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Influence of the Type of Montmorillonite and the Conditions of Fibre Formation from a Polyacrylonitrile Nanocomposite on the Fibre Properties

Abstract

We investigated the influence of the ultrasound disintegration of montmorillonite (MMT) nanoadditions before inserting them into the spinning solution on the structure and properties of fibres spun from a polyacrylonitrile (PAN) nanocomposite. The supermolecular structure, the porosity, and the tenacity were characterised, and the distribution of the nanoaddition on the fibre surface was evaluated. The fibres were formed under conditions related to those for manufacturing fibres with a high tensile strength, and alternatively under conditions appropriate for obtaining fibres with increased porosity, but with tensile strength at a level which would enable their further processing by carbonisation in order to obtain carbon fibres.

Key words: polyacrylonitrile, nanocomposite, fibres, montmorillonite, fibre forming, spinning, drawing, precursor fibres, porous structure, tensile strength.

in the functionality of textile products. It is already known that polymer nanocomposites are composites which are obtained as the result of incorporating structures with at least one dimension at the nanometre level into the polymer matrix. The properties of nanocomposites, such as tenacity and thermal resistance, significantly exceed the properties of traditional composites and classical polymers [5 – 6]. These unique properties result mainly from the increased surface of mutual interaction between the polymer and the nanoaddition, and are caused by the greater disintegration of the nanofiller, compared with the dimensions of the components of a traditional composite. What is more, it can also be observed that with the increase in the dispersion degree of the nanoaddition in the nanocomposite, their mechanical and thermal properties are improved, which when using montmorillonite as nanoaddition means that intercalated or exfoliated structures are obtained, as at the same time is a more uniform distribution of the silicate throughout the whole volume of the composite [5, 6, 10].

Inserting montmorillonite into the matter of polyacrylonitrile precursor fibres was motivated by the intention to incorporate elements with osteoconductive and osteoproducer effects into carbon fibres devoted for medical applications. What is more, in order to achieve better disintegration and dispersion of the nanoaddition in the fibre matter, the nanoaddition in the form of a suspension of montmorillonite in dimethylformamide was subjected to homogenisation by

ultrasounds before inserting it into the polymer solution.

The aim of our work was to estimate the influence of the montmorillonite used and the ultrasound homogenisation of its agglomerates on the structure and the properties of polyacrylonitrile nanocomposite fibres.

In order to estimate the efficiency of the nanocomposite's homogenisation by ultrasound, an analysis of the fibres' mechanical properties was carried out, as were X-ray investigations which enabled the supermolecular structure and the type of dispersion of the nanoaddition in the polymer matter to be determined. Furthermore, the porous structure of the fibres obtained was assessed by mercury porosimetry. This was important, as it is known that the porosity of carbon fibres is the outcome of the porosity of precursor fibres and the porosity created as a result of the carbonisation process [11]. It is also known that in carbon fibres dedicated to medical applications, a higher porosity is preferred, considering that porous materials are more similar in structure to that of the bones of living organisms, and in addition the porous structure of an implant enables it to join better with the tissues, as the latter have the opportunity to root in the pores of the substance [12].

■ Introduction

Many research works have been carried out recently in order to obtain fibres from a new material group [1 – 4] characterised by a content of nanocomposites in the polymer matter. This research allows us to assume that such new-generation fibres would enable a significant increase

■ Materials and methods

Materials

The spinning solution was prepared from PAN terpolymer, produced by

Zoltek (Hungary) and having the following composition:

- 93 - 94% by wt. of acrylonitrile units,
- 5 - 6% by wt. of methyl acrylate,
- about 1% by wt. of sodium allylsulfonate.

Dimethylformamide (DMF) was used as a solvent.

The polymer intrinsic viscosity was $[\eta] = 1.29$ dl/g determined by the viscosimetric method in dimethylformamide (DMF) at 20 °C.

Polydispersity was determined by gel chromatography and carried out at the Institute of Biopolymers and Chemical Fibres. The result obtained was $M_w/M_n = 3.1$.

Nanoparticles

Montmorillonite modified with aminododecane acid: The modification of sodium MMT from Nanocor with aminododecane acid was performed at the Institute of Industrial Chemistry, Warsaw, under the supervision of Dr. M. Kędzierski.

As a result of this modification, the interlayer distances of MMT were increased from 12 Å for sodium MMT to 20 Å for the modified MMT. These values were calculated on the basis of the position of the first low-angle diffraction maximum.

Montmorillonite: Nanomer PGW, a trade product from Nanocor, USA, characterised by interlayer distances of 23.85 Å, and plate dimensions of 800 × 850 nm.

Methods

Fibre spinning

Fibres were spun by the wet process from solution with the use of a laboratory spinning machine which allowed the technological parameters to be stabilised at predetermined levels and kept under continuous supervision. The spinning solution contained 22% of polymer and 3% of nanoaddition (MMT Nanomer PGW or MMT modified with aminododecane acid) in relation to the polymer mass.

Montmorillonite in the form of a suspension in DMF was subjected to homogenisation for 30 minutes, at a temperature of 25 °C and a mixing speed of about 1500 rpm, and as an alternative subjected to ultrasound for one hour in a Polsonic-3 ultrasound washer of 2×60 W power at

a frequency of 40 kHz (independent of the MMT of particles within the range of 50 to 100 nm, packets and plates with micrometric dimension are included in the suspension before processing). Next, the suspension prepared was inserted into the spinning solution during its preparation. The rheological parameters of the spinning solutions were determined in accordance with the method described in [13], and for the solutions without a nanoaddition they were equal to $n = 0.964$ and $K = 27.5$. For spinning solutions including a Nanomer PGW nanoaddition and MMT modified by aminododecane acid, the parameters were similar, at levels of $n = 0.953$ and $K = 29.9$.

A spinneret with 240 orifices, each 0.08 mm in diameter, was used. The solidification process was carried out in a bath containing an aqueous solution of DMF (with a solvent concentration of 60%). Fibres were drawn in two stages: in a plastification bath with DMF content of 50% and at a temperature of 70 °C, and in overheated steam at a temperature within the range of 135 to 140 °C; the deformations in both stages were near the maximum. After rinsing, the fibres were dried at 20 °C under isometric conditions.

Fibre properties

Fibre tenacity was determined according to Polish Standard PN-EN-ISO-268: 1997 with the use of an Instron tensile testing machine.

Fibre porosity was determined by the mercury porosimetry method, by using a Carlo-Erba porosimeter linked to a computer system which allowed the total pore volume, percentage content of pores with dimensions from 5 to 7500 nm and the total internal pore surface to be determined.

The distribution of MMT on fibre surface was assessed on the basis of images taken by a JSM 5400 scanning microscope (SEM) with an EDX LINK ISIS analyser of dispersion energy of characteristic radiation from Oxford Instruments.

The degree of crystallinity and the size of the crystallites were determined by means of wide angle X-ray diffraction (WAXS) method. Diffraction patterns were recorded in symmetrical reflection mode using a URD-6 Seifert diffractometer and a copper target X-ray tube

($\lambda = 1.54$ Å) operated at 40kV and 30mA. Cu K α radiation was monochromised with a Ni filter. WAXS curves were recorded within the range from 2° to 60° with a step of 0.1°, and within the range from 2° to 12° with a step of 0.05°. The fibres investigated were powdered and pressed into a sample holder. Samples of 1 mm thickness with a radius of 2 cm were prepared.

The WAXS curves were analysed and the degree of crystallinity was calculated with the OptiFit computer program [14, 15]. In the first stage, a linear background was determined based on the intensity level at small and large angles and subtracted from the diffraction curve. Moreover, the curves of all samples were normalised to the same value of integral intensity scattered by a sample over the whole range of the scattering angle recorded in the experiment. Next, the experimental diffraction curves were approximated by theoretical curves composed by the sum of functions representing the particular crystalline peaks and the amorphous component. The theoretical curve was fitted to the experimental curve using a multicriterial optimisation procedure and a hybrid system which combines a genetic algorithm and the classical optimisation method of Powell [16].

Both the crystalline peaks and the amorphous halos were represented by a linear combination of the Gauss and Lorentz profiles:

$$F_i(x) = f_i H_i \exp \left\{ - \ln 2 \left[\frac{2(x - x_{oi})}{w_i} \right]^2 \right\} + \frac{(1 - f_i) H_i}{1 + [2(x - x_{oi}) / w_i]^2} \quad (1)$$

where:

- x – the scattering angle 2 θ
- H_i – the peak height
- w_i – the width at half height
- x_{oi} – the peak position
- f_i – the shape factor; f_i equals 0 for the Lorentz profile and 1 for the Gauss profile.

The initial values of the crystalline peak positions were calculated from the PAN unit cell dimensions given by Stefani [17]. According to Stefani, the unit cell of PAN is orthorhombic with dimensions of $a = 10.2$ Å, $b = 6.1$ Å and $c = 5.1$ Å. Using this data, the interplanar distances d_{hkl} for individual families of lattice planes were calculated:

$$\left(\frac{1}{d_{hkl}}\right)^2 = \left(\frac{h}{a}\right)^2 + \left(\frac{k}{b}\right)^2 + \left(\frac{l}{c}\right)^2 \quad (2)$$

Next, using Bragg's law:

$$2d_{hkl} \sin \theta = n\lambda \quad (3)$$

where n is a natural number, the positions of peaks related to a given family of planes were calculated.

The degree of crystallinity was calculated as the ratio of the total integral intensity comprised in the crystalline peaks to the total integral intensity scattered by a sample over the whole range of measurement.

Moreover, using Sherrer's formula:

$$D_{hkl} = \frac{\lambda}{w \cdot \cos \theta} \quad (4)$$

where: w is the width at half-height of a peak related to (110) lattice planes, the size of crystallites D_{hkl} in the direction perpendicular to the family of (110) lattice planes was calculated.

The investigations were carried out by Prof. S. Rabiej, Ph.D., D.Sc., at the University of Bielsko-Biala.

Discussion of the results obtained

Our assumption was to determine the influence of the ultrasound disintegration of the montmorillonite on the structure and properties of polyacrylonitrile nanocomposite fibres. Two montmorillonite types were used in order to obtain a broader spectrum of dependencies.

Taking into account the planned application of our polyacrylonitrile fibres and the demands set for precursor fibres dedi-

cated to carbon fibres for medical use, the fibres were formed in the two following variants:

- Under conditions favourable for obtaining an increased tensile strength, i.e. at a coagulation bath temperature of 15 °C, a concentration of the solvent in the coagulation bath of 60%, and an as-spun draw ratio of -40%.
- Under conditions favourable to obtain an increased porosity of the fibres, while at the same time maintaining the values of tensile strength at a level which would be suitable for carrying out the carbonisation process; these required applying a positive value to the as-spun draw ratio, a coagulation bath temperature of 15 °C, a concentration of the solvent in the coagulation bath of 60%, and an as-spun draw ratio of +10%.

The fibres' tensile strength

On the basis of an analysis of the results obtained (Table 1), we can state that the decrease in susceptibility to deformation, down to 606% at the stage of drawing, is linked to the incorporation of the Nanomer PGW nanoaddition into the PAN fibres spun at a negative as-spun draw ratio, in comparison to fibres spun without a nanoaddition under the same conditions, which are characterised by a total drawing value of 1054% (Table 1). This resulted in a tenacity decrease to the level of 23.7 cN/tex. At the same time, a higher deformation value of 923% was obtained for fibres containing the nanoaddition which was subjected to ultrasound; these fibres were characterised by a tenacity of 36.9 cN/tex. For fibres containing MMT modified by aminododecane acid and not subjected to ultrasound, the level of the deformation value which could be obtained is near to the deformation value

of fibres without any nanoaddition. This level is higher than in the case of fibres including a Nanomer PGW nanoaddition, which results in obtaining tenacity at the level of 38 to 39 cN/tex, depending on whether the nanoaddition is processed by ultrasound or not. In both cases, the negative influence of the presence of a non-fibre-grade nanoaddition in the fibre matter is visible. However, it should also be emphasised that the supermolecular and porous fibre structure affect the level of the tensile strength factors achieved, besides the orientation of the structural elements connected with the value of the deformations applied.

In the case of fibres containing the montmorillonite dispersed by ultrasounds and modified by aminododecane acid, which were spun at a negative value of the as-spun draw ratio, the increase in tensile strength may also be connected with the increase in the content of the crystalline phase in the fibre from 48% to 54%, which in its turn is linked to the increase in the crystallite dimensions from 43 Å to 48 Å. At the same time, the highest value of the crystallinity degree is related to the highest value of the fibres' tensile strength (the sample PMX 1 spun at an as-spun draw ratio of -40%). A similar situation takes place in the case of fibres containing the Nanomer PGW nanoaddition.

The tensile strength values obtained are connected with the phenomenon of the partial exfoliation of the MMT packets, indicated for all types of the PAN nanocomposite fibres tested. However, the scale of this phenomenon was difficult to evaluate on the basis of the WAXS investigation we carried out. A collapse of the MMT galleries also takes place,

Table 1. Spinning conditions, the structure and the properties of PAN fibres including different modified MMT and PAN fibres without a nanoaddition; the temperature of the coagulation bath was for all samples 15 °C; PW 1, PW 2 – fibres without a nanoaddition, MMT–A – fibres including MMT modified by aminododecane acid, MMT-PGW – fibres including MMT Nanomer PGW.

Sample symbol	Type of nanoparticles	Ultrasounds	As-spun drawing ratio, %	Total drawing, %	Content of the crystalline phase, %	Crystallite dimensions D(110)	Total volume of pores, cm ³ /g	Internal surface, m ² /g	Tenacity, cN/tex
PW 1	-	-	-40	1054	-	-	0.245	33.240	47.34
PMU1	MMT - PGW	Yes	-40	923	55	48	0.240	30.800	36.90
PM 3	MMT - PGW	No	-40	606	49	46	0.065	11.630	23.74
PMX 1	MMT - A	Yes	-40	888	54	48	0.252	33.727	39.75
PMY 2	MMT - A	No	-40	1073	48	43	0.108	1.975	38.49
PW 2	-	-	+10	437	-	-	0.387	33.856	40.79
PMU 2	MMT - PGW	Yes	+10	619	56	46	0.200	7.030	29.13
PM 7	MMT - PGW	No	+10	453	52	50	0.120	28.000	15.75
PMX 3	MMT - A	Yes	+10	641	50	45	0.360	22.950	26.04
PMY 1	MMT - A	No	+10	675	51	45	0.370	33.372	29.60

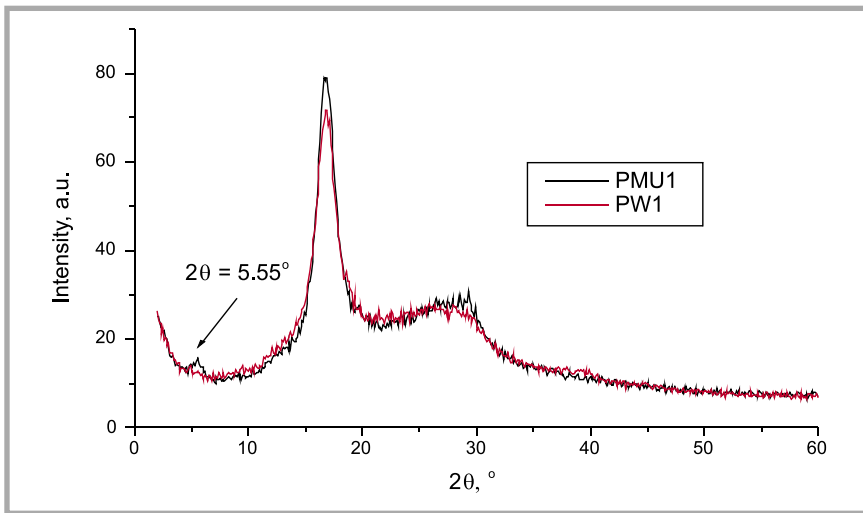


Figure 1. Diffraction curves for fibres PMU 1 including MMT Nanomer PGW and fibres PW 1 without nanoaddition.

a phenomenon we indicated earlier for polyimidoamide (PIA) nanocomposite fibres [18, 19], and identified on the WAXS diffractograms by a shift of the characteristic peak resulting from MMT in the direction of higher 2θ angle values; this latter may be connected with the mutual interaction of the MMT modifier with the solvent. For pure MMT this peak is positioned at a 2θ value of about 3.4 degrees, and in the case of the PAN nanocomposite, it shifts to the right to the 2θ value by about 5.55 degrees (Figure 1). This means that the height of the galleries decreased from 26 Å to about 15.9 Å, which indicates the galleries' collapse. This phenomenon takes place for fibres containing the Nanomer PGW nanoaddition, as well as for those with MMT modified by aminododecane acid.

On the basis of an analysis of tensile strength changes of the fibres including different modified MMT and spun at a positive value of the as-spun draw ratio, we established that, similarly to the fibres spun at a negative as-spun draw ratio, the

effect of disintegrating nanocomposite agglomerates by ultrasound was more apparent while applying the Nanomer PGW nanoaddition (Table 1). The tenacity values of fibres, which include MMT modified by aminododecane acid, are slightly higher than those of the fibres including MMT which was not subjected to ultrasound. In this case, this may have been caused by applying slightly higher deformations in comparison with fibres including a nanoaddition subjected to dispersion. At the same time, for this value of the as-spun draw ratio, the influence of the presence of MMT layers or packets was exposed. These MMT forms probably slowed the run of the diffusion processes, which in turn resulted in creation of a structure more susceptible to deformation at the drawing stage ($R_{total} = 453\% - 673\%$) in comparison with the fibres which do not include MMT (Table 1, sample PW2), and for which the deformation was equal to 437%. The PM 7 fibres were characterised by the lowest tenacity value at a level of 15 cN/tex, for which the

deformation value was only insignificantly higher in comparison to that of the standard (sample PW 2). This means that we obtained an effect similar to applying 'milder' solidification conditions, while decreasing the temperature of the coagulation bath.

Analysing the supermolecular structure of fibres spun at a positive value of the as-spun draw ratio, we could establish that they have a content of crystalline regions at the level of 50 – 56%, which is not essentially higher than that of the fibres spun at a negative value of the as-spun draw ratio, for which this parameter was within the range of 48% to 55%. At the same time, the crystallite dimensions are greater for fibres containing MMT subjected to ultrasound than those of fibres with MMT not processed by ultrasound. The fibre sample PM 7 is an exception, as for these fibres the crystallite dimensions were at the level of 50 Å, and at the same time they were characterised by the lowest tenacity values in the entire series of tests.

The porous structure

By analysing the character of the curves of pore distribution as a function of its radius, for fibres spun at a negative value of the as-spun draw ratio (Figure 2), we can indicate that the pore distribution curves are characterised by local maxima, differentiated by its value, within the ranges of small and medium pores, as well as an increasing content of pores within the range of very great pores. In the case of fibres including MMT modified by aminododecane acid and not subjected to ultrasound, a characteristic maximum appears within the range of great pores. What is more, for all the fibres containing this nanoaddition, a change in the character of the macroporous structure in the direction of a more fine-porous structure

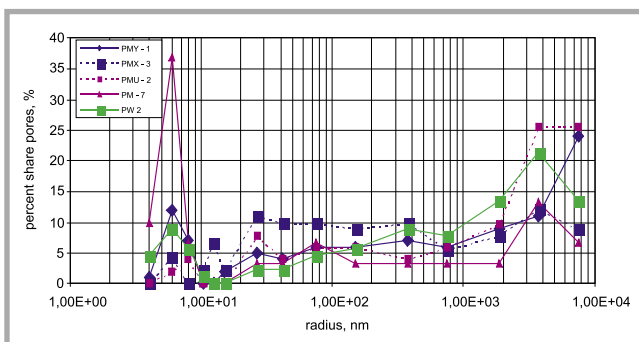


Figure 2. Pore distribution curve as a function of their radius, of fibres spun at a negative value as-spun draw ratio.

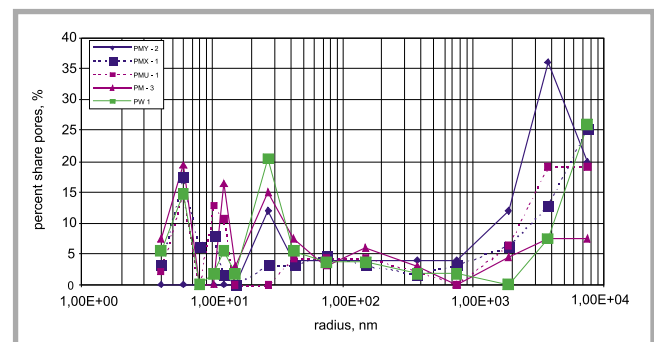


Figure 3. Pore distribution curve as a function of their radius, of fibres spun at a positive value of the as-spun draw ratio.

Table 2. Characteristic of porous structure of PAN fibres.

Sample symbol	As-spun drawing ratio, %	Total drawing, %	Percentage pore content, %			
			Small pores 4-12,3 nm	Medium pores 15-75 nm	Large pores 150 - 750 nm	Very large pores 1875 - 7500 nm
PW 1	-40	1054	27,78	31,48	7,40	33,34
PMU 1	-40	923	40,43	8,50	6,39	44,68
PM 3	-40	606	43,27	28,37	8,96	19,40
PMX 1	-40	888	36,51	11,10	7,93	44,45
PMY 2	-40	1073	0,00	20,00	12,00	68,00
PW 2	+10	437	20,22	8,99	22,48	48,31
PMU 2	+10	619	5,85	17,64	15,68	60,78
PM 7	+10	453	53,34	13,33	9,99	23,33
PMX 3	+10	641	13,33	33,33	24,45	28,89
PMY1	+10	675	20,00	17,00	19,00	44,00

can be observed, as the disintegration effect of MMT agglomerates. This is visible in the decrease of the summarised content of great and medium pores from 80% to 52% (Table 2), and justifies the description of the structure created being essentially similar to a fine-porous one.

An opposite situation arises in the case of fibres including a Nanomer PGW nanoadd-ition. Fibres containing MMT which was not subjected to ultrasound processing are characterised by a fine-porous structure with a content of small and medium pores at a level exceeding 70%. The effect of ultrasound disintegration of the nanoaddition's agglomerates was a decrease in the small and medium pore content in the fibres to just under 50%, and at the same time there was an increase of over twice in the content of very great pores.

This phenomenon may have been caused by a difference in the grain dimensions of both the MMT types. The formation of empty volumes (pores) in the neighbourhood of the incorporated MMT is connected with the presence of nanoadditions in the fibre matter. It is possible that in the case of greater Nanomer PGW agglomerates, the process of their disintegration by ultrasounds causes their partition into a greater amount of particles, which is accompanied by the formation of pores in their surroundings; furthermore, the dimensions of these pores are within the range of very great pores, and this in turn results in the increase described earlier in the share of very great pores within the total amount of pores. In contrast, in the case of MMT modified by aminododecane acid, whose grain dimensions are significantly smaller, the use of ultrasound disintegration created a greater amount of smaller MMT packets,

in whose surroundings pores within the small pores range were formed.

An increase in porosity was linked to the use of ultrasound disintegration on the agglomerates of both MMT types for fibres including MMT modified by aminododecane acid from the total volume of 0.108 cm³/g to 0.252 cm³/g, as well as for fibres including a Nanomer PGW nanoaddition from 0.065 cm³/g to 0.24 cm³/g. This phenomenon was accompanied by an increase in the internal fibres' surface from 1.975 m²/g to 33.727 m²/g, and from 11.63 m²/g to 30.80 m²/g respectively.

Applying the process of disintegration of the introduced nanoaddition enabled us to obtain a structure which was close to the structure of fibres without any nanoaddition but with the typically fine-porous character of the structure.

In contrast, the fibres which did not include nanoadditions either but which were spun at a positive as-spun draw ratio are characterised by a macroporous structure with a majority of great and very great pores at the level of 71%. Their total pore volume was higher and equals 0.387 cm³/g, whereas their internal surface amounts to 33.86 m²/g.

The pore distribution curves of all types of fibres spun at a positive value of the as-spun draw ratio are characterised by a local maximum existing within the range of small pores, and a near-uniform share of medium and great pores, as well as a significant share of the very great pores. As in the case of fibres spun at a negative value of the as-spun draw ratio, applying the disintegration of agglomerates of MMT modified by aminododecane acid by ultrasound processing for fibres spun

at positive values of the as-spun draw ratio causes a change in the character of the porous structure from macro- to fine-porous (Figure 3). This is accompanied by a decrease in the share of very great pores from the level of 44% to down 29% (Table 2). The total shares of small and medium pores also increased, from 37% to 47% respectively.

When incorporating the Nanomer PGW nanoaddition into the fibre matter, an opposite character of the porous structure changes are observed. The share of great and very great pores increases by near twice as much, to the level of 75% (see Table 2) in fibres containing a nanoaddition which was subject to ultrasound processing, to which the change of the fine-porous structure into a macro-porous one is connected. By analysing the change of the total pore volume and the total internal surface for fibres spun at a positive value of the as-spun draw ratio and containing both nanoaddition types, we can confirm the occurrence of different trend changes in the parameters mentioned above, which results from the nanoaddition disintegration, in compari-

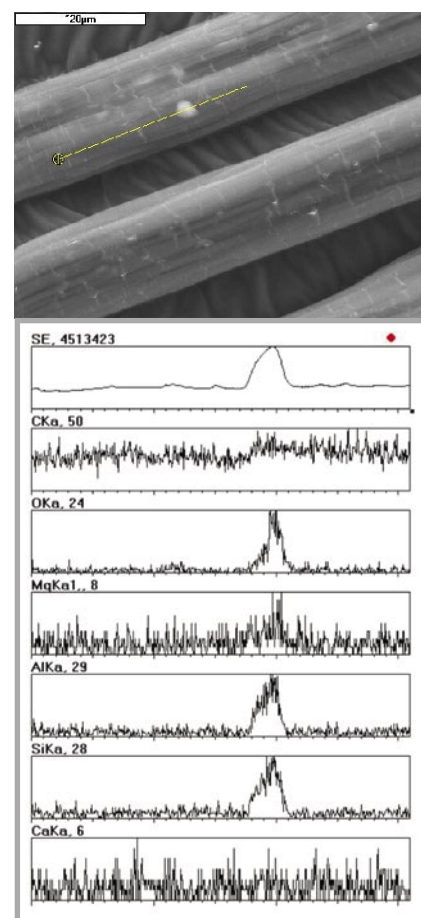


Figure 4. Linear EDS analysis of surface of PAN fibres including MMT Nanomer PGW.

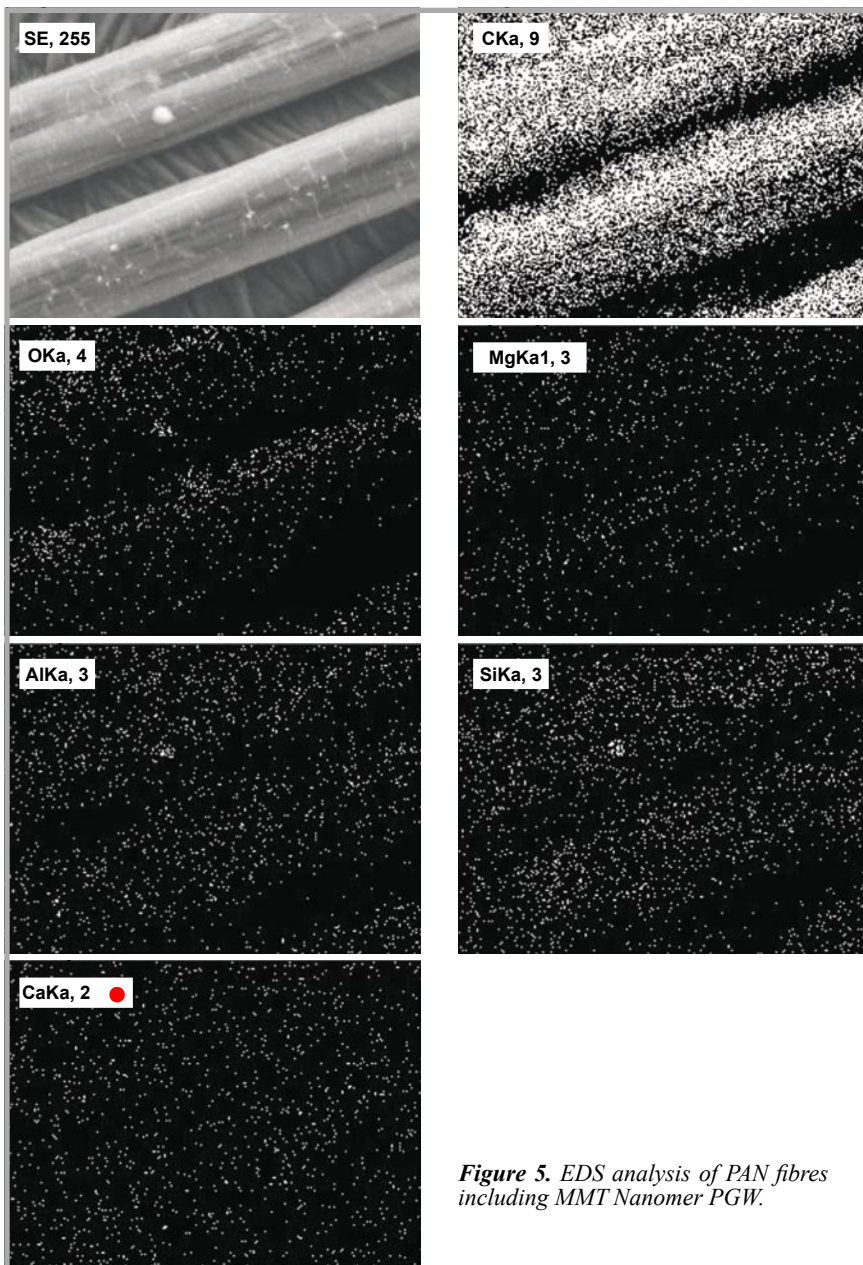


Figure 5. EDS analysis of PAN fibres including MMT Nanomer PGW.

son with fibres spun at a negative value of the as-spun draw ratio. This means that fibres with a nanoaddition which is not subjected to ultrasound processing are characterised by higher values of these parameters (Table 1).

Evaluation of the nanoaddition distribution on the fibre surface

It was possible to confirm the nanoaddition presence in the spun fibres and evaluate the uniformity of distribution on the fibre surface by an X-ray analysis combined with SEM and EDS.

On the basis of photos from a scanning electron microscope working with an EDS analyser, we could establish that the distribution of the nanoaddition on the fibres' surface is quite uniform, with

the exception of occasionally occurring agglomerates.

From the linear analysis presented for the sample PMU 1 (Figure 4), it results that besides the presence of carbon molecules characteristic for the fibre matter, molecules such as magnesium, aluminium, calcium, and silicon also occur, which are linked to the montmorillonite. The dependencies obtained, concerned with the linear segment marked on the photo of the fibre sample, confirm that the nanoaddition distribution on the fibre surface is uniform, and the maximum visible on the dependencies is related to a MMT agglomerate positioned on the fibre surface. The 'mapping' presented in Figure 5, i.e. a map of molecules' concentration on the surface of the fibres

tested, also confirms the uniform distribution of the nanoaddition on the fibre surface.

Conclusions

1. The increase in the tensile strength properties of PAN fibres including a Nanomer PGW nanoaddition is connected with applying disintegration of the MMT agglomerates by ultrasound processing.
2. The deformation value at the stage of drawing is principally decisive on the tensile strength properties of PAN fibre including MMT modified by aminododecane acid, whereas the effect of ultrasound disintegration of the nanoaddition is significantly smaller than in the case of fibres including a Nanomer PGW nanoaddition.
3. The higher tensile strength properties of PAN fibres including MMT modified by aminododecane acid are conditioned by the possibility of creating a greater amount of secondary bonds between the macromolecules of the fibre matter.
4. Applying the process of ultrasound disintegration of MMT agglomerates causes an increase in the total pore volume of the PAN nanocomposite fibres irrespective of the type of the MMT applied.

Acknowledgment

- This research work was sponsored by the Foundation for Polish Science, whose grant holder is Maciej Boguń M.Sc., Eng.
- Grzegorz Szparaga is grant holder of the 'Mechanizm WIDDOK' project supported by the European Social Fund and the Polish State (contract number Z/2.10/II/2.6/04/05/U/2/06).

References

1. Chae H.G., Sreekumar T. V., Uchida T., Kumar S.; *Polymer*; (46) 2005, „A comparison of reinforcement efficiency of various types of carbon nanotubes in polyacrylonitrile fiber”; pp. 10925-10935.
2. Mikołajczyk T., Boguń M., Kowalczyk A.; „Effect of Fibre-spinning Conditions on the Properties of Nanosilica-containing Precursor PAN Fibres”; *Fibres&Textiles in Eastern Europe*; 3 (13) 2005, pp. 30-34.
3. Boguń M., Mikołajczyk T.; “Comparative analysis of the properties of precursor PAN fibres containing nanoparticles”; *V International Conference MEDTEX 2005, Łódź, November 28-29, 2005*; pp. 139-141
4. Sreekumar T. V., Liu T., Min B. G., Guo H., Kumar S., Hauge R. H., Smalley R. E.; “Polyacrylonitrile Single-Walled Carbon

- Nanotube Composite Fibers" *Advanced Materials* Vol. 16, Issue 1, 2004; pp. 58-61.
5. Ray S. S., Okamoto M.; "Polymer/layered silicate nanocomposites: a review from preparation to processing" *Progress in Polymer Science*; Vol. 28, Issue 11, 2003, pp. 1539-1641.
 6. LeBaron P. C., Wang H., Pinnavaia T. J.; "Polymer-layered silicate nanocomposites: an overview"; *Applied Clay Science*; (15) 1999, pp. 11-29.
 7. Yu T., Lin J., Xu J., Chen T., Lin S.; "Novel polyacrylonitrile nanocomposites containing Na-montmorillonite and nano SiO₂ particle"; *Polymer*; (46) 2005; pp. 5695-5697.
 8. Kacperski M.; *Nanokompozyty polimerowe Cz. I Charakterystyka ogólna, napelniacze oraz nanokompozyty na podstawie polimerów utwardzalnych*; *Polimery* (47) 2002, No 11-12; pp. 801-807.
 9. Kacperski M.; *Nanokompozyty polimerowe Cz. II Nanokompozyty na podstawie polimerów termoplastycznych i krzemianów warstwowych*; *Polimery* (48) 2003, No 2; pp. 85-90.
 10. Ranade A., d'Souza N. A., Gnade B.; "Exfoliated and intercalated polyamide-imide nanocomposites with montmorillonite"; *Polimer* (43) 2002; pp. 3759-3766.
 11. Mikołajczyk T., Krucińska I.; "The Effect of Spinning Solution Filterability on Selected Properties of Precursor PAN Fibres and Carbon Fibres Manufactured Therefrom"; *Fibres & Textiles in Eastern Europe*; (1995) Vol. 3, No 3, pp.
 12. Nałęcz M.; *Biocybernetyka i inżynieria biomedyczna 2000, Volume 4 'Biomateriały' - eds: Błażewicz S., Stoch L.*
 13. Mikołajczyk T., Boguń M.; "Effect of Ceramic Nanoparticles on the Rheological Properties of Spinning Solutions of Polyacrylonitrile in Dimethylformamide"; *Fibres & Textiles in Eastern Europe*; (2005) Vol 13, No 1, pp. .
 14. Rabiej M.; "Determination of the degree of crystallinity of semicrystalline polymers by means of the „OptiFit” komputer software"; *Polimery* 47, (2002), p. 423.
 15. Rabiej M.; "Application of multicriterial optimization for determination of crystallinity degree of semicrystalline polymers"; *Polimery* 48, (2003), 288.
 16. Brandrup J., Immergut E. H., Grulke E. A., *Polymer Handbook*, Wiley, New York 1999.
 17. Stefani R. Cherretton M., Garnier M., Eyraud C., *Comptes Rendus de l'Academie des Sciences de Paris*, 251 (1960) 2174.
 18. Mikołajczyk T., Rabiej S., Olejnik M., Urbaniak-Domagala W.; "Strength Properties of Polyimideamide Nanocomposite Fibres in Terms Porosity and Supermolecular Structure"; *Journal of Applied Polymer Science* 104, 339, 2007.
 19. Mikołajczyk T., Rabiej S., Olejnik M.; "Analysis of the Effect of the Mount and Type of Montmorillonite on the Supermolecular Structure, Porosity and Properties of Polyimidoamide Fibres"; *J. App. Pol. Sci*; in press.

Received 17.10.2006 Reviewed 18.03.2007

9th International Conference IMTEX'2007

8-9 October 2007 Łódź, Poland

under the patronage of
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Organised by
**the Faculty of Engineering and Marketing of Textile
of the Technical University of Łódź**

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The 9th Imtex Conference continues the tradition of the cyclical scientific conferences organised by the Textile Faculty, and is linked to the 60th Anniversary of the Faculty. The main goal is to present the scientific achievements of the academic staff members and discuss new ideas within textile engineering.

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