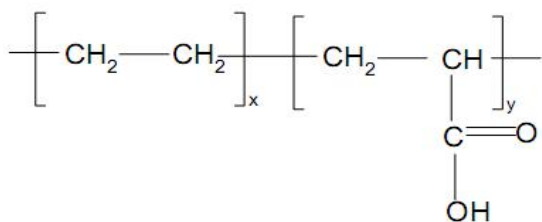
The demands on the products made of polymers are so various that their utilization as a pure polymer is practically impossible. Polymers are combined with further substances – additives forming polymeric blends. Replacement of some synthetic polymers by natural polysaccharides is very interesting, economic and ecological [4, 5, 6]. Application of polysaccharides in polymeric blends contributes to the solution of ecological problems partially substituting the environment ballasting synthetic polymers. Considering the low price and wide availability of polysaccharides, their

application in combination with polyolefins is interesting from the economic point of view.

Production of new polymeric blends brings, however, certain obstacles because majority of polymers is immiscible with one another. Mutual immiscibility due to different structure of components has negative influence on utility properties of blended materials [7, 8]. Immiscibility becomes evident by phase separation of particular components in blend, rough phase structure and poor interfacial adhesion, which leads to weak internal cohesion of material. These characteristics have negative influence on utility properties such as toughness, tensile strength, elongation of resulting material. The negative effects could be suppressed by so-called compatibilization, i.e. way of improving interfacial adhesion of immiscible polymer blends leading to decrease of surface energy, improving and stabilizing of required morphology. The strategy of compatibilization is based on addition of block/graft copolymer consisting of blocks miscible with one or another homopolymer.

The compatibilizer is able to decrease interfacial tension and create more stable

structure more resistant to mechanical degradation and thus change the incompatible blends to useful compatible materials [9, 10].



**Figure 1** The structure of poly(ethylene-co-acrylic acid)

Present work relates to work published in [11]. It is focused on study of application possibilities of xylan Lenzing® and its more thermostable laurate with DS=1.9 in polymeric blends with low-density polyethylene, utilization of poly(ethylene-co-acrylic acid) as a compatibilizer in order to improve interfacial adhesion of prepared blends.

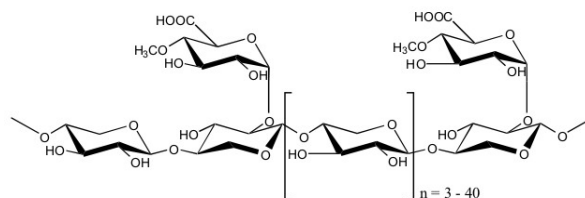
### 1.1 Polysaccharides

Polysaccharides are natural polymers belonging to the most renewable sources on Earth. They occur in all organisms and form majority of plant mass. Polysaccharides play important role primarily as a structural components of plants, animals, fungi or microorganisms (e.g. cellulose) and as an energy source for various biochemical reactions (e.g. starch). Polysaccharides have importance not only in nature but have also widespread utilization in food and pharmaceutical industry. It is assumed that polysaccharides such as cellulose, starch, chitin and hemicelluloses will have ever-rising status in industry compared to synthetic polymers based on petrochemical products [4]. During last decades, interest in so-called functional biopolymers has been rising, especially in various types of polysaccharides of plant and microbial origin being extracted by means of commercial and uncommercial techniques. The functional polysaccharides are prepared from commercial polysaccharide types such as starch, cellulose and its derivatives

(hydroxyethyl cellulose, carboxymethyl cellulose, nitrocellulose, methyl cellulose) and uncommercial polysaccharide types such as various types of xylan (from corn cobs and beech wood).

Preparation of new functional polymers requires research, continuous gain of new information about relations between structure of derivatives and their functional properties [12].

Xylans represent on one hand an unused group of polysaccharides and on another hand an important source of renewable biopolymers. Xylans are the most important hemicelluloses of hardwood that contains less lignin, less mannans and more xylans in 4-O-methylglucurono- form. Xylans occur not only in wood, but also in several other plants such as grass, crop-plants and herbal plants [13]. 4-O-methylglucuronoxylan branched with 4-O-methyl- $\alpha$ -D-glucuronic side chain occurs in hardwood while linear 4-O-methylglucuronoarabinoxylan occurs in softwood. Potential sources of xylans are wood pulp, wood shavings, match-wood and crops of annual plants (straw, stalks, husks, brans, hulls etc.).



**Figure 2** Structural unite of 4-O-methylglucuronoxylan [13]

Xylans are extracted either from plant materials or represents by-products of various technologies, e.g. wood processing of annual plants. 4-O-methylglucuronoxylan belongs to the standard types of xylans. Its main chain consist of D-xylopyranose units linked by (1-4)- $\beta$ -glycosidic linkage, as seen Figure 2. It is found in hardwood and other dicotyledonous plants. D-glucuronic acid, which is mostly present in 4-O-methylene form, is linked to main chain by 1-2 (rarely 1-3)- $\alpha$ -glycosidic linkage. The presence of  $\alpha$ -D-glucuronic side chains increases the

resistance of some (1-4)- $\beta$ -glycosidic linkages in xylan molecule against acid hydrolysis [13].

## 2. EXPERIMENTAL PART

### 2.1 Materials

Low-density polyethylene (LDPE) BRALEN RB 2-62, the suitable EN 71 part 3 (Slovnaft Petrochemicals, Slovak Republic), used in the experiments, was appropriate for packing applications. The poly(ethylene-co-acrylic acid) (EAA) containing 15 wt.% acrylic acid was supplied from Aldrich. Water-insoluble glucuronoxylan (LX) a by-product of viscose production from beech sulfite pulp, was a gift from Lenzing AG (Austria): Xyl = 92.5% (of neutral sugars), MeGUA = 3.7%, Mw ~ 5000 g/mol. Glucuronoxylan Lenzing laurate (LaCOLX) with DS = 1.9 prepared by reaction with lauroyl chloride [14].

### 2.2 Melt blending

Glucuronoxylan Lenzing and its laurate were melt-blended with LDPE in a Brabender Plasti – Corder PLE 331. Mixing was performed at 140°C and 80 rpm for 15 min. For the LDPE/LaCOLX blends, four different levels of polysaccharide were used, namely 1, 3, 5 and 10 wt.%. In these blends, EAA was used as a compatibilizer, in three different amounts, namely 10, 25 and 50 wt.%, based upon polysaccharide.

### 2.3 Light microscopy

Macroscopic and microscopic photos of prepared LDPE/LaCOLX blends were scanned using by light microscope Jenavert.

### 2.4 Mechanical properties of blends

Measurements of the mechanical properties, such as tensile strength and elongation at break, performed according to the Instron

Corporation Material Testing System 1.04, made use of a 5 mm/min crosshead speed. Five measurements were conducted for each sample, and the results were averaged to obtain a mean value.

### 2.5 DSC measurements

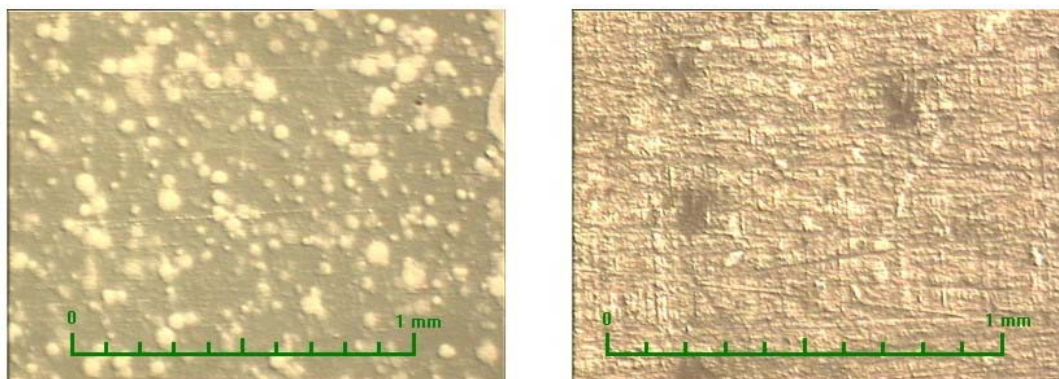
The DSC measurements were done on a Mettler Toledo DSC 821<sup>e</sup>, in the temperature range from -30°C to 350°C, or 5°C to 160°C with a scan rate of 10°C/min, under nitrogen atmosphere.

### 2.6 TGA measurements

The TGA measurements were performed on a Thermobalance Mettler Toledo TGA/SDTA 851<sup>e</sup> thermogravimetric analyzer, under nitrogen atmosphere, at a heating rate of 10°C/min up to 600°C. The mass loss permits to estimate both the glucuronoxylan laurate content and the thermal stability of the blends.

## 3 RESULTS AND DISCUSSION

Compatibility of LDPE/LaCOLX blends was studied by light microscopy. On prepared LDPE/LaCOLX blends were studied mechanical properties, too. Modification of polysaccharides by means of incorporating of hydrophobic groups into macromolecule is believed to increase the interfacial adhesion with synthetic polymer [7, 15]. Figures 4 and 5 show the influence of xylan and its derivative LaCOLX on tensile strength and elongation at break of uncompatibilized blends. The tensile strength and elongation at break of uncompatibilized blends decrease with increasing amount of filler (LX and LaCOLX). The decrease is believed to be due to inhomogeneity of LDPE/polysaccharide blends. This fact is supported by microscopic and macroscopic observation (Figure 3).



**Figure 3** Macroscopic and microscopic images (45x magnified) of LDPE/ LaCOLX (10 wt.%) blends without compatibilizer

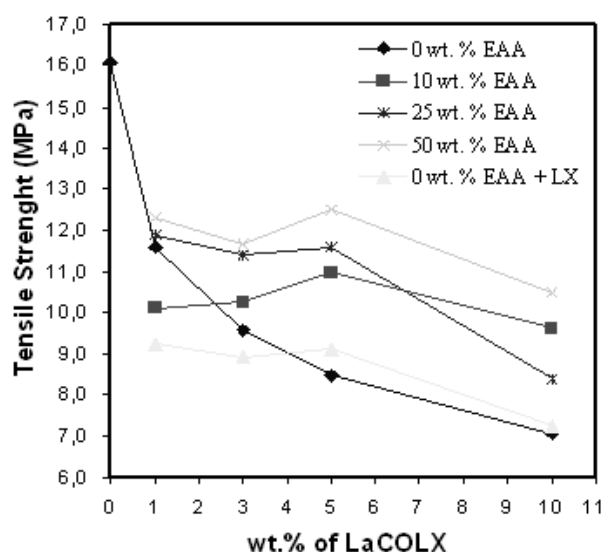
Laurate of xylan LX is almost fully hydrophobized; however, its glucopyranose units retain hydrophilic character that because of weak interfacial adhesion with polyethylene have negative effects on mechanical properties of prepared blends. Light microscopy confirmed that laurate of xylan LX is dispersed into larger domains with insufficient compatibility, which was also confirmed visually during mixing of LaCOLX with polyethylene (Fig. 3). Prevalence of hydrophilicity of esterified glucuronoxylan with DS 1.9 (LaCOLX) causes inability of form continual phase with synthetic polymer (LDPE).

Another possibility how to improve the compatibility between two immiscible polymers is utilization of compatibilizer – compound able to form hydrogen bonds with hydroxyl groups of natural polymer or its derivative.

EAA compatibilizer comprises of polyethylene segments and acrylic acid units that are able to form stable complex with polysaccharide as a result of hydrogen bonds between carboxylic groups of acrylic acid and hydroxyl groups of polysaccharide [16, 17].

Hydrogen bonding was recognized also in polymeric blends consisting of poly (vinylalcohol), poly (vinylphenol), poly (vinylacetate) or polymers containing carbonyl groups [18, 19, 20]. Improved compatibility between LDPE and LaCOLX is expected using EAA compatibilizer. Figure 4 shows tensile strength of EAA compatibilized

LDPE/LaCOLX blends. It is obvious that with increasing amount of LaCOLX tensile strength decreases. Addition of EAA compatibilizer (25 and 50 wt.%) has positive effect on tensile strength, especially in the case of blend with 5 wt.% content of LaCOLX.



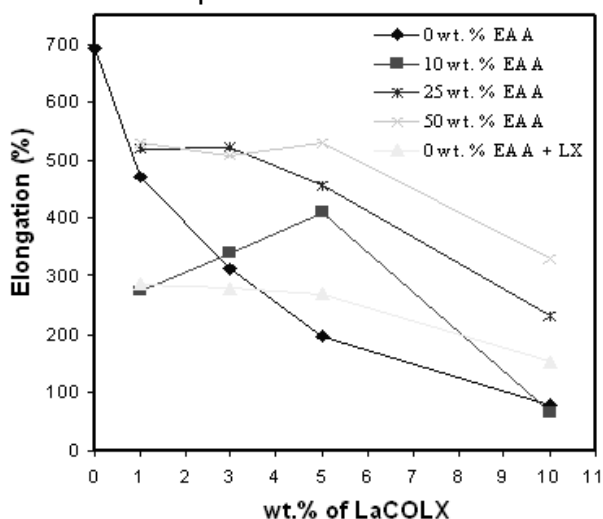
**Figure 4** Tensile strength of EAA compatibilized LDPE/LaCOLX (LX) blends in dependence on LaCOLX (LX) content

Degree of compatibility of polymeric blends is monitored in a range from totally miscible systems to phase separation. Compatibility is a function of polymeric molecules interactions in blend and can be studied by means of various methods including mechanical and interfacial measurements [21]. In compatible blends, mechanical

properties such as tensile strength and Young's modulus show linear functionality vs. blend composition.

It is generally true that negative deviation from linear dependence is considered as a sign of poor compatibility between components, whereas positive deviation is considered as a sign of improved compatibility [22].

Figure 5 shows elongation at break of measured LDPE/LaCOLX blends with varying amount of EAA compatibilizer. Addition of compatibilizer has positive effect, especially in case of blends with 3 and 5 wt.% of LaCOLX. The high improvement was recorded in case of blend with 25 and 50 wt.% of EAA. Similar as tensile strength, elongation at break decreases with increasing content of LaCOLX and any amount of compatibilizer.

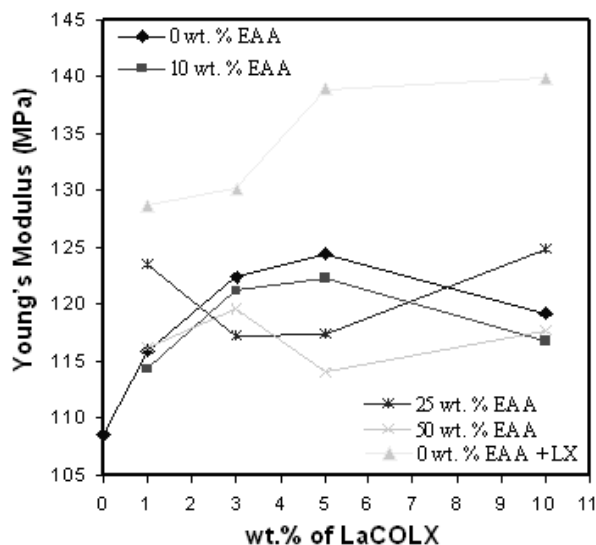


**Figure 5** Elongation at break of EAA compatibilized LDPE/LaCOLX (LX) blends in dependence on LaCOLX (LX) content.

Polysaccharide part in synthetic polymer tends to affect properties of the polymer. In synthetic blends, addition of another immiscible phase into tough matrix causes sharp decrease of elongation at break [23]. In such blends, elongation at break is considered as a high sensitive interfacial interaction. Maximal tolerable amount of polysaccharide was reported to be 15 wt.% [24]. Above mentioned amount of filler, elongation at break as well as tensile

strength dropped sharply. On the contrary, moderate decrease of Young's modulus and tensile strength was monitored with increasing content of polysaccharide [23]. Elongation at break dropped distinctly at 10 wt.% of polysaccharide.

Several theories were proposed to express the dependence of composite properties vs. volume fraction of filler. One of the simplest is Nelson's theory describing elongation providing ideal adhesion between filler and polymeric matrix. Another is Nicolais-Nakris' theory describing tensile strength. Both theories were applied to LDPE/starch blends [25] showing good agreement with theoretical prognoses. However, application of above mentioned theories is not suitable in our case. Low agreement between theory and experimental data of tensile strength and elongation of break is ascribed to poor interfacial adhesion. As already mentioned, Nielsen's theory presuppose ideal adhesion of two phases.



**Figure 6** Young's modulus of EAA compatibilized LDPE/LaCOLX (LX) blends in dependence on LaCOLX (LX) content

Young's modulus of prepared LDPE/LaCOLX and LX blends with and without EAA compatibilizer was measured expressing the degree of material rigidity. Figure 6 shows that Young's modulus decreases with increasing amount of LaCOLX from 1 up to 5 wt.% in case of blends with 25 and 50 wt.%

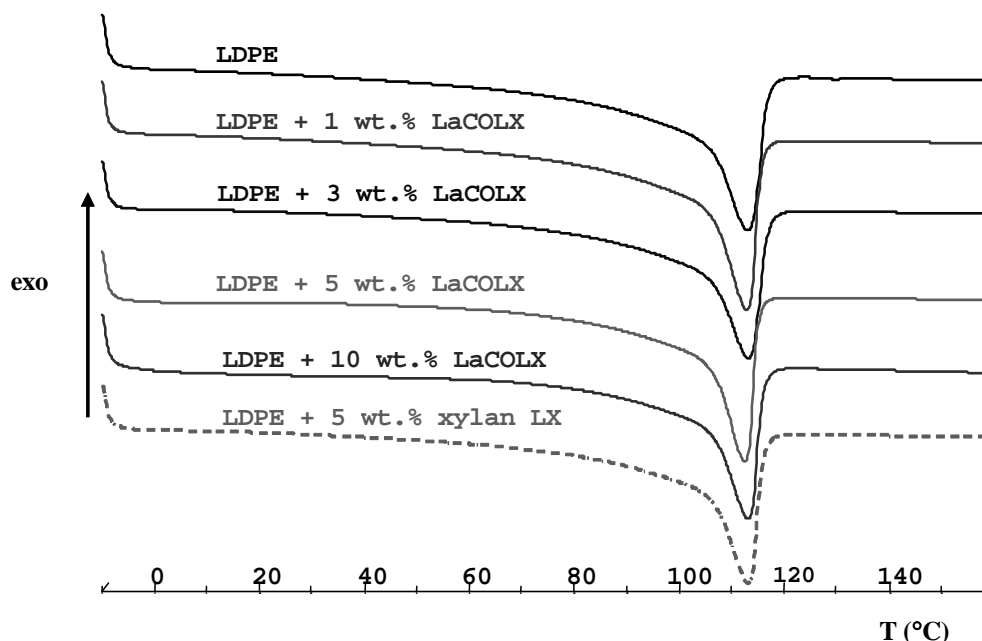
of EAA. In case of uncompatibilized blends and blends with 10 wt.% of EAA Young's modulus moderately rises with increasing content of LaCOLX and LX up to 5 wt.%. Generally, Young's modulus is closely associated with material rigidity [26]. Blending of natural polymer into polyethylene leads to higher standard deviations of Young's modulus compared to monodisperse systems. This is caused either by compatibilizer (EAA) or by the presence of filler (LaCOLX). Incompatible blends and blends with 10 wt.% of compatibilizer and above 5 wt.% of LaCOLX filler show decreasing tendency of Young's modulus. It is probably caused by lower rigidity of xylan associates.

Thermal properties of LDPE/LaCOLX blends with and without EAA compatibilizer were tested by means of DSC and TGA analysis. Only small differences in DSC thermograms of tested blends compared to pure PE

(Figure 7) was recorded. With increasing content of LaCOLX, endothermic peak is slightly shifted to lower temperatures. Melting temperature  $T_m$  and enthalpy changes  $\Delta H$  of LDPE/LaCOLX blends with various polysaccharide content are shown in Table 1. Flory-Huggins' interaction parameter for polymeric blends containing crystalline polymer is expressed from difference of melting temperatures according to well known Wang-Nishi's equation [24]:

$$\frac{1}{T_m} - \frac{1}{T_m^0} = -\frac{R.V_2}{\Delta H_f^0.V_1} \chi_{12}(1-\varphi_2)^2 \quad (1)$$

where  $T_m$  and  $T_m^0$  are melting temperatures of crystalline polymer in blend and pure polymer,  $V_2$  is molar volume of repeating crystal unit,  $\Delta H_f^0$  is melting heat and  $\varphi_2$  is volume fraction of crystal part. Negative values of  $\chi_{12}$  is expected for miscible blends therefore  $T_m < T_m^0$  (melting temperature decreases).



**Figure 7** DSC thermograms (secondary melting) of uncompatibilized LDPE/LaCOLX blends

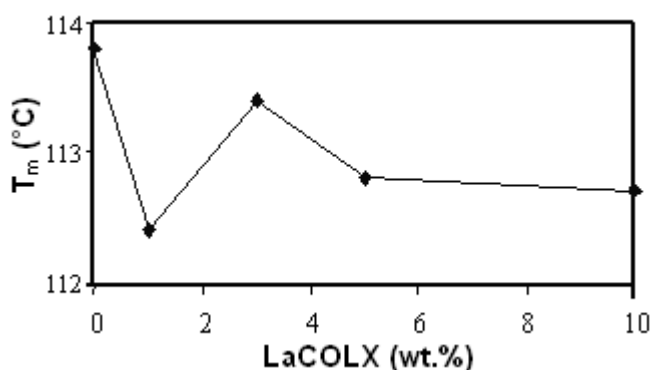


**Table 1** Melting heat of LDPE depending on increasing filler (LaCOLX) concentration for primary and secondary heating

Amount of filler (wt.%)	T <sub>m1</sub> (°C)	ΔH <sub>1</sub> (J/g PE)	T <sub>m2</sub> (°C)	ΔH <sub>2</sub> (J/g PE)
0	113.8	119.6	112.4	125.4
1	112.4	120.3	112.0	126.1
3	113.4	119.8	112.1	124.8
5	112.8	116.7	111.9	119.6
10	112.7	122.2	111.9	122.6
5 *	112.8	119.5	112.2	120.6

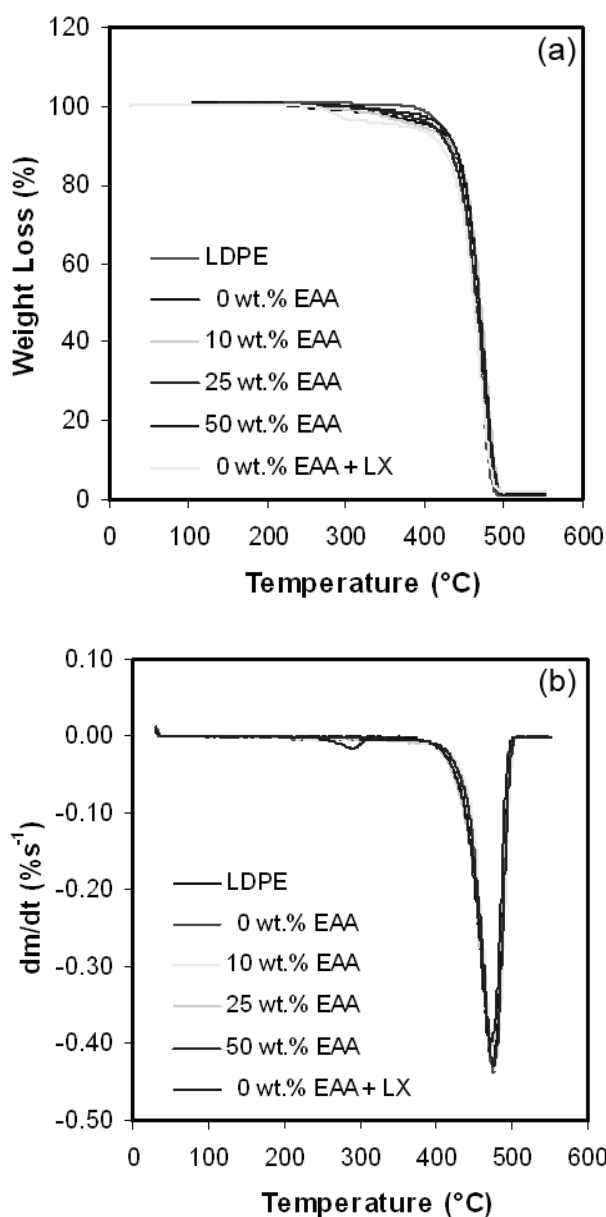
\* glucuronoxylan LX

Figure 8 shows small decrease of T<sub>m</sub>, rare phenomenon depending on blend composition. This is probably due to low (zero to negative) values of interaction parameter between the polymers. When it comes to melting heat, no distinct differences were recorded, however, an unidentified phenomenon related to product of theoretical volumes [24].



**Figure 8** Melting temperature of LDPE/LaCOLX blends depending on amount of LaCOLX in blend

It can be concluded that no distinct differences in behaviour of LDPE/LaCOLX blends occur during melting. LDPE is badly miscible with LaCOLX or the interaction between LDPE and LaCOLX are very poor. Thermostability of LDPE/LaCOLX blends was improved in the presence of EAA compatibilizer by better interfacial adhesion between LDPE and LaCOLX. Figure 9(b) shows derivative thermogravimetry curve of LDPE/LaCOLX and LDPE/LX blends.



**Figure 9** TGA (a) and DTG (b) curves of LDPE/LaCOLX and LX blends with and without EAA compatibilizer

There are two peaks in LDPE/LX blend thermogram at 301 and 485°C corresponding to LX and LDPE, respectively. In case of compatibilized blends, LDPE decomposition peak is shifted to higher temperatures with increasing content of LaCOLX and EAA in blend. This is an evidence of presence of molecular interactions between synthetic polymer (LDPE) and polysaccharide [27]. It can be concluded that presence of compatibilizer and increasing amount of LaCOLX have positive effect on thermal properties of LDPE blends.

#### 4 CONCLUSIONS

Based on the achieved results it can be concluded as follows:

- Tensile strength and elongation at break of uncompatibilized blends decrease with increasing content of filler (LX or LaCOLX). Microscopic and macroscopic observation confirmed that this decrease is caused by inhomogeneity of prepared blends.
- Light microscopy confirmed that LaCOLX is dispersed into larger domains with bad compatibility to LDPE, which was also confirmed visually during mixing of LaCOLX with LDPE. Excess of hydrophilicity of esterified glucuronoxylan with DS 1.9 (LaCOLX) causes inability to form continual phase with hydrophobic synthetic polymer (LDPE).
- In order to improve compatibility between two immiscible polymers, EAA compatibilizer was used. Addition of 25 and 50 wt.% of EAA has positive effect on tensile strength, especially in case of blends containing 5 wt.% of LaCOLX.
- Polysaccharide part in synthetic polymer tends to affect properties of the polymer. In synthetic blends, addition of another immiscible phase into tough matrix causes sharp decrease of elongation at break. Addition of EAA compatibilizer has positive effect on elongation at break, especially in case of blends containing 3

and 5 wt.% of LaCOLX. The biggest improvement was recorded in case of blends with 25 and 50 wt.% of EAA compatibilizer.

- Young's modulus of uncompatibilized LDPE/LaCOLX and LX blends rises moderately with increasing amount of LaCOLX or LX. On the contrary, in case of compatibilized blends Young's modulus decreases. This decrease is probably caused by addition of higher amount of LaCOLX (3 to 10 wt.%).
- Thermostability of LDPE/LaCOLX blends without EAA compatibilizer was tested by means of DSC analysis. Prepared blends show very good thermostability. Presence of compatibilizer and increasing amount of LaCOLX has positive effect on thermal properties of LDPE blends.

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## MECHANICKÉ A TERMICKÉ VLASTNOSTI ZMESÍ LDPE/GLUKORONOKSYLAN

Translation of the article

### Mechanical and thermal properties of LDPE/Glucuronoxylan blends

Využitie polysacharidov, najmä škrobu, celulózy, xylánov a ich derivátov má význam v oblasti polymérov ako súčasť polymérnych zmesí. Väčšina aplikácií je sústredených hlavne do polyetylénu, ktorý sa všeobecne používa ako obalový materiál. Práca sa zaoberá prípravou a štúdiom zmesí nízkohustotného polyetylénu a laurátu xylánu Lenzing s DS=1,9 pri štyroch rôznych hmotnostných pomeroch (1, 3, 5 a 10% hm.) za a bez prítomnosti kompatibilizátora kopolyméru etylénu a kyseliny akrylovej (EAA) v troch rôznych hmotnostných pomeroch: 10, 25 a 50% hm. Kompatibilita pripravených zmesí LDPE/LaCOLX sa študovala svetelnou mikroskopiou. Študoval sa vplyv prítomnosti plniva LaCOLX a kompatibilizátora na mechanické vlastnosti (pevnosť v ťahu, ťažnosť, Youngov modul) zmesí. Pripravené zmesi LDPE/LaCOLX s 25 a 50% hm. obsahom kompatibilizátora EAA sa vyznačovali dobrými mechanickými vlastnosťami. Zvyšujúce sa množstvo LaCOLX a prítomnosť kompatibilizátora pozitívne pôsobí na termickú stabilitu LDPE/LaCOLX zmesí.

# LIGHT REFLECTION OF POLYESTER FIBRES WITH DIFFERENT FINENESS AFTER THERMOSOLATION

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**Abstract:** *In the work is studied the total shade of polyester fibres after thermosolation. Experiments was targeted on quantification of temperature effect, time of thermosolation, quantity of dye in fibres and on intensity of resulting dye shade for three monitored disperse dyes. Comparison was realized on fibres of different fineness.*

*Objectives was find out, how influence temperature and time of thermosolation the intensity of resulting coloured shade of polyethylene terephthalate fibres at three monitored disperse dyes. Comparison was provided at several different temperatures and times. Next concern was finding whether originate colour difference on polyester of different fineness at the same concentration of dye and uniform parameters of dyeing. Experimentally were evaluated the influence of secondary diffusion of disperse dye into fibres and changes of colour intensity.*

**Key words:** *microfibre dyeing, thermosolation, dye diffusion*

## 1. INTRODUCTION

Thermosolation is a continual method of polyester dyeing using disperse dyes. At thermosol method of dyeing is on textile padded dye together with migration inhibitor (thickener) and auxiliaries with dispersing and wetting effects. After padding and drying follow own thermosol action at temperature range 180 - 220°C. Time of thermosolation, according with select dyes, temperatures and textile structure, balances approximately within the limits of 15 to the 60 seconds [1].

During thermosol dyeing disperse dyes penetrate (diffuse) by the treatment of dry heat into the interior of polyethylene terephthalate fibres. Rate of the process is influenced mainly by fibre fineness, temperature and chemical constitution of dye molecule.

The main dye class used for polyethylene terephthalate fibres are disperse dyes of subgroup S, which penetrate into the fibre slower thanks a big molecule and from these reason they have excellent stability in sublimation. On the contrary dyes with small molecule weight diffuse into the fibres faster,

but they have less fastness properties in sublimation.

Dye penetrates to the fiber mass from surface. In case of small dye diffusion (thermosolation under lower temperature or shorter time) dye is places in cross-section of fibre unevenly, higher concentration is in the fibre surface; it is so-called ring coloration. Ring coloration shows lower deepness than the textile which is homogeneous dyed at the same dye content. Secondary diffusion can change radial distribution of dye in the fibre by prolongation of diffusion process, whereas even distribution of dye in fibre mass is developed. So by secondary diffusion it is possible to change radial distribution of dye using longer diffusion process, whereas even distribution in fibre mass occurred. Secondary diffusion process ensures that colourfulness of textile will be directly proportional of dye concentration in the fibre regardless of original radial dye distribution in fibre mass.

### 1.1 The effect of fibre fineness on rate of dyeing

Simplified Fick's law (1) for diffusion coefficient and halftime of dying was used for evaluation of different fibre specific surface for the rate of dyeing.

$$D = \frac{0,00632 \cdot r^2}{t_{1/2}} \quad (1)$$

where D is a diffusion coefficient, r is the radius of dyed fibre and  $t_{1/2}$  halftime of dyeing.

Range of surface adsorption is important "platform" for consequential diffusion into the fibre. Diffusion characteristics of fibres are given by physico-chemical character of the polymer, i.e. they are not dependent on fibre fineness. But the rate of dyeing is an "outer feature" and it considerably changes according to fiber fineness, or their geometry, which defines the extent of a contact with the dyeing bath [2].

The rate of the sorption is dependent on the size of a specific surface of the substrate, which comes into contact with the bath. In the ideal system the following is valid. Compared fibres are of identical polymer, they have a perfectly cylindrical shape with radius r and length of l, flow to the bath is ideal, i.e. flow to fibres is intensive enough to compensate for local decrease of a concentration of dyes in the bath due to adsorption. The sorption speed is then expressed by equation (2).

sorption speed ~

$$\frac{\text{surface}}{\text{mass}} = \frac{2\pi r \cdot l}{\pi r^2 \rho \cdot l} = \frac{\text{const}_1}{r} = \frac{\text{const}_2}{\sqrt{\text{tex}}} \quad (2)$$

where  $\rho$  is specific weight.

Increasing the rate of dyeing is then indirectly proportionate to the fibre radius r, or indirectly proportional to the square root of fineness [tex]. This happens generally, although with smaller deviations, which originate from non-ideal properties of real systems. This principle is especially

encountered in the practical dyeing, after change to dyeing of microfibrils those dyeing is very rapid; this is a consequence of their extremely large specific surface [3-6].

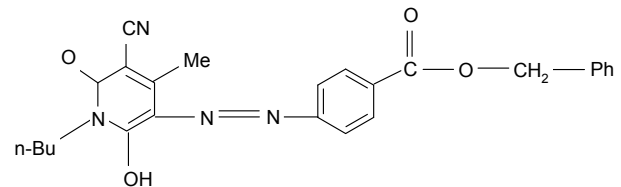
## 2. EXPERIMENTAL

### 2.1 Textile materials and used dyes

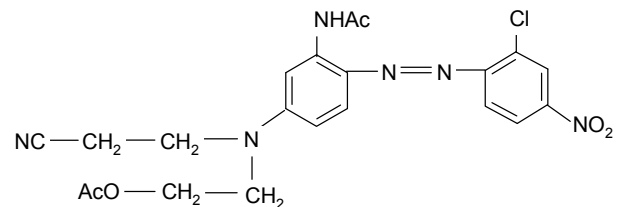
For experiments were used 100 % polyester pre-treated fabrics - textiles of standard fineness (fibre diameter 21  $\mu\text{m}$ ), square weight 170  $\text{g}\cdot\text{m}^{-2}$ , and textile from microfibrils (fibre diameter 9  $\mu\text{m}$ ), square weight 70  $\text{g}\cdot\text{m}^{-2}$ .

Disperse dyes used for experiments:

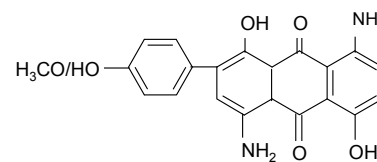
- Foron brilliant yellow S-6GL



- Foron brilliant red S-RGL



- Foron blue S-BGL

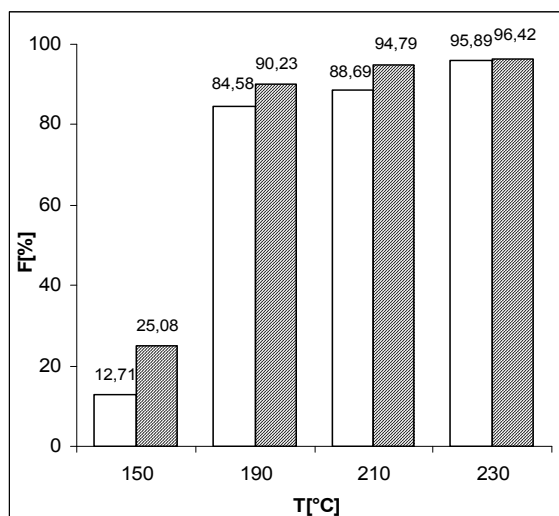


Dyeing bath was applied on laboratory padder, dried and heat treated at 130 till 220°C for 10 to 240 s.

### 2.2 Quantity of fixed dye on standard polyester and microfibrils

For thermosolation time 60 s and various temperatures of thermosolation the quantity of fixed dye for both types of polyester is showed in Figure 1. The reflectance for

standard fibres and microfibrils at the same concentration of the fixed dye are in Figure 2.



**Figure 1** Fixation (F) of Foron Brilliant Red S-RGL at various temperatures (T) on standard and microfibrils (hatched surface in the figure). Thermosolation time 60 s

From Figure 2 is evident, that for microfibrils under identical dyeing conditions the reflectance is higher and so coloration deepness is lower. Differences are given especially by optical characteristics of textiles which are formed by fibres of different fineness.

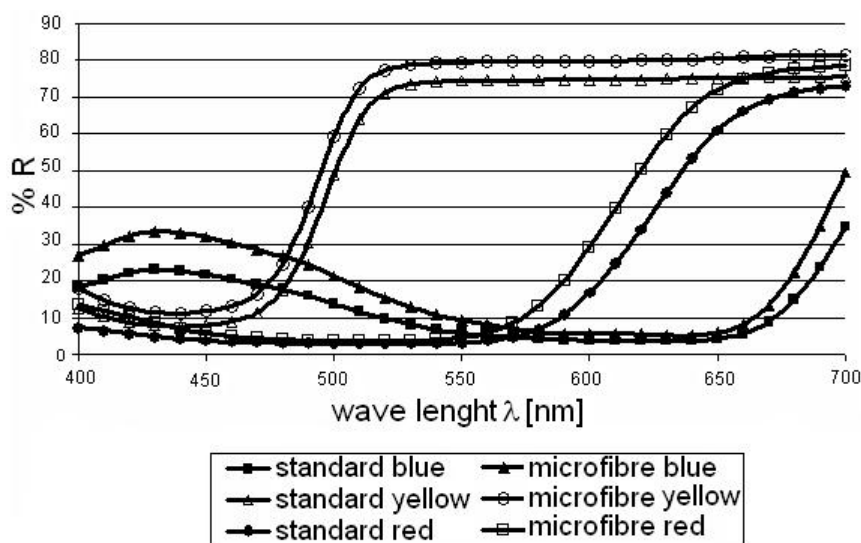
### 2.3 Relation of reflectance values on temperature and thermosolation time

On Figure 3 there are typical thermosol curves for different temperatures and thermosolation time. We can find optimal areas for thermosol technology - it is temperature within the range of 190 - 220°C.

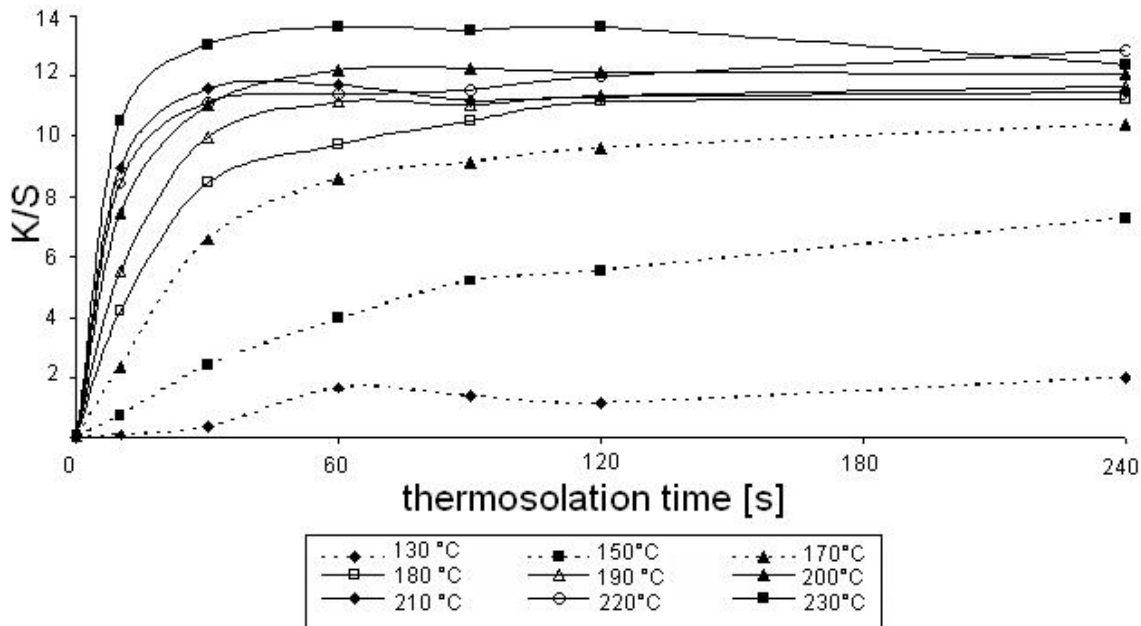
### 3 SECONDARY DYE DIFFUSION INTO THE FIBRE

Secondary heat treatment of dyed fibres was provided under temperature 200°C and time 60 s. A ring dyeing was expected at samples thermosoled at lower temperatures and in relatively short time. The purpose was to improve radial distribution and increase K/S value.

After the thermal exposure of dyed polyester fibres, shifts in the reflectance after such secondary diffusion of disperse dye were found in experiments. It can be generalized that the secondary diffusion is more visible on reflectance of fibres of higher fineness. On the contrary the fibres with lower fineness, the secondary diffusion resulted in a partial sublimation of dye already bound on the fibre and lighter shade, higher reflectance value.



**Figure 2** The reflectance (R) curves of standard and microfibrils after thermosolation for 3 tested dyes at the same temperature and thermosolation time



**Figure 3** A relation of K/S values vs. time at various temperatures of thermosolation for Foron Brilliant yellow S-6GL on standard fibre

#### 4 CONCLUSION

The technological experiences were verified; the optimal temperature for diffusion into fibres of both fineness is between 190 - 220°C. Higher yield of dye on the fibre is not achieved at higher temperatures. On the contrary, the kinetics of thermosolation is insufficient at temperatures lower than 190°C.

By objective measurement of the reflectance on Datacolor instrument was found, that lower fineness fibres show a higher reflectivity of light rays at the comparable concentration of a dye. This means that finer fibres appear lighter to an ordinary consumer at the comparable concentration of the dye on the fibre. The result for the practical management of thermosolation processes and control of the resulting parameters of dyeing is as follows; the colorist should control the thermosolation process to achieve the same colour shade, i.e. the fineness of the material needs to be taken into account.

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# REMISNÍ PARAMETRY POLYESTEROVÝCH VLÁKEN ROZDÍLNÉ JEMNOSTI PO TERMOSOLACI

Translation of article

## Light reflection of polyester fibers with different fineness after thermosolation

**Abstrakt:** V práci je sledována barevnost polyesterových vláken po termosolaci. Experimenty byly zaměřeny na kvantifikaci vlivu teploty, doby termosolace, množství barviva ve vláknech a na intenzitu výsledného barevného odstínu u tří sledovaných disperzních barviv. Porovnání bylo realizováno na vláknech odlišných jemností.

Cílem bylo zjistit, jaký vliv má teplota a doba termosolace na intenzitu výsledného barevného odstínu polyetyléntereftalátových vláken u tří sledovaných disperzních barviv. Porovnání bylo prováděno při několika různých teplotách a časech. Dále šlo o zjištění zda vzniká barevná diference na polyesteru rozdílných jemností při shodné koncentraci naneseného barviva a stejných parametrech barvení. Byl experimentálně vyhodnocen vliv druhotné difúze disperzního barviva do vlákna a změna intenzity vybarvení.

### 1. ÚVOD

Termosolace je kontinuální metoda barvení polyesteru disperzními barvivy. Při metodě barvení termosol je na textilii naklocováno barvivo společně s inhibitory migrace (zahušťovadla) a produkty s dispergačními a smáčecími účinky. Po naklocování a zasušení následuje vlastní termosolační proces při teplotě 180 - 220°C. Doba termosolace kolísá podle zvolených barviv, teplot a struktury textilie přibližně v mezích od 15 do 60 sekund [1].

Při barvení termosolovým způsobem proniká (difunduje) disperzní barvivo ze zasušené vrstvy barviva na povrchu vlákna působením tepla do nitra polyetyléntereftalátového vlákna. Rychlost procesu je ovlivněna zejména jemností vlákna, teplotou a chemickou konstitucí molekuly barviva.

Převažující třídou barviv, kterými se polyetyléntereftalátová vlákna barví, jsou barviva disperzní podskupiny S, která pronikají do vlákna pomaleji díky velké molekule a z těchto důvodů se vyznačují výbornou stálostí v sublimaci. Naopak barviva s malou molekulovou hmotností difundují do vlákna rychleji, ale mají horší stálostí v sublimaci.

Barvivo proniká do hmoty vlákna z povrchu. V případě málo intenzivní difúze barviva (termosolace za nižších teplot resp. kratších

časů) je barvivo rozmístěno v průřezu vlákna nerovnoměrně, vyšší koncentrace je v povrchu vláken – jde o tzv. prstencové vybarvení. Prstencové vybarvení vykazuje nižší sytost než textilie homogenně probarvená při stejném celkovém obsahu barviva. Druhotnou difúzí je možné změnit radiální distribuci barviva ve vláknech prodloužením difúzního procesu, přičemž dochází k rovnoměrnější distribuci barva ve hmotě vlákna. Druhotnou difúzí lze tedy zajistit, že barevnost textilie bude přímo úměrná koncentraci barviva ve vláknech bez ohledu na původní radiální distribuci barviva ve hmotě vlákna [2].

#### 1.1 Vliv jemnosti vláken na rychlost barvení

Zjednodušený Fickovský vztah (1) mezi difúzním koeficientem a poločasem barvení byl použit k důkazu významu měrného povrchu vláken pro rychlost barvení.

$$D = \frac{0,00632 \cdot r^2}{t_{1/2}} \quad (1)$$

kde D je difúzní koeficient,  $t_{1/2}$  je poločas barvení a r je poloměr vlákna.

Jde o rozsah uplatnění povrchové adsorpce jakožto důležitého „nástupišť“ pro navazující



difúzi do vlákna. Difúzní vlastnosti vláken jsou dány fyzikálně-chemickými vlastnostmi polymeru – tedy nezávislejší na jemnosti vláken. Ale rychlost barvení je „vnější vlastností“ – a podstatně se mění podle jemnosti vláken, resp. jejich další geometrie, která určuje rozsah kontaktu s barvicí lázní [2].

Rychlost sorpce závisí na velikosti měrného povrchu substrátu, který přichází do styku s lázní. U zidealizovaného systému jsou srovnávaná vlákna ze zcela totožného polymeru, mají dokonale válcovitý tvar o poloměru  $r$  a délce  $l$ , proudění lázně je ideální, tzn. přítok k vláknům je intenzivní natolik, že se okamžitě vyrovnávají místní úbytky koncentrace barviv v lázni vlivem adsorpce na povrch vláken. Pro tento systém pak platí rovnice (2).

rychlost sorpce ~

$$\frac{\text{povrch}}{\text{hmotnost}} = \frac{2\pi r \cdot l}{\pi r^2 \rho \cdot l} = \frac{\text{konst}_1}{r} = \frac{\text{konst}_2}{\sqrt{\text{tex}}} \quad (2)$$

kde  $\rho$  je měrná hmotnost.

Zvyšování rychlosti barvení je tedy nepřímo úměrné poloměru vláken  $r$ , resp. nepřímo úměrné druhé odmocnině jemnosti [tex]. To se projevuje všeobecně, i když s menšími odchylkami, které plynou z neideálních vlastností reálných systémů. Zvláště výrazně se v praktické koloristice naráží na tuto zákonitost při přechodu k barvení mikrovláken u nichž probíhá barvení velmi rychle – právě v důsledku jejich extrémně velkého měrného povrchu [3-6].

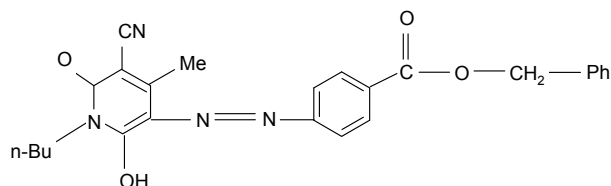
## 2. EXPERIMENTÁLNÍ ČÁST

### 2.1 Textilní substráty a použitá barviva

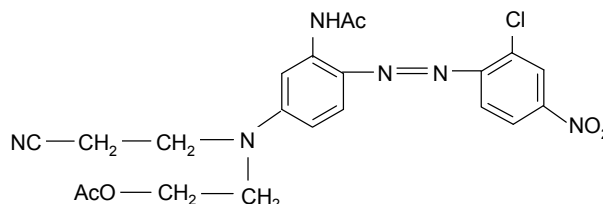
Pro experimenty byly použity textilie ze 100 %ního polyesteru. Textilie standardní jemnosti (průměr vlákna 21  $\mu\text{m}$ ) o plošné hmotnosti 170  $\text{g}\cdot\text{m}^{-2}$  a textilie z mikrovlákna (průměr vlákna 9  $\mu\text{m}$ ) o plošné hmotnosti 70  $\text{g}\cdot\text{m}^{-2}$ .

Použitá disperzní barviva :

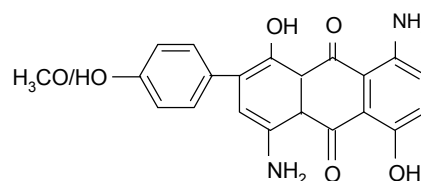
- Foron brilantní žlut' S-6GL



- Foron brilantní červeň S-RGL



- Foron modř S-BGL

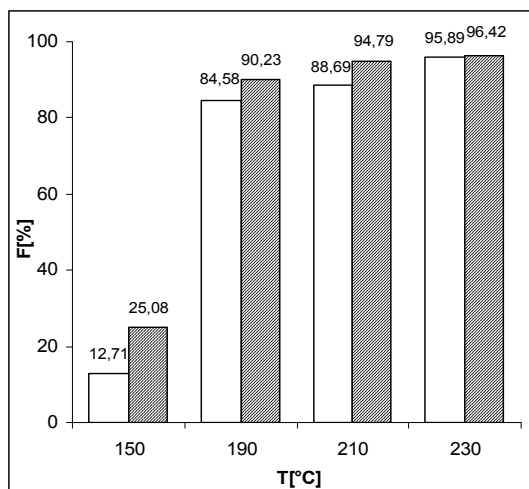


Barvicí lázeň byla na textilií nanesena na laboratorním fuláru, zasušena a termosolována při teplotách 130 až 220°C po dobu od 10 do 240 s.

### 2.2 Množství barviva fixovaného na vlákne standardní jemnosti a mikrovlákna

Pro dobu termosolace 60 s a příslušné teploty je množství fixovaného barviva pro oba typy polyesteru uvedeno na Obr. 1. Vztahy remise (R) pro vlákna rozdílné jemnosti při stejné koncentraci fixovaného barviva jsou na Obr. 2.

Z Obr. 2 je zřejmé, že u mikrovláken je za stejných podmínek barvení vyšší remise a tím i nižší sytost vybarvení. Rozdíly jsou dány zejména optickými parametry textilie tvořené vlákny odlišné jemnosti.



**Obr. 1** Fixace (F) barviva Foron brilliant Red S-RGL při různých teplotách (T) na standardní vlákno a mikrovlákno. Doba termosolace 60 s. V grafu jsou data získaná z pokusů na standardních vláknech (nešrafované sloupce) i na mikrovláknech (šrafované sloupce).

### 2.3 Závislost remisních parametrů na teplotě a době termosolace

Na Obr. 3 je typický průběh termosolačních křivek pro zvolenou teplotu a dobu termosolace. Z průběhu jsou patrné optimální oblasti pro termosolační technologie, tj. teplota v mezích 190 – 220°C.

## 3 DRUHOTNÁ DIFÚZE BARVIVA DO VLÁKNA

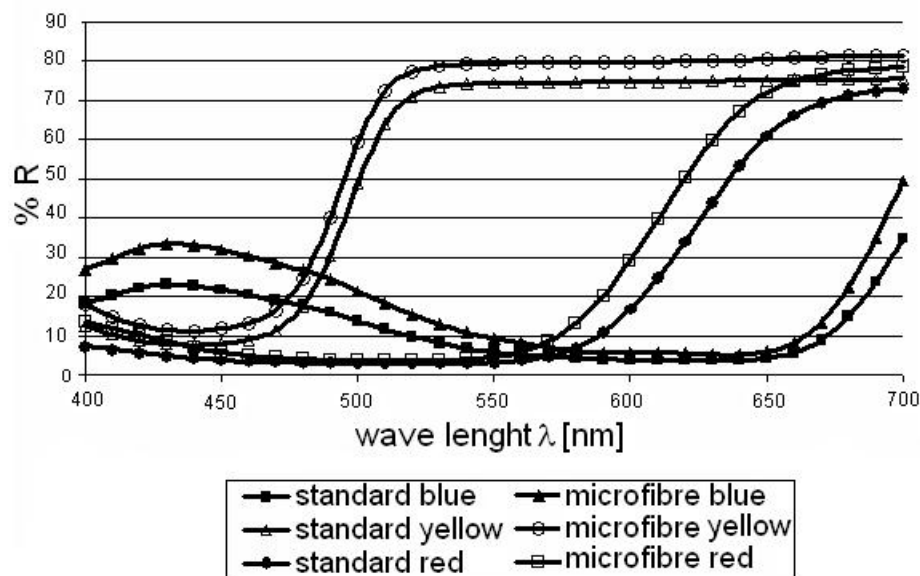
Druhotné tepelné namáhání obarvených vláken bylo prováděno za teploty 200°C a 60 s. Předpokládali jsme, že u vzorků termosolovaných za nižších teplot došlo pouze k prstencovému vybarvení. Cílem bylo zlepšení radiální distribuce a navýšení K/S

hodnot. Po tomto tepelném namáhání obarvených polyesterových vláken byly experimentálně zjištěny posuvy v remisi po takto realizované druhotné difúzi disperzního barviva. Možno zobecnit, že tato druhotná difúze se více projevuje na výsledné remisi vláken o vyšší jemnosti. Naopak u vláken nižší jemnosti se druhotná difúze, zejména u vzorků primárně termosolovaných za vyšších teplot, projevila částečnou sublimací barviva již původně vázaného na vlákne a výsledkem bylo světlejší vybarvení, tedy vyšší remisní hodnoty.

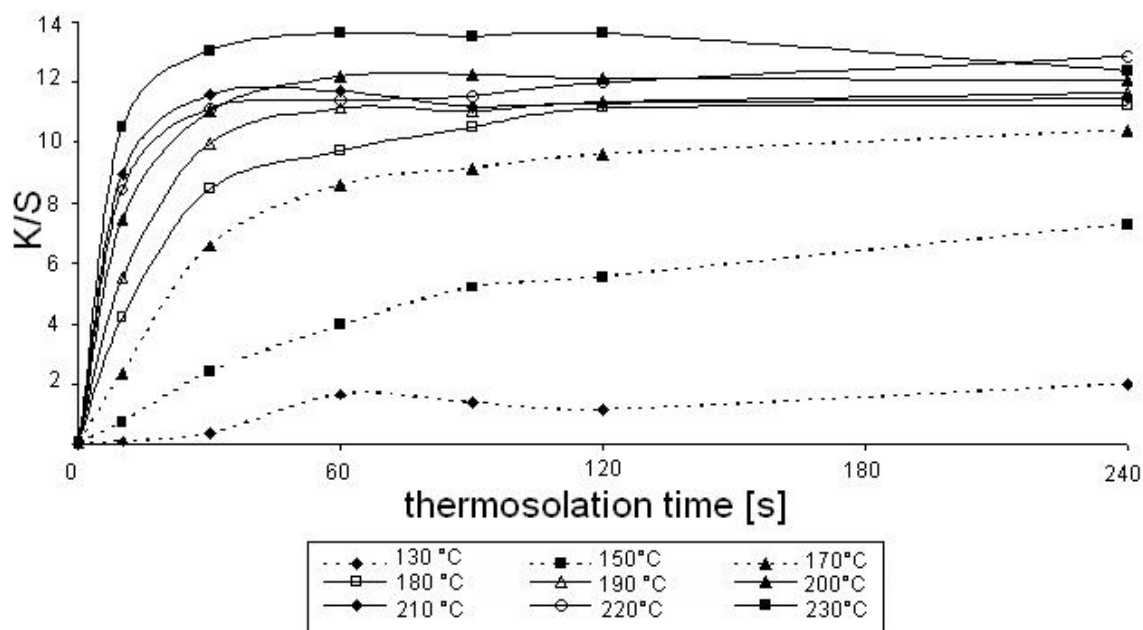
## 4 ZÁVĚR

Byla ověřena technologická zkušenost, že k výrazné difúzi do vláken obou jemností dochází při optimální teplotě v rozmezí 190 – 220°C. Při vyšších teplotách se již nedosahuje „vyšší“ výtěžnosti barviva na vlákne. Při nižších teplotách než 190°C je naopak kinetika termosolace nedostatečná a celý proces by tak trval relativně dlouhou dobu.

Objektivním remitometrickým měřením na přístroji Datacolor bylo zjištěno, že při srovnatelné koncentraci disperzního barviva v polyesterových vláknech vykazují vyšší odrazivost pro světelné paprsky vlákna nižší jemnosti. Z toho plyne, že běžnému spotřebiteli se jemnější vlákna jeví světlejší při srovnatelné koncentraci barviva na vlákne. Pro praktické řízení termosolačních procesů a určování výsledného parametru vybarvení, to znamená, že kolorista musí vést termosolační proces tak, aby bylo dosaženo stejného odstínu, tj. brát v úvahu jemnost materiálu.



**Obr. 2** Porovnaní remisních křivek získaných při termosolaci standardních vláken a mikrovláken všech tří testovaných barviv při stejné teplotě a době termosolace. (Pozn. wave length = vlnová délka).



**Obr. 3** Závislost remise (K/S hodnot) na době termosolace při zvolené teplotě. Jde o výsledky s barvivem Foron brilant žluť na standardním vlákne. (Pozn. thermosolation time = doba termosolace)

# THE STRUCTURE AND PROPERTIES OF THE TEXTILES FROM SPECIAL POLYPROPYLENE FIBRES

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**Abstract:** This paper deals with the preparation of structure and properties of knits and of the thermo – clothes, prepared from the special PP fibers and with classical PP fibers. Physical - mechanical properties of individual fibers and knits, physiological properties of knits and as well utility properties of knits and of thermo – clothes subjectively methods were evaluated. Some properties of the fibers are changed as compared to conventional PP fibers and this change was obtained by change of geometry and hydrophilic modification of PP fibers. These facts are reflected in the objective and the subjective evaluation of utility properties thermo – clothes.

**Keywords:** polypropylene fibers, physiological properties, physical-mechanical properties, utility properties.

## 1. INTRODUCTION

Fibrous materials are important product in the application of fibers destined for clothing production, textiles production and technical textiles production. Different kinds of clothing are used in direct or indirect contact with human skin. The clothes affect the health, welfare and the human psychical state. These types of textiles require appropriate utility properties, mainly suitable physiological properties - transport heat and moisture [1, 2].

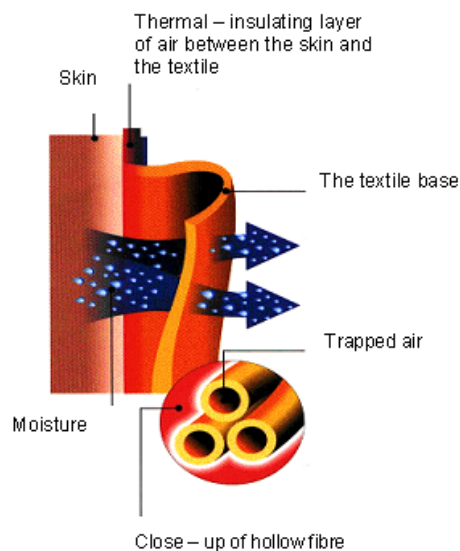
Textile fiber materials can be perceived as a composite of fiber and air. Important evaluation of the parameters of fibers and their products are molecular, supermolecular structure, morphological, macromorphological structure of fibers as well as the structure of the textile product. Properties of textile products depend on basic material properties from which the products are produced as well as from their macromorphological structure [4].

Our work was focused on the study of fabrics made of polypropylene (PP) fibers, classic and from specially prepared fibers.

### Modifications of PP fiber

New modification processes in the manufacture of PP fibers allow to prepare

fibers with improved properties such as elastic, sorptive, properties of the reduced electrostatic charge, improved coloration with of the solutions of dyes and printing [5]. Selection and application of appropriate modification process to improve the properties of PP fibers depends primarily on the requirements that are imposed on their use [5].



**Figure 1** Transport properties of fibrous materials [3]

Knowledge of physical and chemical changes, that occur when modifications, is important to assess the advantages and

disadvantages of the modification process [5].

Modifications of polymer additives, nanoparticles, branched polymer, and polymers for the preparation of polymer blends counts among the most studied modifications to improve the properties of fibers in recent years [6].

Modifications of the PP fibers are primarily directed at the increasing hydrophilicity PP. Among the modifications that have been studied at improving hydrophilicity PP fibers we can include: esc. grafting of a PP membrane surface with poly(N-vinyl-2-pyrrolidone) and PP hollow fibers membrane surface with N,N-dimethylaminoethyl metacrylate leads to the higher hydrophilicity of a PP surface [7].

Modification of PP fibres by oxyfluorination is another method to decrease the water contact angle remarkably and increase the polarity and hydrophilicity of the PP surface [6].

The penetration of organometallic compounds (e. g., Si(OEt)<sub>4</sub> into polymers like PP, PA, PES, and PU surfaces under supercritical CO<sub>2</sub> shows an increased surface hydrophilicity [6]. Among the physical modifications we can include esc. : PP fibres modified via blending with ethylene-vinyl-acetate copolymer and ethylene-propylene copolymer indicate better hydrophilicity and dyeing ability [7]. Modified PP fibers composed of PP and aluminosiloxane

prepared by melt blending and followed by spinning have significantly modified antistatic properties. Polyamideureas as additives to PP contribute to the better sorptive and electrical properties of modified PP fibres. PP fibres modified with alkaline copolyamides have better hydrophilicity, dyeability and electrical properties as well [7].

## 2. EXPERIMENTAL PART

Thermo – clothes was prepared from 3 kinds of PP fibers are shown in Table 1 [18].

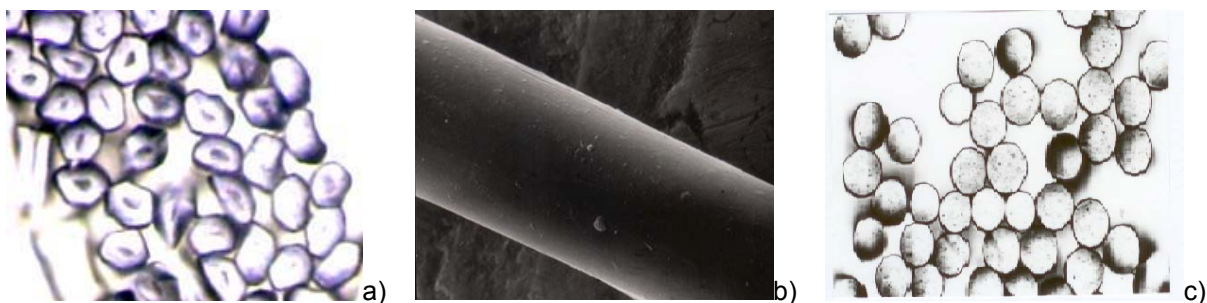
**Table 1** The material used to prepare thermo – clothes

Sample	PP assortment	The material composition of the fibers
A	56/33x2	PP modified hydrophilic additive Colorsvit (IRGANOX) (circular cross section)
B	56/43x2	PP with hollow fiber (circular cross section)
C	56/33x2	PP (circular cross section)

Figure 2 shows the photomicrography transverse and longitudinal geometry of the fibers scanned SEM microscope.

The surface of all samples was treated by antibacterial additive at base of silver.

Physical - mechanical properties of PP fibers are listed in Table 2 [8-10].



**Figure 2** Cross section of PP- hollow fiber (a); surface of PP fiber (b) and circular cross section PP fiber (c)

**Table 2** Physical - mechanical properties of PP fibers according to the standards ISO 2060, 2062, 11 357 - 1, 3146

Exams	Sample A	Sample B	Sample C
Linear density [dtex]	110.1	114.4	110
Tenacity [cN]	253	333	331
Relative tenacity [cN/dtex]	2.3	2.9	3
Elongation [%]	134.2	96.6	104.2
PPM	33	67	49
Degree of crystallinity [%]	32.4	35.6	35.3
Specific surface [m <sup>2</sup> /kg]	338	330	346

There were prepared knits and thermo – clothes from them from these fibers. Mechanical and utility properties of knitted products - T-shirts were evaluated on knits. Measurement results showed (Table 2) that the hydrophilic modification caused a reduction of physical - mechanical properties as well as partially reduction the of degree of crystallinity (Kp) compared with PP fiber type B and C. The specific surface was highest in sample C of classical PP.

Knits were analyzed mainly at:

- capillarity elevation using 0.5% solution of KMnO<sub>4</sub>
- sorption ability of non-conventional method for assessing thermo – clothes
- wetting angle
- abrasion resistance EN ISO 12947-2

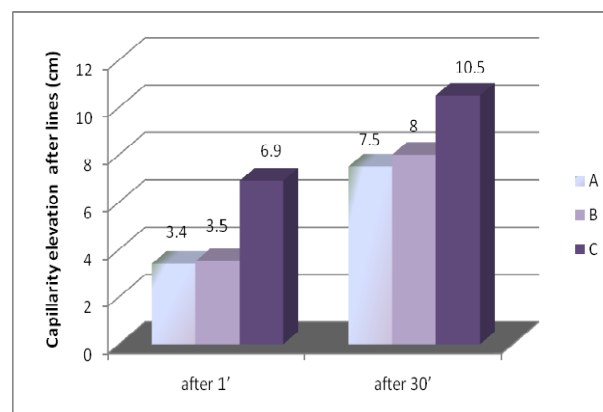
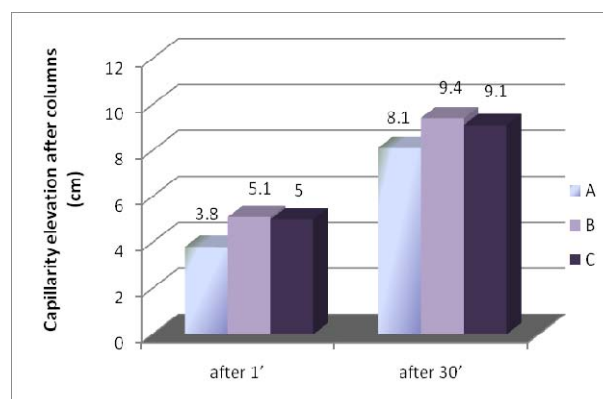
Capillarity elevation was evaluated on samples after washing of 0.5% solution of KMnO<sub>4</sub>.

Samples were evaluated after 1 and after 30 minutes and it was in the direction lines and in direction columns [11]. Results are shown on Figures 3 and 4.

The values of samples B and C were in direction columns approximately the same. Sample A with the hydrophilic modification had the lowest values.

Method of measuring the diameter circular area was selected to compare the ability

knits absorbs liquid [12]. Test was conducted on samples of washed knits. Results of measurement are listed in Table 3.

**Figure 3** Capillarity elevation in cm after the 1' and 30 ' in direction of the line**Figure 4** Capillarity elevation in cm after the 1' and 30 ' in direction columns

**Table 3** Results of determination of sorption of water from of front and back side of knits

Sample	Average drops from the front side [cm]		Average drops from the back on of the front side [cm]			
	for 1'	for 5'	for 1'(verso)	for 1'(recto)	for 5'(verso)	for 5'(recto)
A	2.6	2.8	2.5	2.7	2.8	2.7
B	2.5	2.6	2.1	2.1	2.4	2.3
C	2.1	2.3	2.3	2.4	2.7	2.6

Sample A with a hydrophilic modification had partly higher values than the average circular surface of the sample B and C, it resulted from the determination of water sorption. Determination of wetting angle was further impact assessment of hydrophilic additives. Samples knits were used after washing. Surface of the liquid is -drenched in generally at contact angle  $\theta < 90^\circ$  and no- drenched at  $\theta > 90^\circ$  [13]. The measurement results are listed in Tables 4-6.

**Table 4** Timetable adsorb of drop water - sample A

Time[s]	0	3	5	6	7	8	9
KUZ [°]	113.7	111.5	107.0	96.1	76.0	26.1	0

**Table 5** Timetable adsorb of drop water - sample B

Time[s]	0	1	2	3	4	4.5
KUZ [°]	131.2	130.9	126.1	109.1	103.1	25.5

**Table 6** Timetable adsorb of drop water - sample C

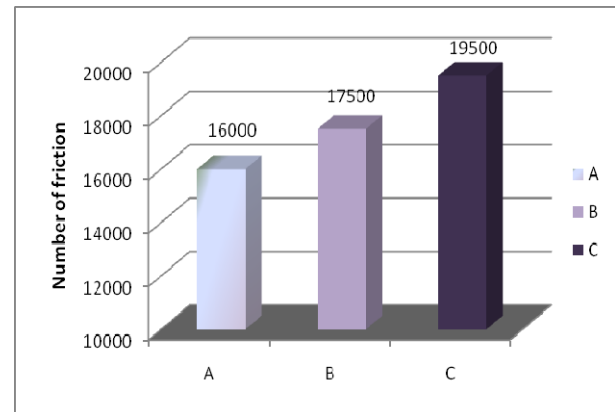
Time[s]	0	1.2	1.5	1.8	2.1
KUZ [°]	123.3	120.7	71.3	24.4	0

KUZ- contact of wetting angle

Measurement results of wetting angle are listed in Tables 4-6, and they show that physical activity surfaces are on all 3 samples different.

Durability is also an important parameter in assessing the utility properties knits.

This test we wanted to find out is how the planar fabric will be resistant against mechanical wear, which can be regarded as one of the most common strain knits in the practical carry. At the Figure 5 is provided abrasion resistance [14].

**Figure 5** Results of abrasion resistance of knitted fabric expressed by the number of rubbing samples A, B, C (EN ISO 12947-2)

The results of abrasion resistance knits (Figure 5) show that sample C needed to rip up the largest number of friction and can therefore be considered the most resistant to mechanical wear. Durability was the lowest in sample A. Resistance to wear knits in sample B is influenced by higher linear density of capillaries.

Thermal - insulating ability is one of the key utility properties thermo – clothes. It is characterized by the heat transfer through the fabric. Thermal - insulating properties were determined using the apparatus ALAMBETA. This device is designed to measure thermo and physical parameters of textiles, especially the thermal conductivity ( $\lambda$ ) and areal thermal resistance ( $r$ ) [15].

$$\lambda_{fa} = (1 - f_p) \cdot \lambda_a + f_p \cdot \lambda_{fi} + \lambda_{rad}. \quad (1)$$

$\lambda_{fi}$  - thermal conductivity of fiber [W/m.K],  $\lambda_{rad}$  - thermal conductivity of radiation [W/m.K],  $\lambda_{fa}$  - thermal conductivity of the fabric [W/m.K],  $\lambda_a$  - thermal conductivity of air [W/m.K],  $f_p$  - (0-1) porosity [%]



Values measured of thermal-insulating properties of the thermo - clothes are listed in Table 7.

**Table 7** Values of measuring thermal conductivity ( $\lambda$ ), specific thermal resistance ( $r$ ), thermal activity ( $b$ ) and thickness ( $h$ ) of samples of the thermo – clothes from A, B, C knits

	$\lambda \cdot 10^3$	$\nu_k$	$r \cdot 10^3$	$\nu_k$	$b$	$\nu_k$	$h$	$\nu_k$
<b>A</b>	44.5	1.9	23.4	1.9	135	2.9	1,0	2.0
<b>B</b>	45.4	1.4	<b>29.2</b>	2.9	<b>128</b>	3.6	1.3	3.1
<b>C</b>	45.2	1	26.1	0.8	130	3.4	1.2	1

$\lambda$  - specific thermal conductivity [ $W m^{-1}K^{-1}$ ],  $r$  - specific thermal resistance [ $W^{-1} Km^2$ ],  $b$  - thermal activity [ $Wm^{-2}s^{1/2}K^{-1}$ ],  $h$  - material thickness [mm],  $\nu_k$  - coefficient of variation

The best specific thermal resistance at evaluating of thermo – clothes has sample B of the hollow fibers. It is needed to find the causal link is in the macromorphological structure of the knits. Measurement of thermal and insulation properties of the thermo – clothes was also performed by the method of infrared cameras and it allows us without contact to measure temperature fields in the surface of the thermo – clothes. Thermo grams of individual samples are given in Figure 6.

Two different rectangular regions of temperature fields were selected to measure and compare temperatures between bare skin and the measured sample and it in area of the neck and blades. Results from thermo grams are listed in Table 8. This method confirmed the fact mentioned above that the best thermal insulation properties show a shirt made from a sample B from the hollow fibers.

Physiological and utility properties of the thermo – clothes require laboratory tests as well as subjective tests of wearing using figurants. The results of these tests are necessary in noticing the ability about of physiological, comfortable, utility properties and about quality of the thermo – clothes was the highest [16].

**Table 8** The temperature measured at the shirts and set to of thermo grams [18]

Sample	$T_{mean}$ [°C]		
	A	B	C
$T_f$	34.1	34.2	33.2
$T_t$	32.8	32.6	32.1
$T_f - T_t$	1.34	1.68	1.12

$T_f$  – average surface temperature in region of the neck,  $T_t$  – average temperature at the surface of the fabric in region of blades,  $T_{min}$  - average minimum temperature,  $T_{max}$  – average maximum temperature,  $T_{mean}$  – average temperature in the selected region

Terms and indicators, which have been established by evaluation of utility properties, are listed in the work [17]. 5 figurants participated in wearing tests. Average values of subjective evaluation of physiological and utility properties of the thermo – clothes are listed in Table 9 in 5 levels (from level 5-the best features after of level 1 - the worst properties).

**Table 9** Average values of indicators utility properties of the thermo – clothes, of PP fiber with the hydrophilic modification, of PP hollow fibers and of classical PP fiber

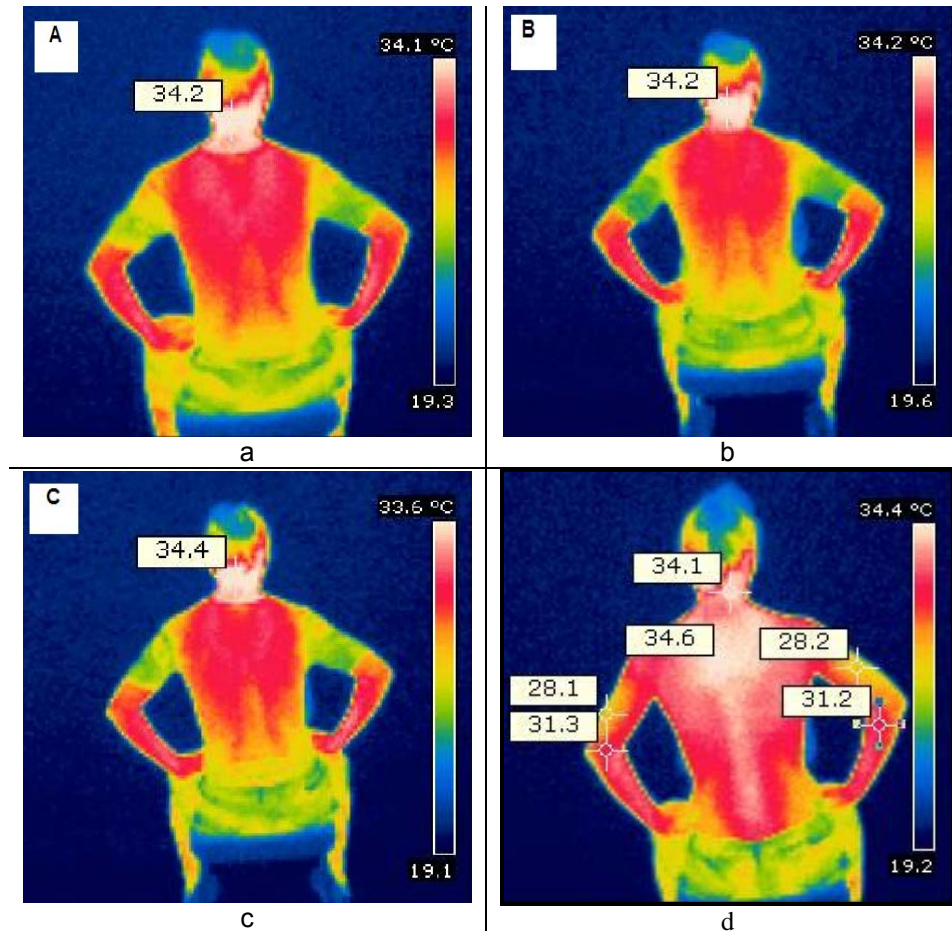
	Sample A	Sample B	Sample C
<b>Feel</b>	soft, warm	rough	rough, soft
<b>Abrasion resistance</b>	5	5	5
<b>Pilling effect</b>	5	5	5
<b>Thermal-insulating property</b>	5	5	5
<b>Shape fastness</b>	4	5	5
<b>Wearing comfort</b>	5	5	4

excellent - 5, very good - 4, good - 3, weak - 2, unsatisfactory - 1

Utility properties of the thermo – clothes, which was evaluated by wearing figurants showed, that t-shirts to wear of comfortable, they had good resistance to abrasion and pilling effects.

Sample A with a hydrophobic modification and sample B made of hollow fibers of improve comfort wear against classical PP. Sample A with a hydrophobic modification had the lowest stability in shape.





**Figure 6** Thermo grams documenting the distribution temperature fields of surface unveiled part of the body (d) and the outer surface material examined of the garment (a, b, c) [18]

### 3. DISCUSSION

The aim of this work was to study the relationship between structure and properties of PP fiber and properties and structure of knits and their products - thermo - clothes.

Physical - mechanical properties of examined of PP fibers are listed in Table 2. The results show that the hydrophilic modification used in the sample A affect physical - mechanical properties of the sample partially negatively (tenacity, degree of crystallinity, specific surface ...).

Results of capillarity elevation knits, listed in Figures 3 and 4 show that the hydrophilic modification made to the sample A had the lowest value compared to samples B and C, which is a consequence of reduced physical activity surface due to part higher sorption moisture (Table 3).

Also evaluation wetting angle (Tables 4-6) showed that physical activity of surfaces on

all 3 samples is different. Determination of water sorption (Table 3) and wetting angle (Tables 4-6) showed that the values of sample A were partially better than values of samples B and C, which implies that the used modifier, to lesser extent, improved hydrophilicity PP.

Evaluation utility properties knits and resistance to abrasion (Figure 5) confirmed the reduced resistance of the sample A with modifiers compared with other samples. Also for sample B, made of hollow fibers had slightly deteriorated abrasion resistance compared to the classical PP what is a consequence of greater linear density of capillaries (Table 2).

The best thermal insulation properties were measured in sample B, made of hollow fibers evaluation measurement of heat resistance (Table 7). This fact was confirmed also by measuring thermo-vision camera (Figure 6).

From subjective point of evaluation by figurants of the finished products was showed that greater comfort achieved sample B and sample A, even though the sample A showed the lowest stability in a shape. All samples of tested shirts have good resistance to abrasion and pilling effects and excellent thermal insulation properties (Table 9).

#### 4. CONCLUSION

Concerning the evaluation of the structure and properties of fibers and knits (of capillarity elevation, sorption, wetting angle) and physical- mechanical properties we can state that the used modifier in the sample A only partially improved of hydrophilicity products of PP fibers compared with samples B and C.

Thermal insulation capability, particular measuring areal resistance ( $r$ ) was better in changing of geometry for the sample B, made of hollow fibers.

Subjective evaluation using figurants also showed that t-shirts from all 3 knits:

- have acceptable resistance to abrasion,
- are resistant to pilling effects,
- are very pleasantly worn,
- have good thermal insulation properties and good comfort.

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## ŠTRUKTÚRA A VLASTNOSTI TEXTÍLIÍ ZO ŠPECIÁLNYCH POLYPROPYLENOVÝCH VLÁKIEN

Translation of Paper

### **The structure and properties of the textiles from special polypropylene fibers**

Príspevok je zameraný na štúdium štruktúry a vlastností pletenín a termobielizne, vyrobenej zo špeciálnych a z klasických PP vlákien.

Hodnotili sme fyzikálno - mechanické vlastnosti vlákien a pletenín, fyziologické vlastnosti pletenín a úžitkové vlastnosti termobielizne a vlastnosti pletenín subjektívnymi metódami pomocou probantov.

Zmena geometrie a hydrofilna modifikácia PP vlákien zmenili v porovnaní s klasickými PP vláknami niektoré ich vlastnosti. Tieto skutočnosti sa prejavili pri objektívnom aj pri subjektívnom hodnotení úžitkových vlastností termobielizne.