Crimping analysis of textured polyester multifilament yarn

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JOVANA STEPANOVIĆ
TATJANA ŠARAC
NATAŠA RADMANOVAC
DUŠAN TRAJKOVIĆ
JOVAN STEPANOVIĆ

ABSTRACT – REZUMAT

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The properties of textured POY PES multifilament yarns are conditioned by texturing temperature, texturing speed, stretching degree and by the ratio of disc peripheral speed and yarn speed. In the paper attention is focused on crimping of yarns. New method for defining crimping limits is proposed. The method is based on the flow analysis of the force-elongation function. POY multifilament polyester yarns, having the fineness of 167f36x1 dtex were analyzed. The texturing of PES multifilament yarns was performed using different first heater temperatures (350 °C, 400 °C, 450 °C) and maintaining the constant temperature of the second heater (180 °C), then with different texturing speeds (500 m/min, 600 m/min, 700 m/min, 900 m/min, 1000 m/min, 1100 m/min), using different ratio of the disc circumferential speed to yarn speed (2.15, 2.20, 2.25) and at the extension degree of 1.665.

Keywords: *texturing, multifilament, polyester, yarn, crimping*

Analiza ondulării firului multifilamentar din poliester texturat

Proprietățile firelor multifilamentare texturate POY PES sunt condiționate de temperatura de texturare, viteza de texturare, gradul de întindere și raportul dintre viteza periferică a discului și viteza firelor. Acest studiu abordează ondularea firelor. Este propusă o nouă metodă pentru definirea limitelor de ondulare. Metoda se bazează pe analiza funcției forță-alungire. Au fost analizate firele de poliester multifilamentar POY, cu finețea de 167f36x1 dtex. Texturarea firelor multifilamentare PES a fost efectuată folosind diferite temperaturi ale primului încălzitor (350 °C, 400 °C, 450 °C) și menținerea temperaturii constante a celui de-al doilea încălzitor (180 °C), apoi cu viteze de texturare diferite (500 m/min, 600 m/min, 700 m/min, 900 m/min, 1000 m/min, 1100 m min), folosind raportul diferit dintre viteza circumferențială a discului și viteza firelor (2,15; 2,20; 2,25) și un grad de extensie de 1,665.

Cuvinte-cheie: *texturare, multifilament, poliester, fir, ondulare*

INTRODUCTION

Texturing is a technological process for the transformation of smooth fibrous structures into the crimped, creating permanent deformations of monofilaments. Multifilamant yarns of thermoplastic fibers are texturized, when crimps are mainly shaped by a combination of heat and mechanical action. Such transformation process increases voluminousness and elasticity, the yarn is softer and more pleasant to touch, and the product made of such yarn is thermo-physiologically comfortable.

In the texturization process, the yarn is exposed to the influence of high temperatures and the tensile and torsion forces, which affects the structure of the yarn and, consequently, its properties [1–3].

Using HT heaters (high temperature contactless heaters) steps have been taken to improve the texturing process, with the aim of increasing productivity while preserving the quality of textured yarn. Increasing the temperature of the heaters results in more intensive warming of the yarn, which in turn requires a shortening of the retention time of the yarn in the heater and consequently a temperature drop over the cross-section of the thread [4–5].

A considerable number of papers deals with the analysis of the properties of textured yarn of extruded polyester filaments (FOY – Fully Oriented Yarn) characterized by a stable structure [6–8].

Papers studying the properties of textured yarns, of partially oriented polyester filaments (POY), were mainly originated by analyzing yarns formed in laboratory conditions [9–11]. Investigation of crimping [12] of textured multifilament yarns produced in industrial conditions [13] indicate that optimal texture parameters must be chosen as a compromise solution.

Since textured filament yarns formed from POY PES filaments produced on machines with HT heaters have not been sufficiently studied, the study of the influence of some parameters of the texturing process on the properties of textured yarns in the zone of elastic deformations is presented in this paper. The elastic deformation zone ends with the yield point [14]. That zone also includes the crimping [15] of textured yarns, which is one of the key characteristics of these yarns. Therefore, in the paper is presented analyzes the crimping of textured POY PES multifilament yarns. A conventional (standardized) method was used for the analysis [16], but a new method based on the analysis of the flow function of the force-elongation of these yarns was proposed.

MATERIALS AND METHODS

Preparation of experimental material was done under industrial conditions on a machine for stretching texturing with high temperature heater: FTF-15 (ICBT, France). Technical characteristics of the machine are: maximum texturing speed – 1500 m/min; the length of the first heater – 1.050 m; the length of the second heater – 1.60 m; cooling zone: 1.24 m; friction aggregate – ICBT aggregate 1-5-1; working PU discs (5 pcs); C profile.

Prepared were samples of textured PES yarn of fineness 167f36×1 dtex, of POY PES multifilament fineness 278f36×1 dtex, from the manufacturer TWD Fibers (Germany). POY polyester filament (poly (ethylene terephthalate)) used in this investigation was partially oriented with very low crystallinity degree (less than 5%), so that its structure and properties could be changed to a great extent by changing texturing process parameters.

In the texturing process of yarns various temperatures of the first heater were used (350 °C, 400 °C and 450 °C) at constant temperature of the second heater (180 °C), then at different texturing speeds (500 m/min to 1100 m/min), with the stretching degree of 1.665 and at different D/Y ratio (2.15, 2.20 and 2.25).

A standardized method according to DIN 53840-1 [16] was applied for the analysis of the crimping of textured PES multifilament yarns.

In addition, in order to contribute to the development of a new method for determining the curvature, a method based on the analysis of flow of the force-elongation of textured multilayer yarns was presented.

For determination of characteristics of experimental materials, automatic dynamometer USTER TENSORAPID 4 was used (DIN 53384).

Crimping limits of textured PES yarns were determined by analyzing $F(\varepsilon)$ function. Figure 1 shows the first derivative of $F(\varepsilon)$ function, on the basis of which force intensities and the values of relative elongation at the crimping limit of analyzed texture PES yarns were determined.

Further, using the results obtained determined was the work of the force to the crimping limit. The work of the force was defined by the surface under force-elongation curve to the limits defined by the flow analysis of that function [17].

RESULTS AND DISCUSSION

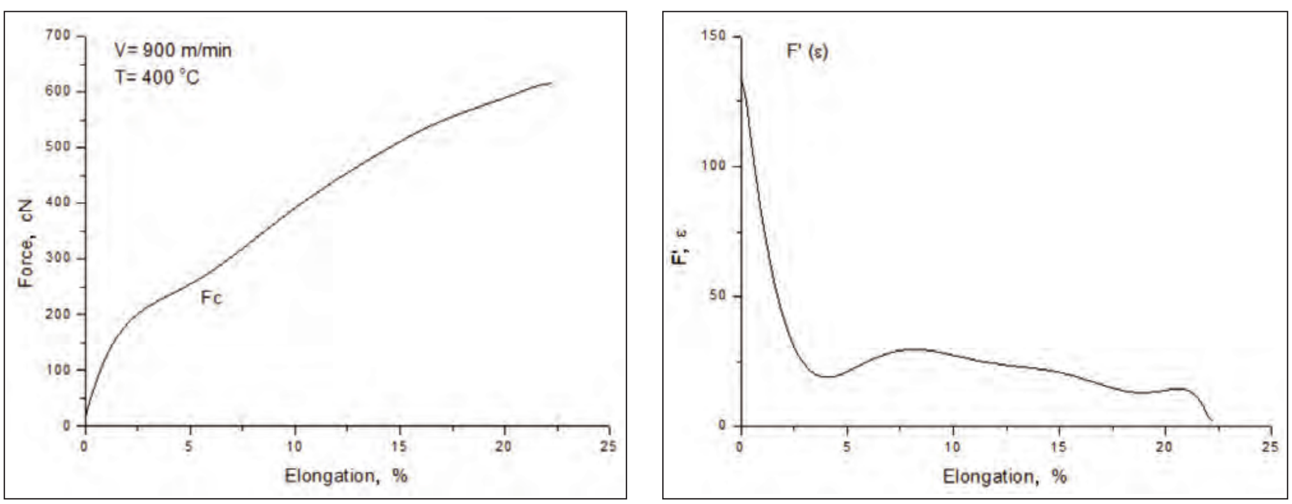
Results obtained by analysis of textured PES multifilament yarns are shown in tables 1 to 3.

Tables 1–3 show the texture parameters and some characteristics of the analyzed textured POY PES multifilament yarn (v_i – texture speed – m/min; T – temperature of primary heaters – °C; Cc – characteristic crimp – %; F_r – relative breaking force – cN/tex; ε – relative breaking elongation – %; F_c – force to the crimping limit – cN; ε_c – elongation at the crimping limit – %; A_c – work of the force to the crimping limit – cN cm.

Figures 2 to 4 show the graphs of the trend of changes in characteristic crimp (Cc) and elongation at the crimping limit (ε_c) at different texturing speeds, different temperatures of primary heaters and different D/Y values.

In most cases, analogue changes of the analyzed parameters of textured multifilament yarns can be noted (figures 2 to 4).

During yarn stretching, first the straightening of crimps, formed in the texturing process takes place. In the beginning, a higher curve slope can be noticed, due to faster force increase with regard to elongation of textured PES yarn (figure 1, *a*). This can be the effect of monofilament interlacing which appears in



a *b*

Fig. 1. Typical F-ε curves (a) and the first F'(ε) derivative (b) of the function

Table 1

RESULTS OF ANALYSIS OF TEXTURED PES MULTIFILAMENT YARN (D/Y = 2.15)

Sample no.	v (m/min)	T (°C)	Cc (%)	Fr (cN/tex)	CV Fr	ε (%)	CV ε	F_c (cN)	ε_c (%)	A_c (cN cm)
1	1100	350	9.2	34.2	4.4	19.2	9.2	222.27	2.90	217.70
2	1000	350	12.5	36.0	5.8	20.9	13.2	252.87	3.48	295.74
3	900	350	17.6	36.2	3.1	27.0	6.6	226.65	3.97	320.44
4	700	350	11.5	36.5	2.9	24.6	6.9	213.12	3.75	291.41
5	600	350	10.9	36.5	2.7	26.4	7.2	206.15	3.83	288.46
6	500	350	14.3	37.8	3.2	25.2	8.9	216.54	4.32	319.10
7	1100	400	9.4	34.3	5.3	18.6	11.3	220.39	3.28	234.29
8	1000	400	15.3	36.5	6.0	21.2	14.4	238.84	3.41	269.45
9	900	400	18.1	37.3	2.9	25.7	6.2	233.43	4.32	343.93
10	700	400	19.5	38.4	3.0	26.3	5.6	216.53	4.29	311.90
11	600	400	15.5	37.8	2.6	25.9	5.8	215.31	4.27	314.19
12	500	400	18.9	38.3	3.7	24.7	8.2	216.46	4.90	332.77
13	1100	450	13.7	37.4	6.9	21.4	12.4	219.89	2.88	211.17
14	1000	450	15.0	37.8	5.6	25.5	12.5	207.03	3.22	219.07
15	900	450	19.6	37.9	2.8	25.6	5.9	215.46	4.38	306.84
16	700	450	20.0	38.8	2.5	26.0	6.1	210.01	4.26	298.05
17	600	450	16.5	38.9	2.6	26.0	5.6	209.62	4.54	300.30
18	500	450	26.3	39.6	1.8	25.4	5.2	210.19	4.21	293.38

Table 2

RESULTS OF ANALYSIS OF TEXTURED PES MULTIFILAMENT YARN (D/Y = 2.20)

Sample no.	v (m/min)	T (°C)	Cc (%)	Fr (cN/tex)	CV Fr	ε (%)	CV ε	F_c (cN)	ε_c (%)	A_c (cN cm)
19	1100	350	9.1	34.6	5.4	19.8	11.4	234.00	3.11	247.6
20	1000	350	12.5	35.2	6.0	20.7	12.1	249.14	3.42	291.2
21	900	350	13.5	35.9	3.9	27.8	7.2	222.92	3.87	311.6
22	700	350	10.7	36.8	4.2	25.0	7.7	212.45	4.02	302.5
23	600	350	11.7	37.0	2.0	26.4	4.4	211.24	3.95	296.4
24	500	350	14.1	38.0	3.1	25.0	8.2	214.34	4.11	305.2
25	1100	400	10.4	35.4	5.6	19.6	10.3	223.04	3.02	223.8
26	1000	400	15.0	36.3	14.0	20.6	11.9	233.09	3.28	258.2
27	900	400	17.7	37.0	3.4	26.9	8.3	236.41	4.06	337.1
28	700	400	21.5	38.7	2.3	25.8	6.4	218.33	4.53	320.2
29	600	400	15.4	38.0	2.7	26.2	5.3	216.11	4.13	308.1
30	500	400	20.4	38.7	3.8	26.0	7.4	203.13	4.54	293.3
31	1100	450	12.6	35.9	8.0	21.5	16.5	226.03	3.38	250.4
32	1000	450	15.7	36.9	6.4	21.0	11.4	227.61	3.77	271.6
33	900	450	20.8	38.4	2.4	26.6	6.3	222.45	4.83	340.8
34	700	450	20.1	39.4	2.6	26.0	6.0	217.36	4.48	317.4
35	600	450	17.3	38.7	1.9	26.3	4.7	190.33	4.29	263.4
36	500	450	26.5	39.0	3.3	25.1	6.5	208.25	4.07	283.0

the process of false twisting, because not all monofilaments are heated to the same temperature due to the position in multifilament yarn and therefore do not receive the same torsion energy. During further stretching, releasing of interlaced monofilaments takes place and to the point F_c (the point of crimp straightening point) decline of the slope of force – elongation function can be seen. At this point recorded is the force needed for crimp straightening (F_c) and also corresponding elongation (ε). The force F_c

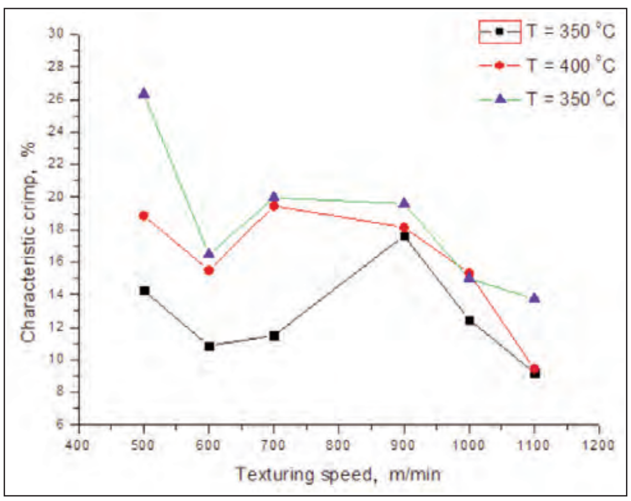
Table 3

RESULTS OF ANALYSIS OF TEXTURED PES MULTIFILAMENT YARN (D/Y = 2.25)										
Sample no.	v (m/min)	T (ºC)	Cc (%)	Fr (cN/tex)	CV Fr	ε (%)	CV ε	F_c (cN)	ε_c (%)	A_c (cN cm)
37	1100	350	10.2	34.3	4.8	19.4	10.0	221.15	3.10	225.86
38	1000	350	12.5	36.1	6.5	20.4	13.1	257.45	3.67	330.14
39	900	350	13.7	35.8	2.8	27.3	6.8	218.61	3.78	304.28
40	700	350	10.6	35.9	3.1	24.6	6.7	214.92	4.02	313.69
41	600	350	12.0	37.0	1.6	25.8	3.9	216.34	4.12	317.33
42	500	350	14.6	38.2	3.3	25.9	9.3	211.98	4.08	299.57
43	1100	400	10.1	35.6	5.7	19.1	11.0	216.26	2.75	199.03
44	1000	400	13.9	37.3	5.2	22.1	12.3	256.05	3.57	307.16
45	900	400	18.0	36.7	3.1	26.5	7.4	221.62	4.04	315.28
46	700	400	16.5	37.9	2.0	25.3	6.9	190.92	4.07	254.69
47	600	400	15.9	38.3	1.6	26.5	4.9	212.98	4.42	322.55
48	500	400	20.4	38.7	2.3	24.6	6.4	216.50	4.47	319.97
49	1100	450	11.3	41.4	7.0	20.7	12.5	200.31	2.72	185.66
50	1000	450	14.5	36.0	7.8	20.9	15.2	226.14	4.21	291.62
51	900	450	20.4	38.1	2.9	25.7	7.6	224.93	4.45	330.48
52	700	450	20.2	38.6	2.5	25.6	5.5	204.31	4.14	281.16
53	600	450	17.5	38.8	2.9	26.0	3.9	198.31	4.25	272.41
54	500	450	27.0	39.4	3.0	25.6	7.0	200.53	3.99	268.82

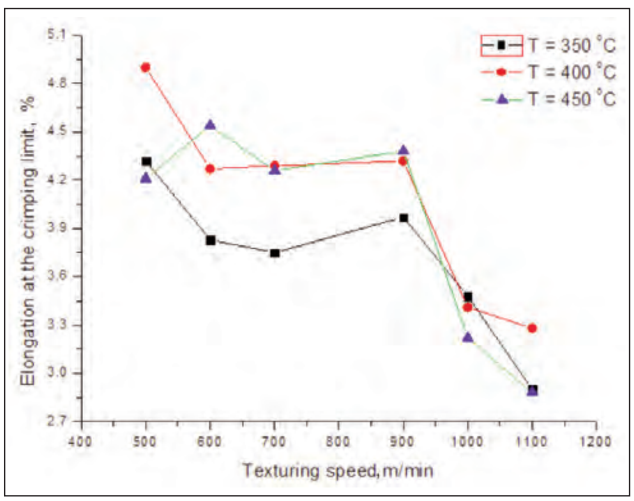
is determined on the basis of the force-elongation graph at the point of local minimum of the first derivative of the function (figure 1, *b*).

The results obtained show the decline of yarn elongation with increase of texturing speed. It can be concluded that higher texturing speed negatively affects the crimping properties of textured PES yarn (figure 2, *a* to 4, *b*). At speeds over 900 m/min a considerable reduction of yarn crimping is observed. However, in relation to the peripheral disk velocity and the yarn speed of 2.25, it is noted that the crimp decreases at texturing speed greater than 1000 m/min (figure 4, *b*). This picture confirms the finding that a higher D/Y ratio contributes to the greater crimp of textured PES yarns.

At the same time, elongation results show that yarns textured at higher temperature have higher crimping compared to yarns textured at lower temperature. Namely, increasing yarn temperature weakens intermolecular interactions resulting in increased mobility and flexibility of macromolecular chains and structural elements enabling easier formation of ordered structures - crystallities. Individual results deviations from expected results can be the effect of yarn being damaged at lower speeds and higher texturing temperatures. Moreover, POY polyester filament yarn in

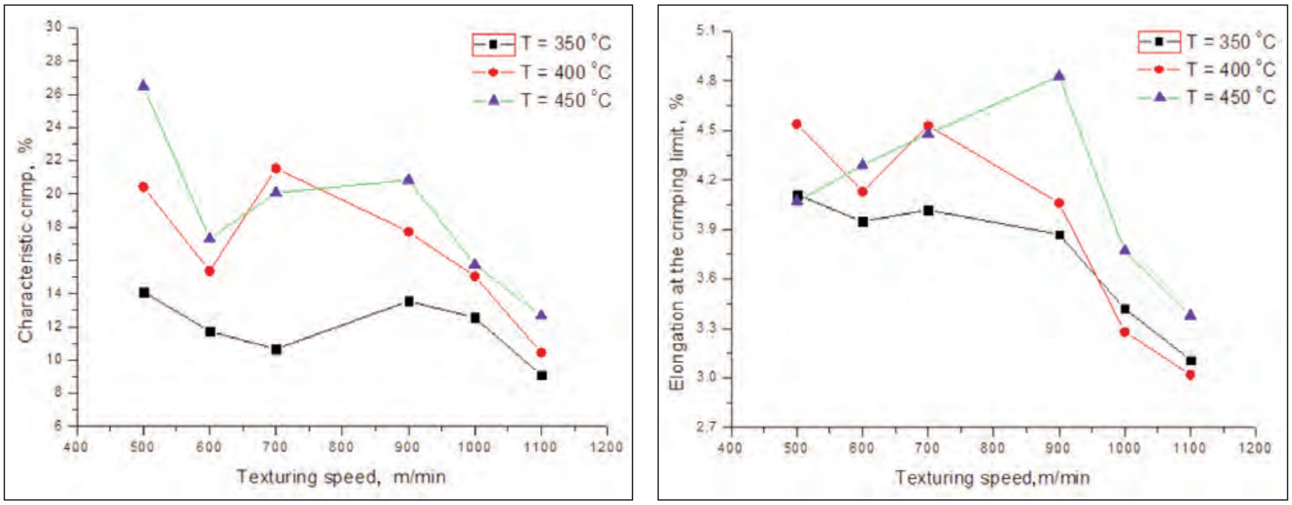


a



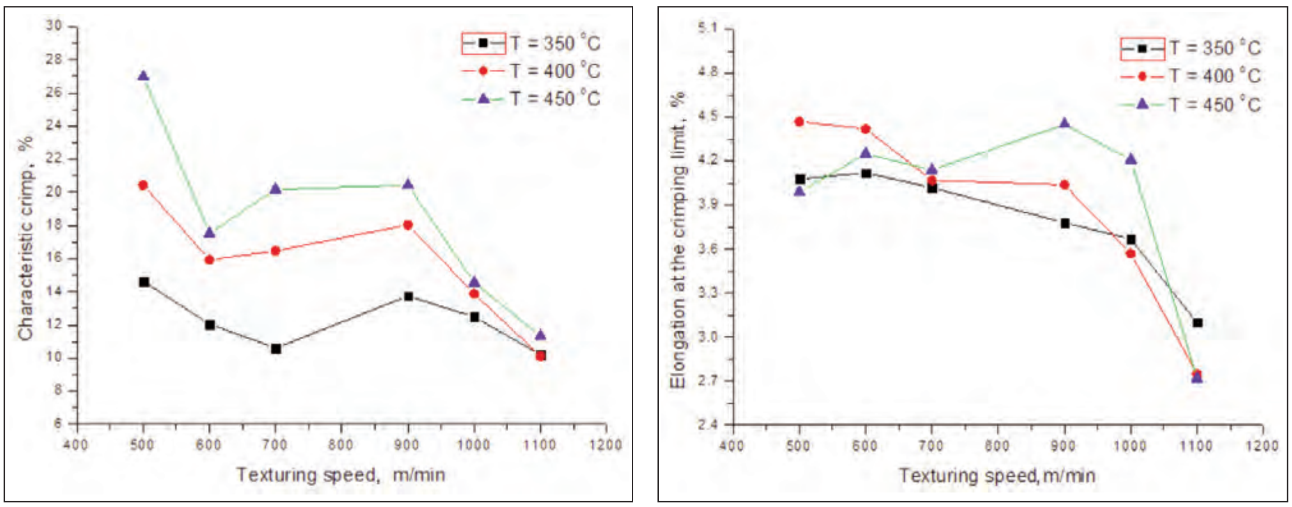
b

Fig. 2. Characteristic crimp (a) and elongation at the crimping limit (b) D/Y 2.15



a *b*

Fig. 3. Characteristic crimp (a) and elongation at the crimping limit (b) D/Y 2.20



a *b*

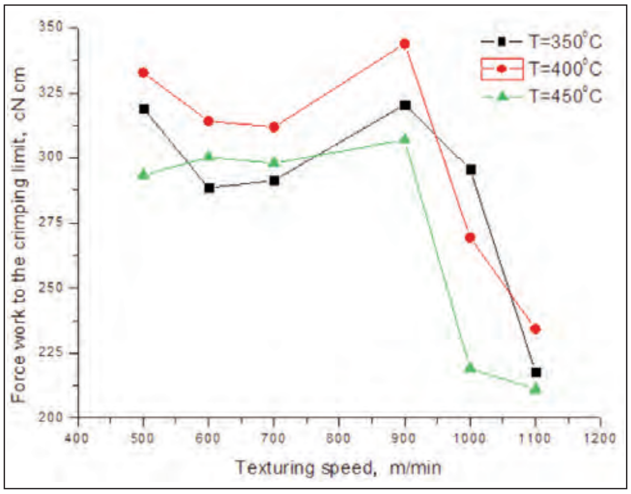
Fig. 4. Characteristic crimp (a) and elongation at the crimping limit (b) D/Y 2.25

the process of texturing by false twisting is exposed to the action of both external stretching and twisting forces and internal straining, i.e. contraction due to relaxation processes and increased molecules mobility due to increased temperature. The ability of yarn to resist these force actions depends on the changes in yarn temperature determined by texturing speed and heater temperature. The influence of these two parameters on the straining in yarn is opposed, i.e. by increasing the texturing temperature the breaking of intermolecular interactions is easier and material softens resulting in lowering yarn straining, while by increasing texturing speed the external forces acting on yarn and internal straining in yarn increase. The detected results deviations from the expected can also be the result of the fact that textured multifilament yarns consist of a large number of individual filament threads entering the heater as a thick and compact beam. In that way the migration of individual threads in the twisted filament beams prevented, in the texturing zone. This leads to uneven temperature distribution (temperature gradient) over the filament yarn cross section (filament threads on the outside surface of the beam will receive more heat than the threads inside the beam) and to asymmetric stretching so that twisting forces distribution is therefore reflected on the crimping of individual threads in multifilament.

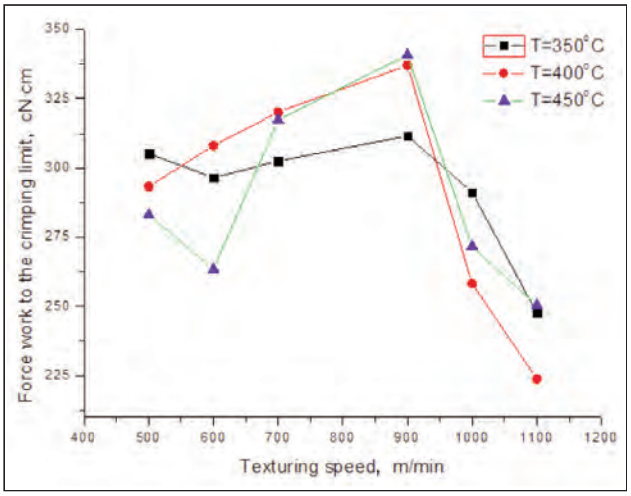
Interesting results offer the values of force work to the crimping limit and to the elasticity limit. Figure 5 shows the influence of texturing speed and temperature of the first heater on the force work to the crimping limit.

The results show that at texturing speeds higher than 900 m/min, force work values to the crimping limit and force work values decline (figures 5, *a* and *b*, D/Y 2.15 and 2.20). However, the force work to the boundary of crimp in the multifilament yarn produced at a ratio D/Y of 2.25 decreases at a texture speed greater than 1000 m/min (figure 5, *c*, D/Y 2.25).

At high texturing speeds, yarn retention time in the heater is shorter; the yarn is less and unevenly heated from outside surface towards the core and therefore



a



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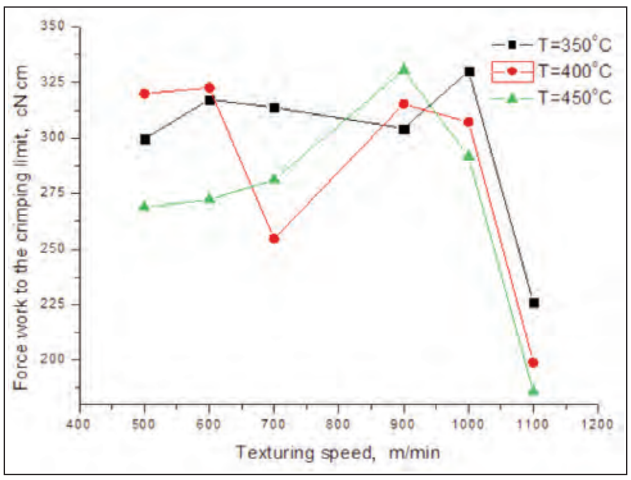

c

Fig. 5. The force work to the crimping limit (*a* – D/Y = 2.15; *b* – D/Y = 2.20; *c* – D/Y = 2.25) of textured PES filament yarns

in the process of stretching the orientation of molecular chains in filaments is more uneven. On the other hand, lower texturing speeds and higher temperatures damage the yarn also having a negative effect on the quality of textured yarns

Retention time and temperature during yarn heating have an influence on the mutual position of molecular chains striving to the equilibrium state in filament which is in direct relation with the natural tendency of all physical systems to have the minimum potential energy.

Texture speed is a very important parameter from the aspect of productivity of the process, but also the quality of the produced yarns. The obtained results of the coefficient of variation of the relative breaking force and the elongation at break (tables 1 to 3) indicate a significant increase of deviation of the results of the analyzed yarn parameters (*CV* value) with increasing texturing speed. Therefore, the texturing process parameters must be carefully selected, with the aim of achieving high productivity and high quality of produced yarns.

CONCLUSIONS

Analyzing the flow of force-elongation function significant data can be obtained showing the properties of textured yarns, and the effect of individual process parameters on the properties. Analyzing parameters of textured yarn in the zone of elastic deformations it is possible to obtain information on voluminosity and elasticity of these yarns which represent a special interest for further yarn processing to final textile materials.

The analysis is based on the fact that the monofilament of multifilament yarn begins to provide a more uniform resistance to stretching forces after correcting the crimps formed in the texturing process. The given point, on the force-elongation graph, represents the boundary of the crimping and is defined by the minimum of the first derivative of the function.

Since the zone of elastic deformation is an insufficiently explored area of textured PES yarn, the investigation had the primary goal to propose methods of characteristics analysis of textured PES filament yarns by interpretation of force-elongation function flow. This of analysis of textured yarn characteristics can be a starting point for development of new methods for prediction of characteristics of textured filament yarns according to the future purpose.

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Authors:

JOVANA STEPANOVIĆ, TATJANA ŠARAC, NATAŠA RADMANOVAC,
DUŠAN TRAJKOVIĆ, JOVAN STEPANOVIĆ

Faculty of Technology, University of Niš/Bulevar oslobođenja 124, 16000 Leskovac, Serbia

e-mail: stepanovicjovana@yahoo.com, tangerine.art83@gmail.com, radmanovac@tf.ni.ac.rs,
dusan@ tf.ni.ac.rs, jovan@tf.ni.ac.rs

Corresponding author:

JOVAN STEPANOVIĆ

e-mail: jovan@tf.ni.ac.rs