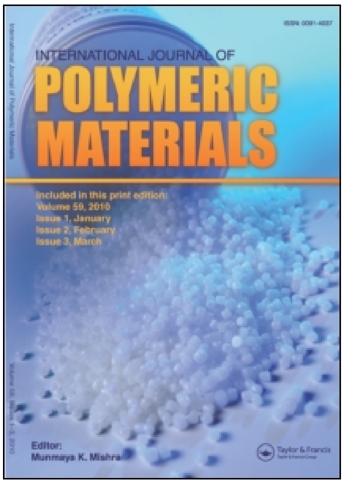

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The Curling Phenomenon of Polypropylene Yarns

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Polypropylene is a thermoplastic polymer which, because of its intrinsic properties (it doesn't absorb water, it has low density, low thermal conductivity, good resistance to different chemicals, it doesn't irritate skin *etc.*), is penetrating new markets at the expense of other polymers. This is why there is a need in industry of polypropylene fibers for developing new products with new or better properties.

In the research work on the polypropylene yarns the conditions for production of polypropylene fibers which crimp after drawing were established.

The goal of research work was to investigate the influence of spinning temperature on the formation of crimps and the degree of crimp.

Keywords: Polypropylene; spinning; crimping; curling

INTRODUCTION

Synthetic fibers are, when they are spun, by the definition straight filaments without any surface characteristic or crimp. On the contrary natural fibers, especially wool fibers, are not straight, but of 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 cross-section of fiber. These two halves differ in fine structure. Wool fibers have, because of

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this difference, helical crimped configuration. Wool is in fact a natural bicomponent fiber.

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

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

As an alternative to these traditional thermomechanical techniques, a method is available for producing fibers which posses crimp as an integral part of their structure, somewhat analogous to that of wool. This is possible when produced fibers consist of two componenets, which have different shrinkage characteristic, and are arranged in side by side order. The fiber in which the two components differ in shrinkage characteristic 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 side by side order. In the second group of methods, the 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 developments of polypropylene fibers it was noticed that polypropylene, spun at certain conditions, developed a helical crimp when it was cold drawn. Numerous method are feasible for formation of conjugate structure of polypropylene fibers and with this also self crimped fibers [1–6].

The asymmetrical quenching method is very promising because we don't need any additional equipment. Although a theoretical work on the conditions needed for the formation of self crimped PP fibers by asymmetrical quenching method has been done [1–3], there is still a question why it has not been more successful on the industry scale. While in recent years some new approaches for the producing of self crimped PP fibres has been inovated [3–6], there is still an ambition to produce self crimped PP fibers by asymmetrical quenching method.

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

EXPERIMENTAL

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

The melt spinning of yarns was carried out on an Extrusion Systems Ltd. laboratory spin-draw device. The molten polymer was extruded and then asymmetrically quenched with cold air. The temperature of the blowing air was −3°C. The yarns were then wound up on the winding machine and than subsequently additionally drawn on a Zimmer draw device.

The designation of samples and spinning and drawing conditions are presented in Table I and in Table II.

The textile mechanical properties, *i.e.*, linear density, breaking force, extension at break and specific stress were analysed (Tab. III). The tensile tests were performed on Instron tensile tester INSTRON – 6022.

The formation of crimps was simulated on as spun yarns by stretching the yarns to 140% extension and by loading the yarns with different loads (0.75 N, 1.00 N, 1.25 N, 1.50 N and 1.75 N). The number of crimps was then analyzed (by counting the crimps on length of 10 cm). The results are presented in Table III.

The crimp degree was calculated from the ratio between the difference of lengths of straight crimped fiber (the crimps are unfolded) and straighten crimped fiber (the crimps are still present) and the length of straighten crimped fiber (Tab. III).

TABLE I Designation of samples: the as spun samples are designated according the applied spinning temperature (180–20 means that the spinning temperature was 180°C and the temperature of the blowing air was 20°C), the drawn samples are designated according the applied spinning temperature and draw ratio

	Designation of samples					
As spun samples	180–20	180	200	220	240	260
Drawn samples	180–20–24	180–2,4	220–2,4	220–2,6	240–3	260–3

TABLE II Spinning conditions

Material	
Polymer polypropylene	Hostalen PPN 1060F (Hoechst)
MFI (230°C/2,16 kg)	2 [g/10 min]

		Spinning conditions *Sample* 180–20	180	200	220	240	260
Extruder temperature	zone 1	240	240	240	240	240	240
	zone 2	240	240	240	240	240	240
	zone 3	240	240	240	240	240	240
Gear pump temperature	(°C)	180	180	200	220	240	260
Spin pack temperature	zone 1	180	180	200	220	240	260
	zone 2	180	180	160	175	190	200
Quench chamber temp.	(°C)	20	−3	−3	−3	−3	−3
Winding speed	(m/min)	112.8	112.8	112.8	169.8	160.8	160.8
Drawing conditions							
Drawing temperature	(°C)	100	100	100	100	100	100
Draw ratio		2.4	2.4	2.4	2.6	3	3

TABLE III The textile mechanical properties (linear density, tenacity at break and extension at break), number of crimps (developed at 1,25 N load and at 140% extension), crimp percentage and elasticity recovery (immediate and after 180 seconds)

Sample	*Tt* (*tex*)	σ (*cN/dtex*)	ε (%)	*Number of crimps* 1,25 *N* (*number/cm*)	140%	*Crimp degree* (%)	*Immediate el. recovery* (/)	*El. recovery after* 180 *s* (/)
180–20	29.6	1.51	370.9	0	0.24	47	0.48	0.69
180	26.8	0.82	199.6	0.17	1.86	82.5	0.27	0.42
200	27.05	0.83	196.7	0.22	2.44	91	0.24	0.40
220	17.2	1.03	207.5	3.6	3.84	96	0.23	0.39
240	16.5	1.34	269.4	3.92	4.2	94	0.23	0.37
260	16.3	1.54	346	2.1	4.16	96	0.28	0.39

The creep of material was measured according the DIN standard 1774. The creep was measured in the process of cyclic loading where the yarns were loaded (1.25 N) or stretched (140%), holding at that point for 60 seconds (where the creep was measured), returned back to zero load (where the immediate elasticity recovery was measured) and holding at zero load for 180 seconds (where the elasticity recovery was measured). The first cycle was than repeated again. The results of creep measurements are presented in Table III.

RESULTS AND DISCUSSION

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

As it was explained earlier the formation of crimps was simulated by stretching the yarns to 140% extension and by loading the yarns with load 1,25 N. The results (number of formed crimps) are presented in Figure 1.

As it can be seen from Figure 1 the number of crimps increases with increasing spinning temperature to temperature 240°C and than it levels off (at samples stretched to 140%) or it drops (at samples loaded with 1,25 N load). The highest number of crimps is, in both cases, exhibited at samples formed at spinning temperature 240°C. It can also be seen from Figure 1 that if the samples formed at 180°C and 200°C, are loaded with 1,25 N load, the crimps are not formed and if they are stretched to 140%, the crimps are formed. On the basis of these facts, it can be forecast, that for the formation of crimps certain stretch or draw ratio should be applied (the yield point of the material

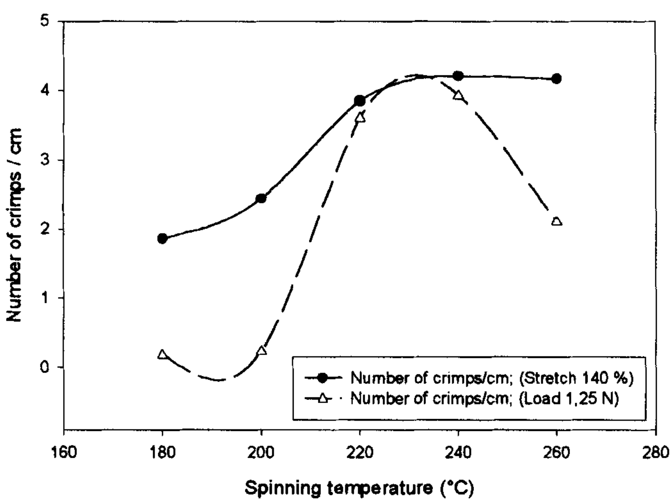

FIGURE 1 Number of crimps/cm formed by stretching the yarns to 140% and by loading the yarns with 1,25 N load at different spinning temperatures.

should be exceeded). Further more it can be anticipated that the number of crimps will increase with increasing load or stretch ratio (Fig. 2).

As shown in Figure 3, the relationships between the crimp degree and spinning temperature and number of crimps and spinning temperature are very similar. Both, the crimp degree and number of crimps, are increasing with increasing spinning temperature.

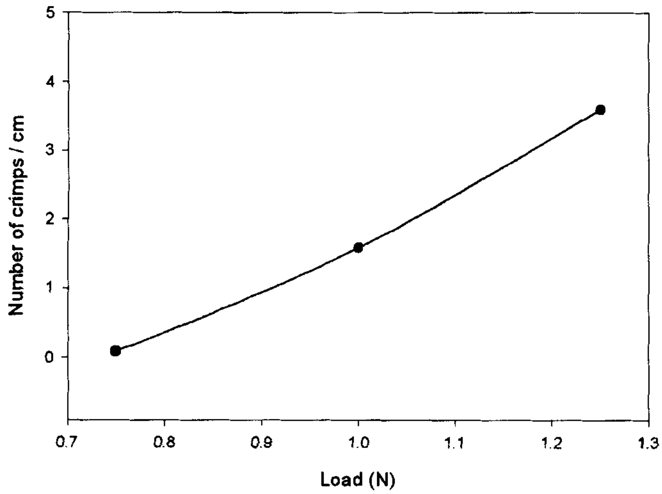

FIGURE 2 Number of crimps/cm formed by loading the yarns at different loads.

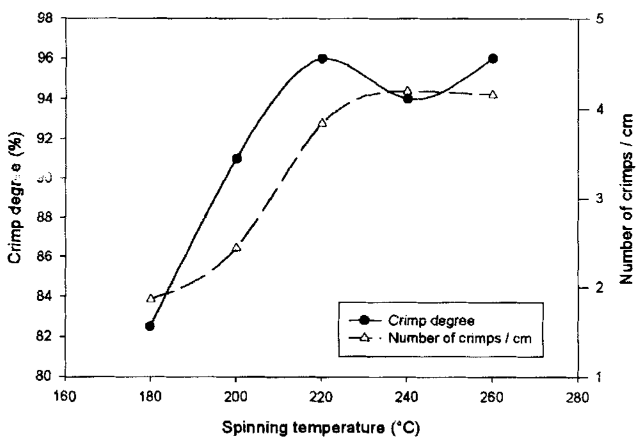

FIGURE 3 Crimp degree and number of crimps at different spinning temperatures.

The dependence of creep and crimp degree is shown on Figure 4. It is clearly shown that the samples with highest creep and crimp degree are spun at temperature 220°C.

At loads higher than 1.25 N is creep very much pronounced and at samples which were asymmetrically quenched the crimps begin to form after the load is removed. At higher loads the creep and crimping of material are more pronounced.

After the second cycle of loading of the material it was seen that the crimps which were formed after first cycle remain. It can be predicted that crimps are permanent as long as the bilateral structure of yarns is not changed or destroyed.

The material spun at different spinning temperatures have different morphologies (fine structure) which can be forecast from the creep behaviour of material, from the stress strain curves obtained during the tensile tests and from the textile mechanical properties of material (Tab. III) *etc*. The samples, spun at higher spinning temperatures, have lower linear density and higher breaking extension and tenacity. The yield points of samples, spun at higher temperatures, are higher and for this reason the limiting draw ratios for the formation of crimps are also higher. On the basis of these facts, it can be forecast, that

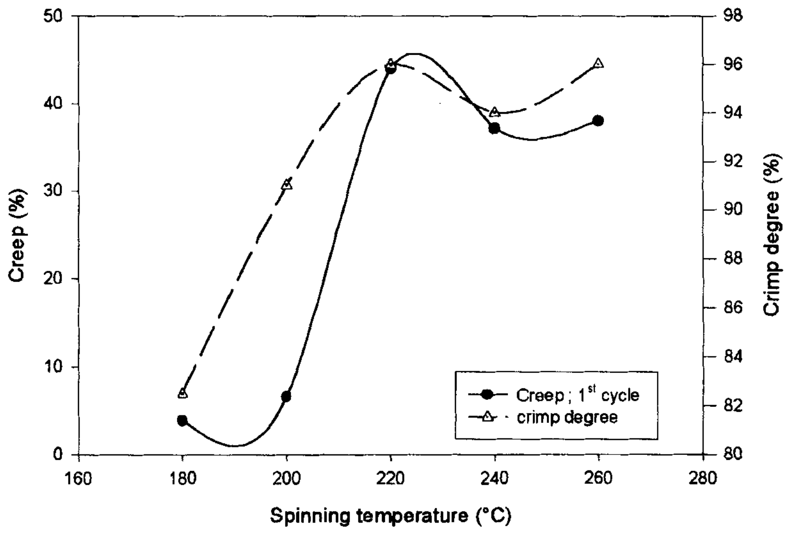

FIGURE 4 Creep and crimp degree at different spinning temperatures.

the conditions for the formation of crimps certain at samples which are spun at different spinning conditions, are different.

It is also clear that the formation of crimps is a result of bilateral structure of asymmetrically cooled yarns. The consequence of bilateral structure of polypropylene yarns is formation of crimps after drawing. The number of crimps and crimp degree are dependent on the spinning temperature. As it can be seen on Figure 1, the highest number of crimps have samples spun at spinning temperature 240°C.

CONCLUSIONS

In this paper the conditions for production of crimped PP yarns are presented. The focus was made 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 filament is thus provided and the crimps are formed after drawing of the filament.

The experiments clearly showed that asspun, 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 characteristic and are responding on stretching differently. 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 increase.

The filaments, extruded at different spinning temperatures, have different structures. Each sample, spun at different temperature, has thus also different optimum conditions for the formation of crimps.

It was shown, that at applied spinning conditions, the optimum spinning temperature for the production of crimped PP yarns is 220°C to 240°C. The number of crimps and crimp degree are, at that temperature, the highest.

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