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CRIMPED POLYPROPYLENE YARNS

KODRANA POLIPROPILENSKA VLAKNA

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Polypropylene is a thermoplastic polymer which, because of its intrinsic properties (it does not absorb water, it has low density, low thermal conductivity, good resistance to different chemicals, it does not irritate skin etc.), is penetrating new markets at the expense of other polymers. This is why there is a need in industry of polypropylene fibres for developing new products with new or better properties. In the research work on the polypropylene yarns the conditions for production of polypropylene fibres which crimp after drawing were established. The goal of this research work was to investigate the influence of spinning temperature on the formation of crimps and the degree of crimp.

Key words : polypropylene, melt spinning, crimping, curling

Polipropilen (PP) je termoplastični polimer, ki se, zaradi njemu lastnih lastnosti (ne navzema vlage, ima nizko gostoto, je odporen na različne kemikalije, ima nizko toplotno prevodnost, ne draži kože itd.), vedno bolj uveljavlja na različnih področjih uporabe ter osvaja nova tržišča na račun drugih polimerov. V industriji polipropilenskih vlaken je prav zaradi tega močno izražena težnja po odkrivanju novih izdelkov. V sklopu raziskav postopka oblikovanja polipropilenskih vlaken ter njihovih lastnosti, smo na katedri za tekstilne surovine in preiskave, Naravoslovnotehniške fakultete, Univerze v Ljubljani, izdelali polipropilenska vlakna s povsem novo značilnostjo, s sposobnostjo kodranja. Razvili smo postopek v katerem je možno na klasični predilno - raztezalni napravi, kontinuirno, izdelati kodrana polipropilenska vlakna. V prispevku je predstavljen vpliv pogojev oblikovanja polipropilenskih na pojav in stopnjo kodranja.

Ključne besede: polipropilen, predenje iz taline, kodranje

1 INTRODUCTION

When synthetic fibers are spun, they are by definition straight filaments without any surface characteristics or crimp. In contrast, natural fibers, especially wool, are not straight, but exhibit a marked helical configuration. This crimp gives woolen yarns and fabrics a high degree of bulk, contributing to the warm and pleasant tactile properties of wool products. The curling property of wool results from its unusual bilateral structure, where ortho and para cortex are arranged in asymmetrical, side by side, order in the cross-section of the fiber. These two halves differ in fine structure. Wool fibers have, because of this difference, a helical crimped configuration. Wool is, in fact, a natural bicomponent fiber.

Through out the history of the development of synthetic fibers there has always been an explicit tendency to produce fibers which are, as far as possible, similar to natural fibers. One of these properties is the crimping ability of natural fibers and their resulting bulkiness.

The crimping of melt spun fibers is mainly done by thermomechanical means. These methods have in common the mechanical deformation of a straight filament into a crimped form, followed by a heat setting of the deformed configuration.

As an alternative to these traditional thermo-mechanical techniques, a method for producing fibers, which posses crimp as an integral part of their structure, somewhat analogous to that of wool, is available. This is possible when the produced fibers consist of two components, which have different structure (shrinkage) characteristics, and are arranged in a side by side order. The fiber in which the two components differ in shrinkage characteristics will crimp.

There are two groups of spinning methods for producing bicomponent fibers with self - crimping ability. In first group there are methods where special equipment is needed to conjugate two different components together in a side by side order. In the second group of methods, a nonsymmetrical character across the cross-section of the filaments is introduced to the filament on the classical spinning devices, without any special additional apparatus.

Since the early days of the development of polypropylene fibers it was noticed that polypropylene, spun under certain conditions, developed a helical crimp when it was cold drawn. Numerous methods are feasible for the formation of the conjugate structure of polypropylene fibers and with this also self crimped fibers[1-6].

The asymmetrical quenching method is very promising because we do not need any additional equipment. Although theoretical work on the conditions needed for the formation of self crimped PP fibers by the asymmetrical quenching method has been carried out[1-3], there is still the question as to why it has not been more successful on the industrial scale. While in recent years some new approaches for the production of self crimped PP fibres have been inovated[3-6], there is still an ambition to produce self crimped PP fibers by the asymmetrical quenching method[7].

In the present study the conditions for the formation of self-crimped PP fibers on a classical spinning machine and some of their characteristics are presented.

2 EXPERIMENTAL

PP yarns (monofilament) were spun from commercial Hoechst Hostalen PPN polypropylene homopolymer, i.e. a low melt-flow rate polymer (MFI = 2g/10min).

The melt spinning of yarns was carried out on an Extrusion Systems Ltd. laboratory spin - draw device. The molten polymer was extruded through the one hole spinneret with the diameter of the hole equal to 2 mm. The solidifying melt was then asymmetrically quenched with cold air. We produced two series of samples, one with and one without asymmetrical cooling. The temperature of the asymmetrically blowing air was 4°C. The yarns were then wound up on the winding machine.

The designation of samples and the spinning conditions are presented in **Table 1** and **Table 2**.

Table 1: Designation of samples: the as spun samples are designated according to the applied spinning temperature and the mode of cooling

Tabela 1: Oznaka vzorcev: oblikovani vzorci so označeni glede na temperaturo oblikovanja vzorcev ter način ohlajanja

As spun samples/ not cooled	180	200	220	240	260	280
As spun samples/ cooled	180-4	200-4	220-4	240-4	260-4	280-4

Table 2: Spinning conditions

Tabela 2: Pogoji oblikovanja

samples	180 180-4	200 200-4	220 220-4	240 240-4	260 260-4	280 280-4
Polymer polypropylene	Hostalen PPN 1060F (Hoechst)					
MFI (230°C, 16 kg)	2 (g/10min)					
spineret hole diameter (mm)	2					
Extruder temperature						
zone 1	180	200	220	240	260	280
zone 2	180	200	220	240	260	280
zone 3	180	200	220	240	260	280
Gear pump temperature (°C)	180	200	220	240	260	280
Spin pack temperature						
zone 1	180	200	220	240	260	280
zone 2	180	200	220	240	260	280
Winding speed (m/min)	129	129	129	129	129	129

The textile mechanical properties, i.e. linear density, tenacity at break, extension at break, elasicity modulus, density and the highest number of crimps were analysed and are presented in **Table 3**. Also the number of crimps was analysed with stretching the yarns to different extensions (100% to 700%). The number of crimps was defined by counting the crimps on a length of 10 cm. The results are presented in **Table 4**.

The creep of the material was measured in the process of loading the yarns with different loads (0,5 N and 1.0 N) and by holding the yarn at that load for 180 s. The results of creep measurements are presented in **Figures 1-4**.

The tensile tests as well the analyses of creep and crimping at different extensions, were performed on an Instron tensile tester INSTRON- 6022. The density of the samples was measured in the density gradient column.

Table 3: The textile mechanical properties (linear density, tenacity at break and extension at break,), elasicity modulus, density and the highest number of crimps are presented

Tabela 3: Predstavljene so tekstilno mehanske lastnosti (dolžinska masa, pretržna napetost, pretržni raztezek), modul elastičnosti, gostota ter najvišje število kodrov

samples	Tt (tex)	σ (cN/dtex)	ε (%)	E_0 GPa	ρ (g/cm^3)	The highest No. of crimps
180						
200	16,32	1,38	427,0	0,44	0,90159	3,6
220	16,01	1,25	463,6	0,41	/	2,4
240	15,53	1,25	580,4	0,40	/	2
260	14,87	1,02	786,0	0,19	0,90111	3,7
280						
180-4	16,41	1,16	309,6	0,47	0,90426	11,3
200-4	16,12	1,16	347,6	0,36	0,90172	31,4
220-4	15,85	1,28	407,1	0,46	0,89879	26,1
240-4	15,13	1,36	469,8	0,41	0,89612	11
260-4	14,92	1,06	660,8	0,22	0,90053	12,5
280-4	15,81	0,70	857,2	0,19	0,89096	19,5

Table 4: The number of crimps developed at different extensions

Table 4: Število nastalih kodrov pri različnih raztezkih

	number of crimps/100 mm developed at different extensions (%)						
	extension (%)						
samples	100	200	300	400	500	600	700
180							
200	2,7	2,4	3,6	2,2			
220	2,4	3	2	0	0		
240	1,6	2	2	0	0		
260	1,4	2,6	2,3	2,3	3,7	2,8	3
280							
180-4	6,1	11,3	6,3				
200-4	19,3	31,4	20,5				
220-4	17,1	26,1	16,4	12,8			
240-4	10,1	11,0	8,9	7,6			
260-4	1,5	2,3	6,6	11,4	11,3	12,5	12,0
280-4	1,0	2,3	2,7	2,7	1,1	10,8	19,5

3 RESULTS AND DISCUSSION

Spinning tests were carried out at various spinning temperatures with a constant throughput of molten polymer. The extruded polymer was then asymmetrically quenched by quenching air over a length of 1,5 m. The cooled polymer was then wound up on the winding machine.

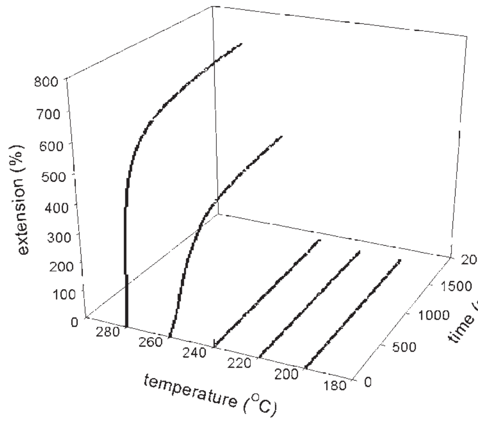

Figure 1: The creep of as spun, not asymetricaly cooled, samples spun at different spinning temperatures (180, 200, 220, 240, 260, 280) at a load of 0.5 N

Slika 1: Lezenje ne asimetrično ohlajanih vzorcev, oblikovanih pri različnih temperaturah (180, 200, 220, 240, 260, 280), pri obremenitvi 0,5 N

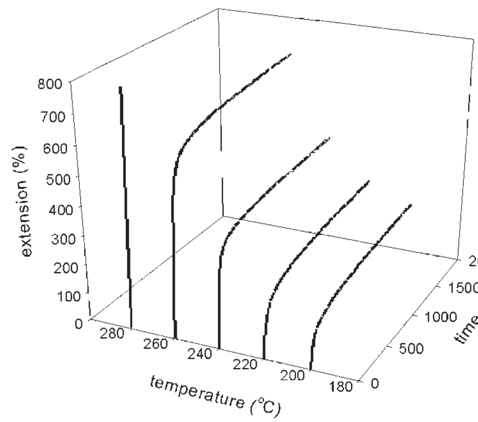

Figure 3: The creep of as spun, not asymetricaly cooled, samples spun at different spinning temperatures (180, 200, 220, 240, 260, 280), at load of 1 N

Slika 3: Lezenje ne asimetrično ohlajanih vzorcev, oblikovanih pri različnih temperaturah, (180, 200, 220, 240, 260, 280) pri obremenitvi 1 N

As was explained, the creep of the material was measured by loading the yarns with 0,5 N **(Fig. 1 and 2)** and 1 N **(Fig 3 and 4)** load.

As can be seen from **Fig 1 and Fig 2**, where the curves of creep for all as-spun samples, which were loaded with 0.5 N load, are presented, the samples which were spun at spinning temperatures lower than 240°C, are still in the region of elastic recovery because these samples show almost no creep at this load. This means that the supermolecular structure is not yet destroyed and that for the rearrangement of the supermolecular structure higher loads are needed. In contrast in the samples which were spun at the temperatures higher than 240°C, creep appeared, which means that the supermolecular structure is destroyed and a new molecular order was created.

As can be seen in **Figs 3 and 4** all samples exhibit creep at 1 N load. The creep is more pronounced in samples which were spun at higher spinning temperatures. So the highest creep was exhibited in samples which were spun at 280°C and inversely the lowest creep was exhibited in samples which were spun at 180°C.

The materials spun at different spinning temperatures have different morphologies (fine structure) which can be expected from the creep behaviour of the material, from the stress strain curves obtained during the tensile tests and from the textile mechanical properties of the material **(Table 3)** etc. The samples, spun at higher spinning temperatures, have lower linear density and higher breaking extension. The breaking extensions of samples, spun at higher temperatures, are higher and for this reason the limiting draw ratios for the formation of

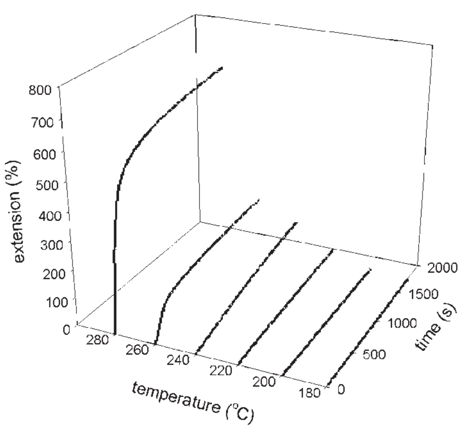

Figure 2: The creep of as spun, asymetricaly cooled, samples spun at different spinning temperatures (180-4, 200-4, 220-4, 240-4, 260-4, 280-4) at load of 0.5 N

Slika 2: Lezenje asimetrično ohlajanih vzorcev, oblikovanih pri različnih temperaturah (180-4, 200-4, 220-4, 240-4, 260-4, 280-4), pri obremenitvi 0,5 N

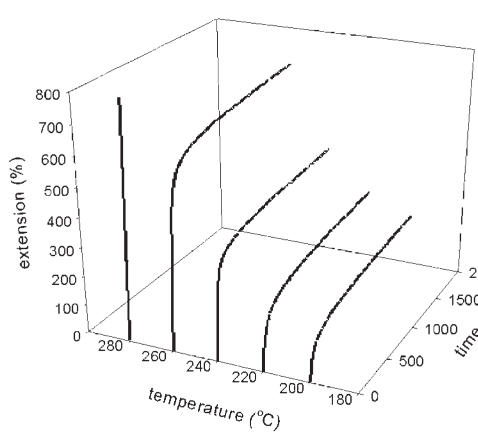

Figure 4: The creep of as spun, asymetricaly cooled, samples spun at different spinning temperatures (180-4, 200-4, 220-4, 240-4, 260-4, 280-4) at load 1 N

Slika 4: Lezenje asimetrično ohlajanih vzorcev, oblikovanih pri različnih temperaturah, (180-4, 200-4, 220-4, 240-4, 260-4, 280-4), pri obremenitvi 1 N crimps are also higher. On the basis of these facts, it can be forecast, that for the formation of crimps a certain stretch or draw ratio should be applied (the yield point of the material should be exceeded). It can be also said, that the conditions for the formation of crimps, in samples which are spun at different spinning conditions, are different.

It is also clear that the formation of crimps is a result of the bilateral structure of asymmetrically cooled yarns. The consequence of the bilateral structure of polypropylene yarns is the formation of crimps after drawing. The number of crimps and the crimp degree are dependent also on the spinning temperature. As can be seen in **Tables 3 and 4**, the highest number of crimps in asymmetrically cooled samples, have samples spun at a spinning temperature of 200°C.

4 CONCLUSIONS

In this paper the conditions for the production of crimped PP yarns are presented. The study focused on the influence of spinning temperature on the formation and frequency of crimps. The basic condition for the formation of crimped PP yarns is that the extruded filament is asymmetrically quenched. The bilateral structure of the filament is thus provided and the crimps are formed after drawing of the filament.

The experiments clearly showed that as-spun, asymmetrically cooled, filaments should be stretched for crimps to form. This is because the fine structures on the opposite sides of the yarn are different, they have different shrinkage characteristics and respond differently to stretching. If the yield point during drawing is not exceeded, crimps are not formed. It can also be anticipated, that with increasing draw ratio, the number and frequency of crimps with increase until the optimal draw ratio is reached, and after the optimal draw ratio is reached the number of crimps is reduced. The filaments, extruded at different spinning temperatures, have different structures. Each sample, spun at a different temperature, has thus also different optimum conditions for the formation of crimps.

It was shown, that under the applied spinning conditions, the optimum spinning temperature for the production of crimped PP yarns is 200°C to 220°C. The number of crimps and crimp degree are the highest at these temperatures.

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