IMPACT OF ASPIRATION AIR PRESSURE IN THE SPINNING SHAFT ON THE FORMATION OF HOLLOW POLYAMIDE 6 FIBRES

Tatjana Rijavec[1], Anela Kljajić[1] and Sabina Jakomin[2]

[1]University of Ljubljana, Faculty of Natural Sciences and Engineering, Aškerčeva 12, 1000 Ljubljana, Slovenia
[2]AquafilSLO, Letališka cesta 15, 1000 Ljubljana, Slovenia
tatjana.rijavec@ntf.uni-lj.si, sabina.jakomin@aquafil.com

***Abstract:** An influence of aspiration air pressure under spinnerets on properties of hollow polyamide 6 fully drawn multifilament yarns is presented in the article. Experiment was made on an industrial spinning machine. Aspiration air pressure in the spinning shaft of 50 Pa and 100 Pa influenced on decreasing of spinnerets temperature, on a quantity of monomer in yarns and breaking force, which both increased, but breaking elongation of yarns decreased. The changes of mechanical properties are related with changes in supramolecular structure and ability of yarns for dyeing.*

***Keywords:** hollow fibre, polyamide 6, fully drawn yarn.*

1 INTRODUCTION

Polyamide 6 (PA 6) is a fibre forming polymer formed from a monomer ε-caprolactam in a ring-opening polycondensation reaction [1, 2]. At the end of the polymerization reaction, 2–10% of unreacted monomer and acyclic/cyclic oligomers (i.e. low molecular weight fraction) are always present in the polymer melt [3]. Before spinning of PA 6 fibres, low molecular weight fraction is partially extracted from PA 6. Low molecular weight fraction influences on rheological properties of polymer melt and also on fibres properties, particularly on their tensile properties [3].

At spinning of PA 6 yarns, low molecular weight fraction, particularly monomer, evaporates from jets under the spinnerets at a length of a first 5-15 cm [3]. Monomer deposits on spinnerets and on spinning shaft walls, where a few millimeters thick layers in few days can be formed. Monomer can be removed by mechanical cleaning in regular time intervals. To prevent monomer deposition, an aspiration of cooling air under the spinnerets is used. Aspiration is carried out with the help of:

(i) A water pump, which creates a vacuum to aspirate cooling air under the spinneret, and monomer condensates and dissolve in a water jet.

(ii) A vacuum suction of cooling air through gaps, mounted under the spinnerets, which is the most often used method. Gaps are usually mounted on each spinning position, near the extruded filaments. Lower air pressure in gaps than in a spinning shaft causes an aspiration of the cooling air. Effective monomer suction is only if the gaps are transient.

Aspiration of monomer under the spinnerets can influence on solidifying process of polymer jets. In the case of spinning hollow filaments, irregularities of openings or clogging of hollow filaments may occur. Similar to solid filaments, hollow filaments are also prone to breaking filaments in spinning line [4]. In this study an influence of aspiration air pressure on morphology, structure and properties of hollow fully drawn PA 6 filament yarns was studied in real, industrial conditions.

2 EXPERIMENTAL

2.1 Materials

Yarns for the experiment were produced on an industrial fully drawn yarn (FDY) spinning machine Teijin Seiki (Japan). All the yarns were made from the same semi dull polymer polyamide 6. Solidification of the extruded jets was accelerated by using cross air flow. Temperature of blown cooling air was around 19°C. Due to heat emitted by spinnerets and polymer jets cooling air was heated up under the spinnerets up to 100°C. The cooling air under the spinnerets carried monomer and oligomers. The velocity of aspirated cooling air through the gaps was higher than the velocity of the blown cooling air and was adopted to prevent deposition of monomer and oligomers on the gaps and filling them up. In our experiment the velocity of the aspiration air (Table 1) was between 0.0 (no aspiration) and 4.0 m/s (aspiration air pressure 100 Pa). Samples were collected from twelve bobbins made on two spinning positions (six bobbins per position). Before winding the yarns, filaments were interlaced. Winding velocity was a little over 4000 m/min. Spinneret temperature in the spinning line was measured with a laser thermometer Raytek Rayngen MX. Yarn stress was measured with tensiometers on-line in five positions (Figure 1).

Table 1 Designation and spinning conditions of samples

Sample	Aspiration air pressure [Pa]	Aspiration air velocity [m/s]	Average spinneret temperature [°C]	Average yarn stress, measured in spinning line positions 1 to 5 (Fig. 1) [cN/yarn]				
				1	*2*	*3*	*4*	*5*
AP0	0	0.0	243	3.5	6	8.3	3	4
AP50	50	0.2–0.3	240	3.7	6	8.5	3.5	4.2
AP100	100	2.5–4.0	237	3.9	6.2	9.3	3.8	4.9

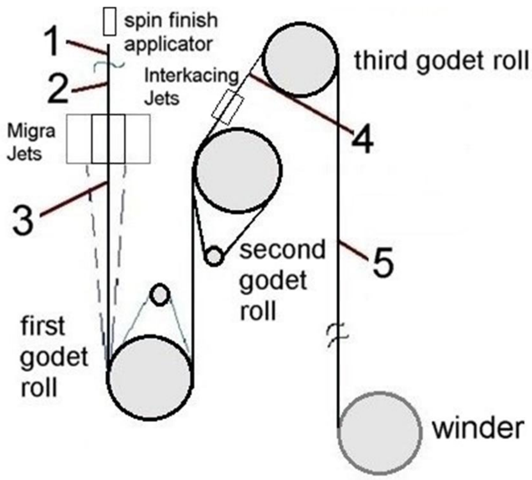


Figure 1 Schema of spinning line between application of spin finish and winding of yarns, with positions of on-line tensiometers (numbers 1–5)

2.2 Methods

Linear density was measured gravimetrically in accordance with a standard EN ISO 1973:1999. Breaking force and elongation were measured on a dynamometer Statimat M (Textechno, Germany) according to standard EN ISO 2062:2010. Dynamic thermal tensile test was made on a Dynafil C apparatus (Textechno, Germany) at temperature 150°C, pretension 30 cN, yarn speed 200 m/min and extension of 30%. Quantity of monomer and low molecular weight fraction were determined from extracts, which were prepared by treatment of samples in methanol at 95°C for four hours. With a HPLC method quantity of monomer and oligomers was determined. Samples were firstly dissolved in HCOOH for HPLC analysis. Average molecular weight was determined from viscosity measurements of samples solution of 0.1% sulfuric acid. Longitudinal view and filaments cross section were made on a scanning electron microscope Jeol JSM-6060, where filaments diameter was also measured.

3 RESULTS AND DISCUSSION

Measured spinneret temperature was 243°C without using aspiration of cooling air (Table 1). Aspiration of cooling air caused decreasing of spinneret temperature for 6°C when the aspiration air pressure was 100 Pa. Decreasing spinneret temperatures influenced on increasing yarns stress in all measured positions 1–5 (Figure 1) with increasing aspiration air pressure.

3.1 Linear density and filament cross section

Aspiration of cooling air had no significant influence on linear density, but caused some imperfections of filament cross-section:

- Average linear density of yarns samples was 37.4 dtex (Table 2). Considering the expected linear density of 44 dtex for solid filament yarn made at the same spinning conditions, the hollow filament yarns had for about 15% lower linear density than solid filament yarns would have. Filament thickness was in the range 20.8-22.8 μm. Aspiration air pressure had no significant influence on samples linear density.
- Cross-section of filaments (Figure 2) was circular with triangular openings in the middle. Decreasing of spinneret temperature accelerated solidifying of polymer jets. Average cross-section area was calculated on the basis of SEM micrographs (Figure 2). It was 406.5 μm^2 for samples AP0 and AP100, but for the sample AP50 it was a little lower, 384.2 μm^2 (Table 3). On the Figure 2 are seen two incomplete formed cross-sections on the sample AP100 (marked with arrows), which was the consequence of the too fast solidifying spinning jets, before two ends merged together and formed hollow filaments. Average hollowness, calculated from the average cross-section of filaments and average cross section of the middle hollow part of filaments, was between 10.60 and 11.64%.

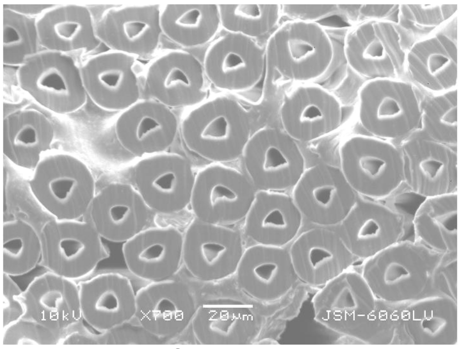
Table 2 Yarn linear density and filament thickness

Sample	Yarn linear density [dtex]			Filament thickness [μm][a)]	
	Average	*SD*[b)]	*Range*	*Average*	*SD*
AP0	37.3	0.135	37.3–37.1	20.83	1.00
AP50	37.4	0.15	37.7–37.2	22.75	1.05
AP100	37.35	0.11	37.5–37.3	21.43	0.97

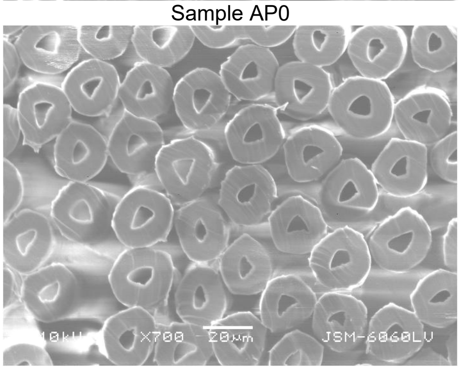
[a)] Number of measurements = 10; [b)] Standard deviation

Table 3 Filaments cross-section area and hollowness

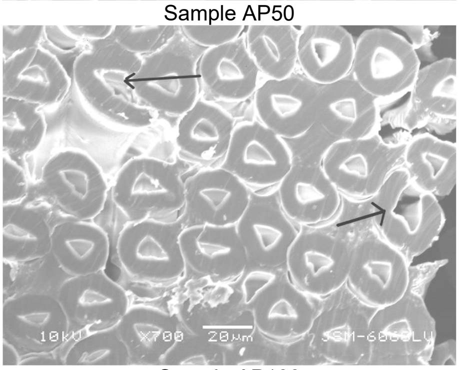
Sample	Cross-section area [μm^2]		Hollowness [%]	
	Average	*SD*	*Average*	*SD*
AP0	406.54	40.61	10.60	1.98
AP50	384.16	32.56	11.64	2.61
AP100	406.55	41.60	10.60	4.61



Sample AP0

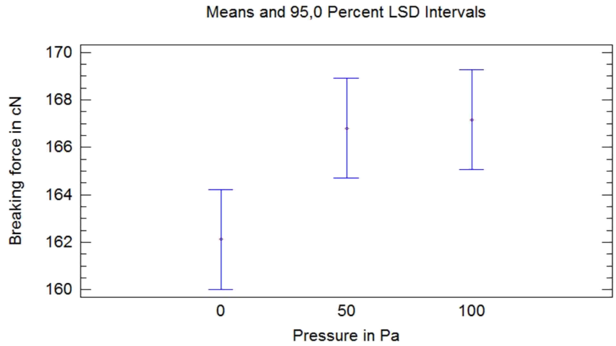


Sample AP50

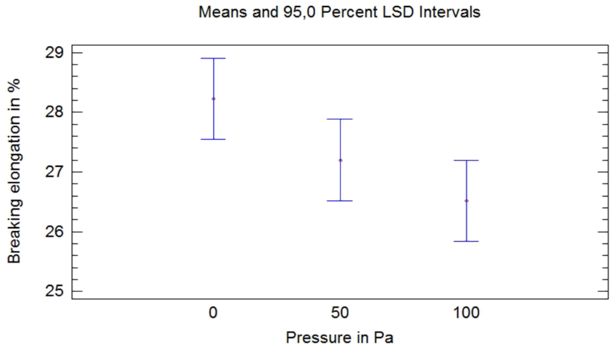


Sample AP100

Figure 2 Influence of aspiration air pressure on a cross-section of fully drawn polyamide 6 yarns (SEM, magnification 700x)



a)



b)

Figure 3 Influence of aspiration air pressure on breaking force (a) and breaking elongation (b) of hollow PA 6 fully drawn yarns

3.2 Tensile properties

From the tensile properties of samples is seen that aspiration of cooling air influenced on filament supramolecular structure, because:

- Samples made at aspiration air pressure of 50 Pa and 100 Pa showed higher average breaking force and lower average breaking elongation as sample AP0, made at aspiration air pressure zero (Figure 3).
- Influence of aspiration air pressure is evident on the curves of specific stress/elongation (Figure 4). Samples AP50 and AP100 show a little higher specific stress in the whole deformation range. Modulus of elasticity was in the range of 4.19-4.53 GPa.
- Dynamic thermal analyses showed for about 10% higher tensile force of samples, made with aspiration cooling air in comparison to sample AP0, made without it (Table 4).

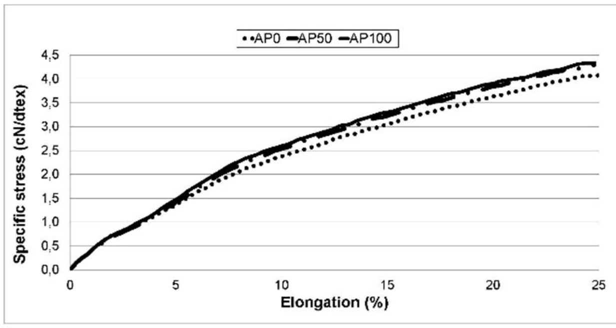


Figure 4 Specific stress-elongation curves of samples

Table 4 Dynamic thermal analyses

Sample	F [cN]	SD [cN]	F_{max} [cN]	F_{min} [cN]
AP0	67.635	0.54	68.22	66.845
AP50	74.435	1.225	76.135	73.295
AP100	74.945	1.13	76.085	73.32

3.3 Quantity of monomer and oligomers

Measured average viscosity molecular weight was the same for all samples, 15185.89 g/mol. With an extraction of samples in methanol, 2.05% of extract from the sample AP100 was obtained, 1.95% from the sample AP50 and 1.92% from the sample AP0. Lower spinneret temperatures at higher aspiration air pressure influenced on slower evaporation of monomer and oligomers from the spinning jets therefore higher quantities were kept in the filaments. Analysis of the extracts (Figure 5) has shown an increasing of quantities of monomer, trimers and hexamers in yarns made with aspiration of cooling air. On the other hand the quantities of dimers, tetramers, pentamers and hexamers have decreased with aspiration of cooling air. The most pronounced change was at monomer, which increased from 7.5% (AP0) to 13.55% (AP100).

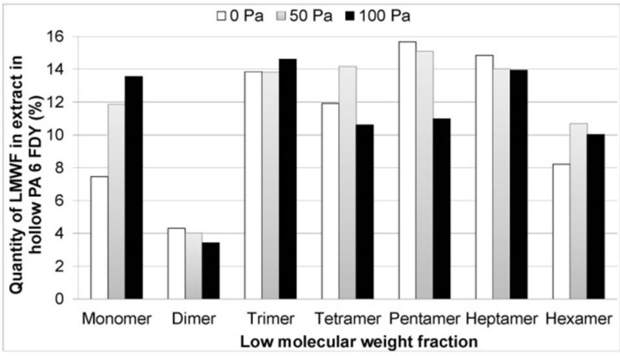


Figure 5 Influence of aspiration air pressure on a quantity of low molecular weight fraction (LMWF) of hollow PA 6 FDY

4 CONCLUSION

In the study was found out that aspiration of cooling air under the spinnerets which effectively prevents the monomer deposition on the spinnerets and on the spinning shaft walls, influenced also on the lower monomer evaporation from spinning jets. On the other hand aspiration of cooling air has a definite negative influence on the morphology of hollow filaments (incomplete forming hollows of filaments) and mechanical properties (increasing of breaking force, decreasing of breaking elongation, increasing of tensile force in dynamic thermal analysis). Changes of mechanical properties were small, but statistically proven. All these changes of yarn's properties originated from the changes in yarns supramolecular structure, because of decreasing of spinneret temperature.

5 REFERENCES

1. Reimschuessel H.: Polyamide fibers. In Handbook of fiber science and technology, Volume IV. Fiber chemistry, Edited by Menachem Lewin, Eli M. Pearce, New York, Basel, Marcel Dekker, 1985, pp. 74-81, Maxwell J. C.: A Treatise on Electricity and Magnetism, Oxford: Clarendon, 1892
2. Sbrolli W.: Nylon 6. In Man-made fibers. Science and technology, Volume 2, Edited by H.F. Mark, S.M. Atlas, E. Cernia, New York, London, Sydney, Interscience Publishers, 1968, pp. 232-239
3. McIntyre J.E.: Synthetic fibres: nylon, polyester, acrylic, polyolefin, Cambridge, Woodhead Publishing, 2005
4. Periyasamy, A.: Chapter 4. Production of manufactured fibers [online], Slide share [cited 6.7.2017], Available on: https://www.slideshare.net/abiramprince/production-of-manufactured-fibers