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Influence of New Fiber-forming Polymers Structure on Garment Hand Parameters

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The investigation presents experimental comparison of fiber-forming polymers (polylactide, cotton, soybean protein, tencel and bamboo) structural and mechanical parameters. Tests were carried out on knitted fabrics of the same linear density (14.8 tex) and knitting structure (plain jersey). Employing several analysis methods such as X-ray diffraction analysis, thermal analysis and fabric hand parameters' determination, it was stated that internal polymer structure determines the level of mechanical parameters. Reliable correlation between diffraction maximums intensity and fabric hand parameters were also determined.
Keywords: fiber-forming polymers, X-ray diffraction analysis, thermal analysis, mechanical properties, textile hand.

1. INTRODUCTION

The beginning of the 21st century is associated with the development and increasing production of new fiber-forming polymers (polylactide – 2003, soybean protein – 2001 – 2003, tencel – 2005 and bamboo – 2002). Innovation and handling of these polymers into industry established fair differences between the following polymers and traditional fiber-forming materials. Manufacturers promote excellent properties of given fibers; as biological activity, antibacterial, hygienic properties and wear comfort. Most of above mentioned fibers, except tencel, are vegetable fibers, which are produced from renewable sources without oil consumption [1, 2]. Polylactide is a synthetic fiber, produced from corns. Its structure is composed of linear macromolecules with lactic acid ester segments. While heating it foams up. Soy fiber is composed of soybean protein. The fiber is mechanically strong, but heat resistant. Tencel (lyocell) is a lactic acid fiber produced employing bioengineering technologies [1]. Ecological bamboo fiber is produced from bamboo leaves and stems applying processes of alkaline hydrolysis. It is characterized by antimicrobial and excellent absorption and evaporation properties [2].

Literature sources provide controversial information about new biodegradable fibers e. g. it is stated that polylactide is characterized as having "very soft hand" [1]. It is hardly surprising because coming of the new product is always accompanied by lack of objective information.

These materials find major use in practical life. Hygienic and good performance having clothes, bedding, mattresses and other household products are produced from these materials.

However, since age of many of these textiles is less than the decade, it is understandable that their properties are little investigated.

In particular little data exist on new fiber-forming materials mechanical and electrical properties, and their relation with properties of polymer's structure. Previous researches of mechanical [3] and triboelectrical [4] properties of these fiber-forming materials showed, that shapes of polymer's molecular structures play a crucial role for values of consideration properties [5 – 6].

The aim of this work is to investigate structural peculiarities of new fiber-forming polymers, to compare them with traditional cotton and to determine the influence of structure parameters on mechanical properties, which determine wear comfort of coming garment.

2. EXPERIMENTAL

Five knitted fabrics from different fiber type were selected for investigation (Table 1). Tests were carried out on knitted materials of the same linear density (14.8 tex) and knitting structure (plain jersey). All objects of investigation had the same final processing with cationic chemical softener "Belfasin SI".

The X-ray powder diffraction (XRD) data were collected with "ДРОН-6" (Russia) diffractometer using Ni-filtered CuK_{α} radiation, with the anodic voltage U_a = 30 kV, emission current I = 20 mA. The X-ray diffraction patterns were registered when the step-scancovered the angular range 10° – 30° in steps of 0.02°, measurement of intensity duration in the step – 0.5 s.

Simultaneous thermal analysis (STA: differential scanning calorimetry DSC and thermogravimetry TG) was performed using "Netzsch STA 409 PC Luxx" (Germany) thermal analyzer. DSC parameters: heating rate was 10 °C/min, temperature range was 30 °C – 475 °C, reference was empty Pt/Rh crucible, atmosphere – air.

Determination of mechanical properties ($P_{\max}$ is maximal extraction force, tgα – initial slope of the curve $H-P$ angle, which characterizes stiffness of the fabric, A

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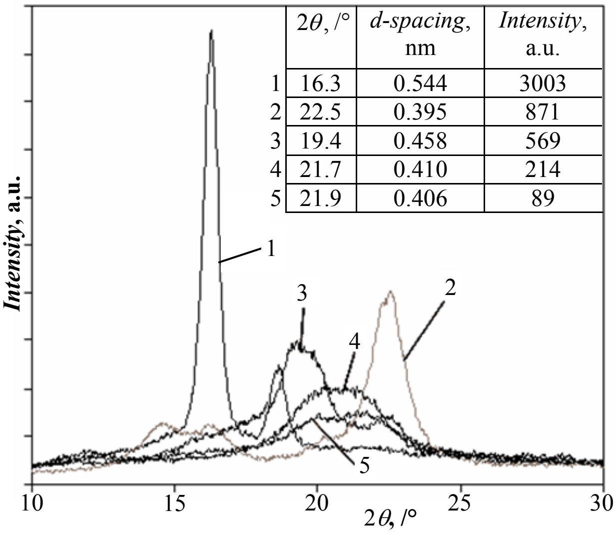
Table 1. Objects of investigation

Symbol	Composition	Density Course/Wale, cm^{-1}	Area density, g/cm^2	Thickness δ, mm
1	100 % Polylactide	20/17	305	0.87
2	100 % Cotton	19/16	227	0.75
3	100 % Soybean protein	19/17	240	0.77
4	100 % Tencel (reclaimed cellulose)	18/15	235	0.70
5	100 % Bamboo	19/15	248	0.70

is pulling (resistance) work, $\Delta\delta$ – specimen thickness change under different loads, H_{max} – maximum deflection height, Q – complex hand rate) of investigated objects was performed using KTU-Griff-Tester [7 – 10] according to optimized methodology [11 – 13]. A number of specimens varied from 6 to 8.

3. RESULTS AND DISCUSSIONS

According to the data of X-ray diffraction analysis it was determined that objects of evaluation significantly differ in microstructure (Fig. 1). Analyzing height and shape of the diffraction patterns' distinctive peaks it was identified that structure of polylactide and cotton fibers is crystalline. Low reflection intensity of tencel and bamboo fibers showe that their structure is typically amorphous.



	2θ, /°	*d-spacing*, nm	*Intensity*, a.u.
1	16.3	0.544	3003
2	22.5	0.395	871
3	19.4	0.458	569
4	21.7	0.410	214
5	21.9	0.406	89

Fig. 1. X-ray diffraction patterns of investigated objects: 1 – polylactide; 2 – cotton; 3 – soybean protein; 4 – tencel; 5 – bamboo

Whereas, soybean protein's structure is semi-crystalline. X-ray diffraction peaks of all investigated objects, registered according the angle 2θ, were scanned in 15 – 25 degree range. Hereby comparing the new fibers with traditional cotton according the degree of crystallinity, it is evident that polymer microstructure differ significantly.

Results of simultaneous thermal analysis showed that investigated objects are characterized by different thermal stability (Fig. 2). Curves of TG indicated that the same dissociation of one stage is typical for all investigated materials.

After the comparison of investigated materials' melting temperatures it can be stated that soybean protein fiber is least stable. It can be explained by the lowest melting temperature of the fiber (288 °C). However cotton fiber appeared to be the most stable, i. e. its melting temperature is the highest (339 °C).

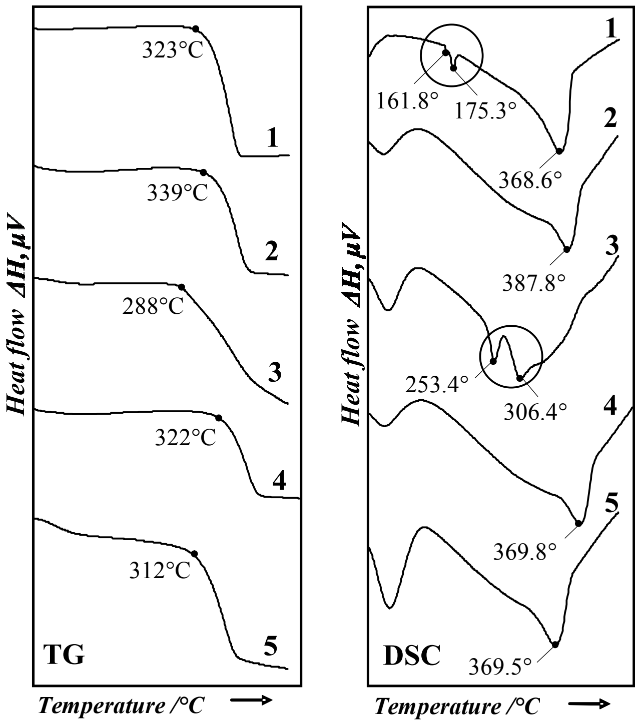


Fig. 2. TG and DSC curves of the investigated objects: 1 – poylactide; 2 – cotton; 3 – soybean protein; 4 – tencel; 5 – bamboo

These experimental results are confirmed by the data presented in [2]: bamboo fiber's hygroscopicity is the highest. This is expressed by moisture evaporation interval on TG curves. Compared with cotton the mass of bamboo decreased almost twice at the zone until 100 °C. According the mass loss in this zone, evaluated objects could be arranged in such an order: bamboo (12.4 %), tencel (9.9 %), soybean protein (7.6 %), cotton (6.4 %), polylactide (0.3 %).

DSC curves also express some differences. In DSC curve of polylactide fiber double endothermal effect at 162 °C – 175 °C temperatures range is observed. Such effect is not related with mass changes but it is obviously influenced by possible impurities or by depolymerization. However 2-stage dissociation was observed for soybean protein fiber, i. e. two well-marked endothermal peaks in DSC curves were defined at the temperatures range 253 °C – 306 °C. According to the resistance of thermal dissociation, evaluated objects could be arranged in such an order: cotton (339 °C), polylactide (323 °C), tencel (322 °C), bamboo (312 °C), soybean protein (288 °C).

Table 2. Hand parameters of investigated objects

Symbol	Composition	P_{max}, N	tgα	A, Ncm	$\Delta\delta$, %	H_{max}, mm	Q
1	Polylactide	14.0 ±1.3	8.18 ±0.71	40.2 ±3.5	12.1	55.0 ±1.6	0.526
2	Cotton	5.2 ±0.3	3.31 ±0.22	16.1 ±0.4	12.8	55.2 ±0.3	0.199
3	Soybean protein	2.6 ±0.1	1.77 ±0.07	7.3 ±0.3	11.5	53.8 ±0.3	0.168
4	Tencel (reclaimed cellulose)	2.1 ±0.1	1.01 ±0.05	5.4 ±0.4	11.4	51.9 ±0.4	0.181
5	Bamboo	3.3 ±0.2	2.28 ±0.17	9.5 ±0.4	16.7	53.8 ±1.4	0.122

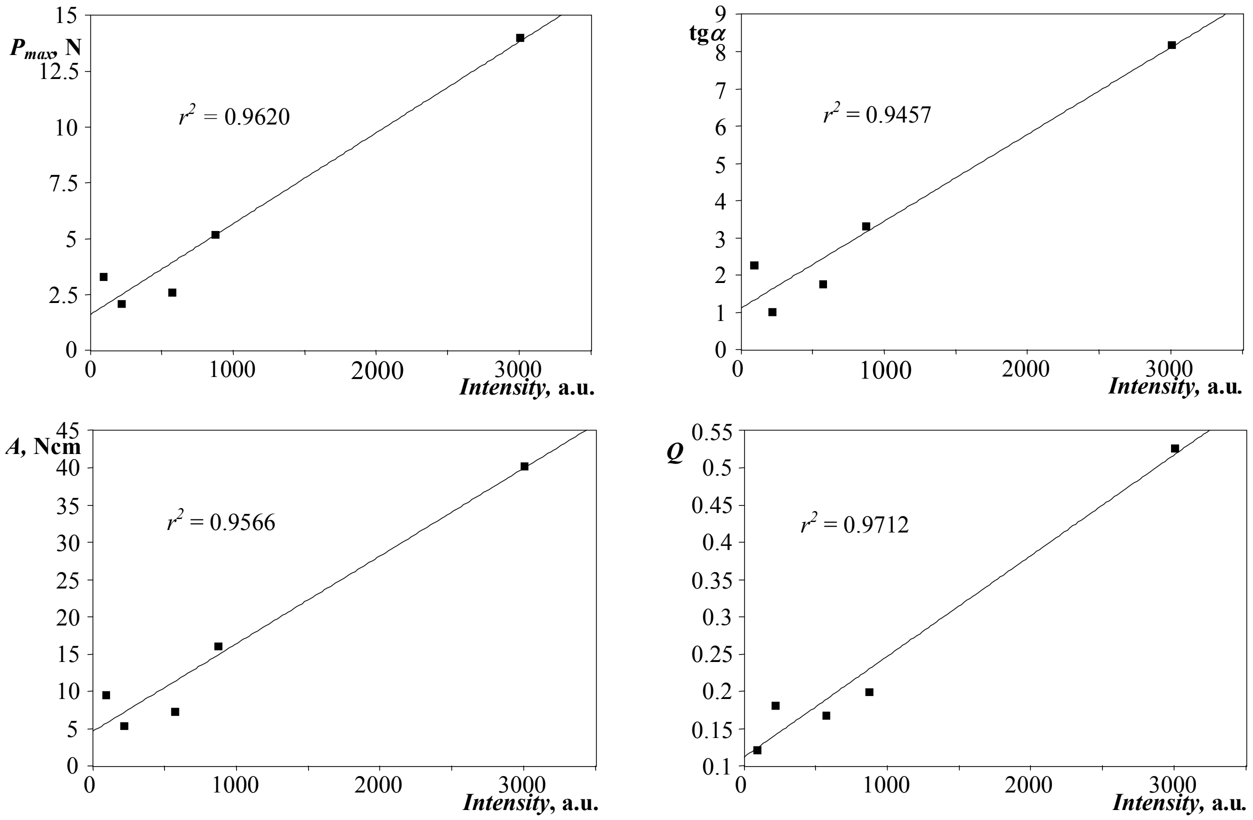


Fig. 3. Correlation between intensity of X-ray diffraction maximums and hand parameters P_{max}, tgα, A and Q

Comparative analysis of textile hand parameters (Table 2) showed that the worst hand of all evaluated objects was determined for knitted fabric from polylactide fibers. Differences between polylactide hand parameters and other evaluated materials are from 4.3 times (complex hand rate Q), to 6.7 (force P_{max}) and to 8.1 times (rigidity tgα).

According hand parameters' level, cotton knitted fabric can be excluded from remaining four fabrics. Its parameters are twice worse comparing with the corresponding hand parameters of soybean protein, tencel and bamboo fiber fabrics. Comparative analysis of complex hand rate Q showed that the best total hand value was determined for bamboo material.

Arrangement of the evaluated objects in such an order according to hand parameters level is evidently related to internal fiber structure. Materials with crystalline structure are always characterized by stability of mechanical and geometrical properties. Consequently such materials are less flexible comparing to amorphous structure ones. It's clearly defined in hand parameters values (Table 2).

Comparative analysis of structure and mechanical parameters of investigated objects showed that reliable correlation between degree of crystallinity and hand parameters P_{max}, tgα, A and Q values exists. In all cases it is expressed by linear equation $y = a + bx$ (Fig. 3), where x is intensity in relative values, and y is P_{max}, tgα, A or Q. Correlation coefficient r^2 varies from 0.9457 to 0.9712.

4. CONCLUSIONS

1. Comparative analysis of structural and mechanical properties between new fiber-forming polymers polylactide, soybean protein, tencel, bamboo and cotton fiber showed that polylactide fiber markedly differed from remaining ones. Its' inherent crystalline structure influences increase of mechanical stiffness.
2. According to X-ray diffraction analysis data and mechanical parameters remaining three fibers (soybean protein, tencel and bamboo) are relevant to cotton. The only difference is that soybean protein fiber is characterized by 2-stage dissociation, and consequently – by the lowest resistance of thermal dissociation.

3. It should be also stated that complex hand rate parameter of bamboo fiber is superlative comparing to relevant parameters of all objects of investigation. Structure of bamboo fiber is relevant to amorphous, therefore it is characterized by softness and flexibility (expressed by hand parameters), also superior hygroscopicity is proved by shape of TG curve with long – oblique initial part (water evaporation zone).
4. Comparative analysis of X-ray diffraction and hand parameters showed that between four most importante hand parameters, determined using KTU-Griff-Tester, and radiation intensity values at typical peaks angles reliable correlation exists.

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