I. Gruszka, S. Lewandowski, E. Benko, M. Perzyna

Institute of Textile Engineering and Polymer Materials, University of Bielsko-Biała, Poland
ul. Willowa 2, 43-309 Bielsko-Biała

Structure and Mechanical Properties of Polyamid Fibres

Abstract
We investigated polyamide fibres of the PA 6.0 and PA 6.6 types. These are produced in the form of filaments and staple fibres. The assortment of filaments includes monofilaments and multifilaments. All the proposed fibres, namely staple fibres and multifilaments and texturised fibres, are marked by very good mechanical properties. The investigations performed proved that all the tested fibres have comparable and similar degrees of crystallinity, but generally the PA 6.6 polyamide fibres have a greater degree than does PA 6.0. Furthermore, we state that there is a direct relationship between the size of crystalline zones and the linear density of the fibres tested.

Key words: *polyamide fibres, monofilament, multifilament, texturised fibres, supermolecular structure, degree of crystallinity.*

Introduction

Polyamide fibres of the PA 6.0 and PA 6.6 types belonging to the group of polymer thermoplastic fibres have a very wide spectrum of applications, especially in the field of thermal underwear and hosiery products, in which plain stitch knitwear plays a predominant role. Polyamide fibres are produced in the form of filaments and staple fibres. The assortment of filaments includes monofilaments and multifilaments, e.g. elementary continuous fibres and multifilament yarns. All the fibres discussed, e.g. staple fibres and multifilaments and texturised fibres, show very good mechanical properties. The high abrasion resistance is the most valuable feature of these fibres (it is tenfold higher than those of cotton, wool and viscose fibres). For this reason polyamide fibres are also used for the production of floor and stair carpets, as well as furniture fabrics.

Low thermal stability, high sensitiveness toward exposure to sunlight, electrification during spinning and the susceptibility to pilling of goods manufactured from polyamide fibres are their most essential disadvantages.

Physical properties of polyamide fibres

The physical properties of polyamide fibres are presented in Table 1.

Table 1. *Physical properties of polyamide fibres.*

shape of fibre	round
hygroscopicity in normal conditions in saturated air	 4.2 – 4.5% 10%
density	1.14 g/cm^3
dried strength	37 - 52 cN/tex
wet tenacity	33 - 47 cN/tex
dried extension	20 – 40%
wet extension	28 – 43%
abrasion resistance	very high
elasticity	very high
sensitiveness toward exposure to sunlight	very high
softening point	175^{0}C
melting point	218^{0}C
shrinkage in boiled water	8 – 12%
solvents	phenol, formic acid, hydrochloric acid
susceptibility to electrification	very high
susceptibility to pilling	very high

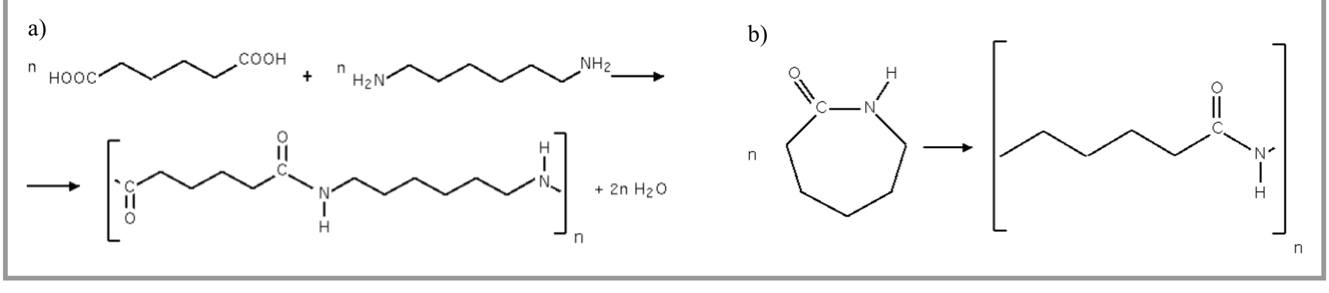

Figure 1. *a) polycondensation of dicarboxylic acids with diamines, b) ring-opening polymerisation of lactames.*

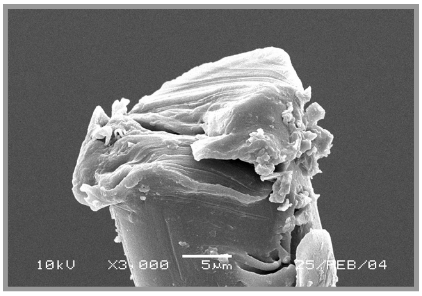

Figure 2a. PA60 staple – single fibre.

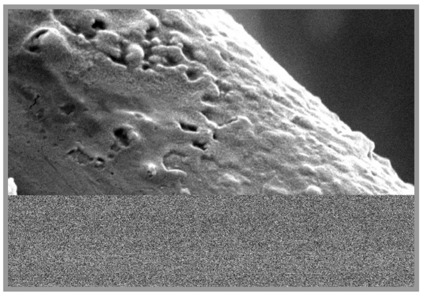

Figure 3a. PA66 staple – single fibre.

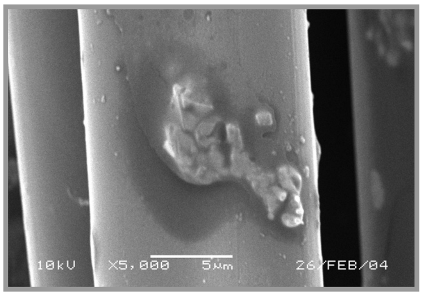

Figure 4a. PA60 multifilament – single fibre.

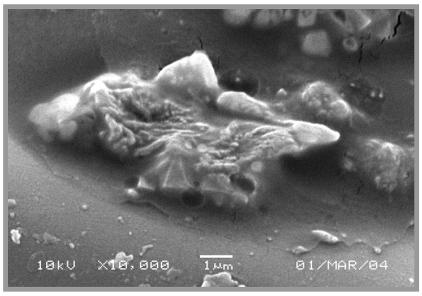

Figure 5a. PA66 multifilament – single fibre.

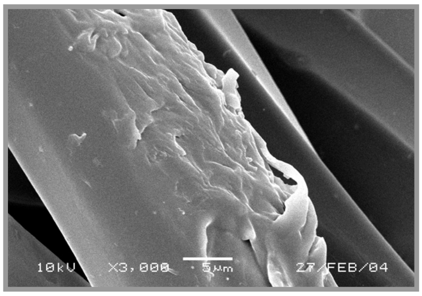

Figure 6a. PA60 texturized – single fibre.

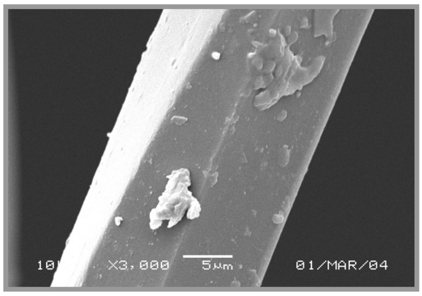

Figure 7a. PA66 texturized – single fibre.

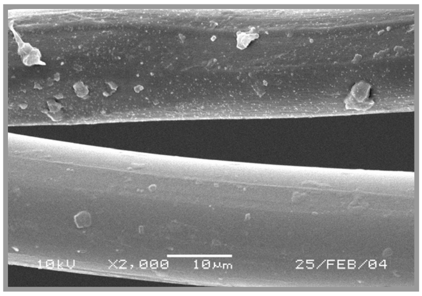

Figure 2b. PA60 staple – bundle fibre.

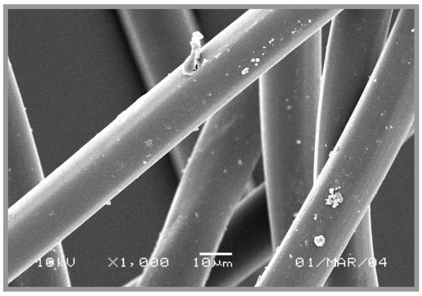

Figure 3b. PA66 staple – bundle fibre.

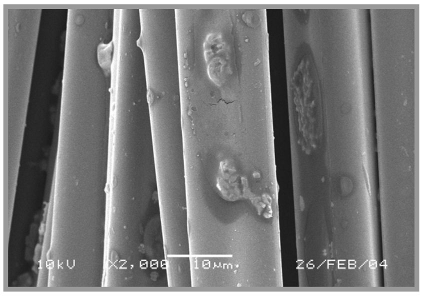

Figure 4b. PA60 multifilament – bundle fibre.

Figure 5b. PA66 multifilament – bundle fibre.

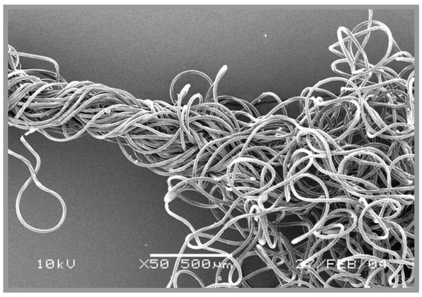

Figure 6b. PA60 texturized – bundle fibre.

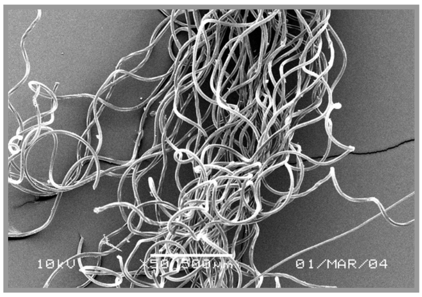

Figure 7b. PA66 texturized – bundle fibre.

Application of polyamide fibres

Polyamide fibres are applied in the production of:

- technical products such as tyre cords and filters & insulations,
- stocking products such as stockings, tights, socks,
- decorative products in the form of carpets, fitted carpets and tapestries
- clothes products, in particular sports outfits, suits, underwear (comprising lingerie, corset products and others).

Chemical composition and methods of preparing textile polyamides

Polyamides are polymers which contain amide bonds C(O)-NH in their main chain. These fibres show a strong tendency to crystallise, which is additionally strengthened by the formation of hydrogen bonds between the oxygen and nitrogen atoms of two various amide groups. Thanks to this property, polyamide fibres are harder and stiffer, and so more difficult to fuse than polyester fibres and vinyl polymers.

Among polyamide polymers, PA 6.6 nylons, aramids and plastics which show improved mechanical resistance are the main fibres produced. The latter ones can be used for the production of gear wheels.

Methods of preparation of polyamide fibres

A scheme of polycondensation of dicarboxylic acids with diamines and of ring-

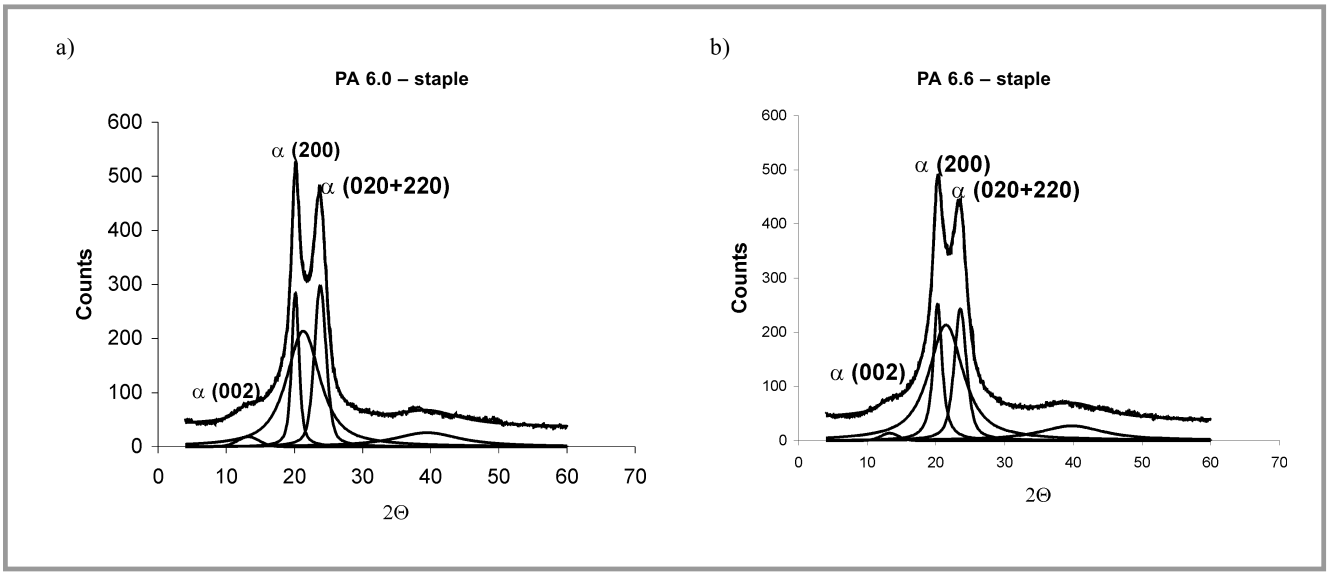

Figure 8. *Experimental and calculated theoretical diffraction patterns of polyamide staple fibres.*

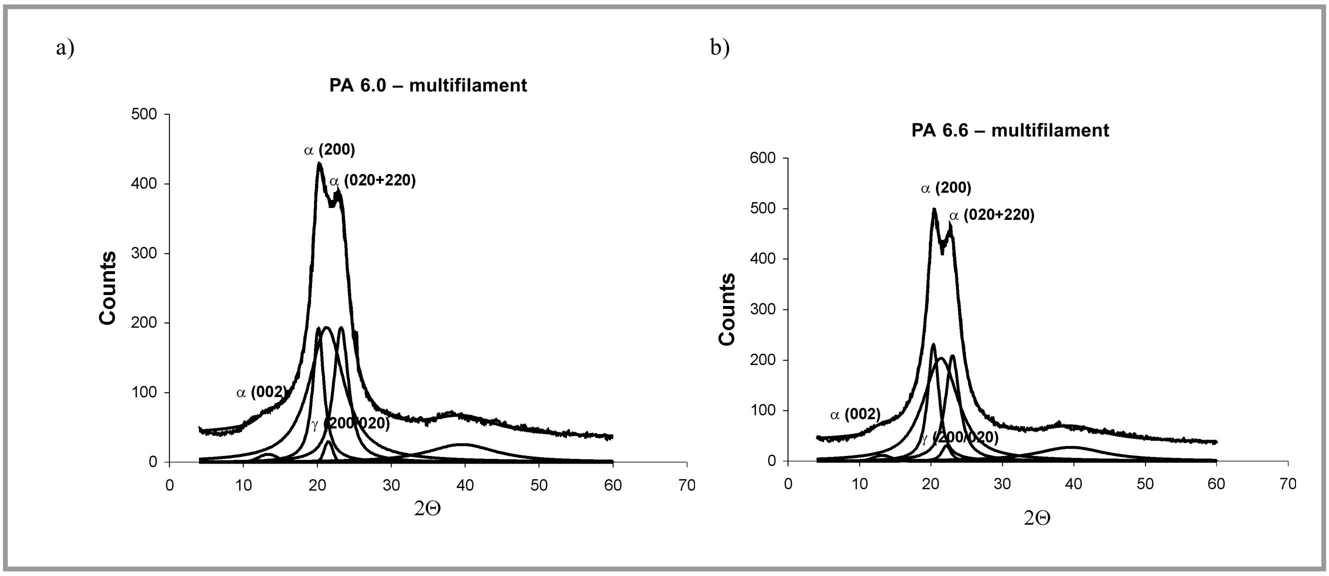

Figure 9. *Experimental and calculated theoretical diffraction patterns of polyamide multifilament fibres.*

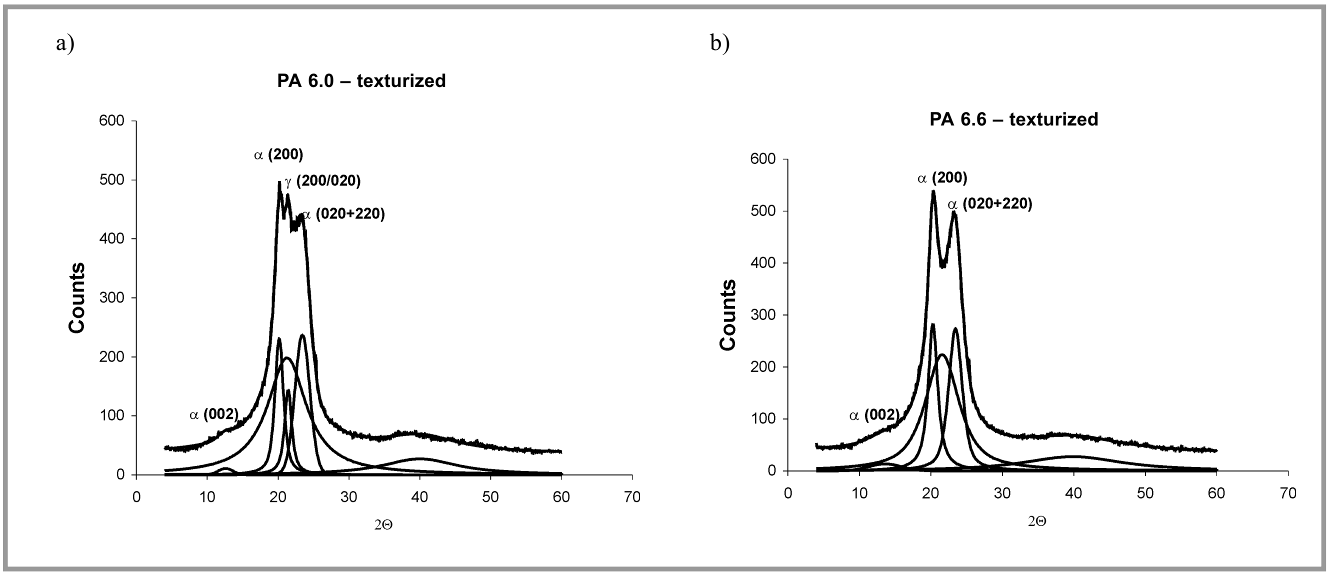

Figure 10. *Experimental and calculated theoretical diffraction patterns of polyamide texturised fibres.*

Table 2. Degree of crystallinity and size of crystalline zones.

Kind of fibres	Degree of crystallinity	Size of crystalline zones $D_{\alpha(200)}$	Size of crystalline zones $D_{\alpha(020+220)}$	Size of crystalline zones $D_{\alpha(200/020)}$
	[%]	[nm]	[nm]	[nm]
PA 6.0 staple	40	7.2	4.5	-
PA 6.6 staple	41	5.8	3.9	-
PA 6.0 multifilament	39	2.9	3.1	6.2
PA 6.6 multifilament	40	5.3	3.5	5.9
PA 6.0 texturised	37	6.3	3.6	7.4
PA 6.6 texturised	38	6.6	4.0	-

opening polymerisation of lactames are presented in Figure 1.

Morphological investigations: SEM

Microscopic studies were carried out using a JSM-5500LV electron scanning microscope. The microphotographs were obtained in conditions of high vacuum with the aid of a secondary electrons (SE) detector. In Figs. 2-7, the differences in topography and arrangement of the investigated fibres are visible. The staple polyamide PA 6.0 fibres can be characterised by their fibrillar structure. However, the PA 6.6 fibres can be characterised by their surface structural agglomeration (Figure 2b, 3b). Both multifilament polyamide fibres, PA 6.0 and PA 6.6, are oriented in parallel in the bundle, whereas the texturised polyamide multifilaments PA 6.0 and PA 6.6 (Figure 4b, 5b) are also oriented in parallel. Additionally, we note the tangling and adhesion of these fibres. However, the texturised staple polyamide fibres are randomly arranged in the bundle, with their mutual connections (Figure 6b, 7b)

The microphotographs of single PA 6.0 and PA 6.6 fibres are shown in Figures 2a – 7a.

The microphotographs of bundled PA 6.0 and PA 6.6 fibres are shown in Figures 1b – 6b.

Parameters of supramolecular structure investigated by the WAXS method

The investigations of the wide-angle X-ray scatterings (WAXS) were carried out by means of a Seifert URD-6 diffractometer equipped with a detector, e.g. a scintillation counter. CuK radiation and Ni (nickel) filter were applied.

Using the WAXS method, we assessed the degree of crystallinity xk and the mean size of the crystalline zones D(hkl).
The diffraction patterns of tested specimens are presented in Figures 8 to 10, whereas the degrees of their crystallinity are given in Table 2.

Conclusions

On the basis of the investigations performed into supermolecular structure, we can conclude that:

- all the tested fibres have a comparable and similar degree of crystallinity, but generally PA 6.6 polyamide fibres show higher crystallinity than PA 6.0 fibres;
- among all the tested fibres, PA 6.0 polyamide fibres in the staple form exhibit the highest degree of crystallinity;
- there is a strict relationship between the size of the crystalline zones and the linear density of the tested fibres. PA 6.0 polyamide fibres are characterised by the largest crystalline zones. They also exhibit the highest linear density. The thinnest PA 6.0 multifilament fibres show the lowest linear density.

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