

The Dependence of Air-textured PES Thread Mechanical Properties on Texturing Parameters

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Stress-strain properties including loop strength, stress relaxation and elastic recovery of air-textured PES/PES core-wrap sewing threads manufactured on “Eltex” air-texturing machine with HemaJet® air-texturing nozzle are investigated. Torlen FY HT PES 13.3 tex multifilament yarn distinguished by increased strength was used as raw material. Two PES yarns were fed to the nozzle as core threads and one as wrap effect. The properties of threads manufactured alternatively with thermosetting and without it are studied in dependence on overfeed of wrap yarn and pressure of air fed into the texturing nozzle.

ZWICK/ROELL BDO-FBO.5TH testing machine with a 50 N load cell was used performing the tests. Mechanical properties of the PES multifilament yarns are markedly changed by air-texturing. Breaking tenacities of PES/PES air-textured sewing threads are only one half of those of the raw PES yarn due to core-wrap structure of the air-textured threads and the disordering of filaments of core threads during air-texturing. PES/PES threads are pretty less responsive to loop testing if comparing with straight thread test than the raw PES yarn. Air-pressure and overfeed in texturing are influential factors in respect of stress-strain properties and loop strength of air-textured PES/PES sewing threads. Their influence is markedly affected by thread thermosetting: lower air pressure and overfeed values are advantageous factors while texturing without thermosetting but they are disadvantageous ones while texturing with thermosetting. The thermosetting of threads does not markedly influences relaxation behaviour of air-textured PES/PES threads, but the thermoset threads show to have more stable elastic power at higher strains.

Keywords: air-jet texturing, sewing yarns, polyester, stress-strain, relaxation, recovery

INTRODUCTION

Polyester (PES) multifilament yarns are very useful as the raw material for air-texturing [1]. Because of the efficiency of manufacturing process, low production costs and good properties of the textured yarns, the air-texturing process is in current use and variety of new jet designs are produced over last decades. Air-jet texturing enables the production of sufficiently thick sewing threads, which ensure the stability of the seams, which are very important to get good quality products.

An influence of yarn composition, texturing mode and main texturing parameters to stress-strain properties of air-textured PES yarns has been studied by Rengasamy et al. [2, 3]. It was determined that tenacity, modulus and extensibility of air-textured yarns are the indices being very sensitive to such texturing parameters as air pressure and overfeed. Jonaitiene and Stanys [4] investigated the influence of thermosetting on the stress-strain properties of air-textured PES and PES/PTFE yarns. Unfortunately, up to now there is little knowledge about viscoelastic properties of air-textured PES yarns. Experiments on stress relaxation in PES yarns provided by Meredith and Hsu [5] revealed relaxation as the process highly influenced by mechanical pre-history of the yarn. In the work of Vitkauskas [6] the dependence of the intensity of PES yarn relaxation on alternating strain rate was stated. Among studies on main regularities of yarn recovery from extension the works of Kašparek [7], Abbott [8], and Guthrie et al. [9, 10] should be mentioned in which it has

been stated that recovery of fibres and yarns was greater for lower values of extension, and that the longer was time of loading, the slower was recovery of extension.

The goal of this research is to compare strain-stress properties, stress relaxation and features of elastic recovery of raw PES yarn and those of air-textured PES/PES sewing threads, and to determine the dependency of manufacturing parameters on the thread properties.

EXPERIMENTAL METHODS

Torlen FY HT polyester 13.3 tex multifilament yarn distinguished by increased strength was chosen as raw material in the study. Air-textured PES/PES sewing threads were manufactured on “Eltex” air-texturing machine [11] with HemaJet® air-texturing nozzle. Three multifilament PES yarns were fed to the nozzle: two of them as core threads and one as wrap effect. In the process of manufacture the following parameters, making an essential influence on a quality of a final product, were varied:

- overfeed of wrap yarn (the core yarns were always fed with 5 % overfeed);
- pressure of air fed to the texturing nozzle;
- thermosetting (alternatively).

Temperature of thermosetting was 190 °C, as it has been determined [4] to be the optimum for PES yarns. The air-texturing parameters of the yarns are presented in Table 1.

ZWICK/ROELL BDO-FBO.5TH testing machine [12] with a 50 N load cell was used performing the tests. The tests were provided at gauge length (500 ± 1) mm, testing speed 500 mm/min, and the specimen pretension of

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Table 1. Main manufacturing parameters of the investigated yarns

| Parameter | Yarns and their codes | PES yarn | Textured PES/PES threads | | | | | |
|-----------------------------------|-----------------------|----------|--------------------------|------|------|-----------------------|------|------|
| | | | With thermosetting | | | Without thermosetting | | |
| | | | 1 | 3 | 7 | 11 | 12 | 13 |
| Linear density (T), tex | | 13.3 | 44.7 | 44.3 | 44.3 | 44.3 | 45.0 | 44.3 |
| Overfeed of wrap yarn, % | | – | 20 | 20 | 15 | 25 | 25 | 15 |
| Air pressure ($\times 98,9$ kPa) | | – | 9 | 6,1 | 7 | 11 | 7 | 7 |

Table 2. Indices of stress-strain properties of the PES yarn and air-textured PES/PES sewing threads

| Parameter | Yarns and their codes | PES yarn | Textured PES/PES threads | | | | | |
|--|-----------------------|----------|--------------------------|-------|-------|-----------------------|-------|-------|
| | | | With thermosetting | | | Without thermosetting | | |
| | | | 1 | 3 | 7 | 11 | 12 | 13 |
| Breaking force (F_b), N | | 8.71 | 14.33 | 15.30 | 15.63 | 12.80 | 13.51 | 14.46 |
| Elongation at break (ε_b), % | | 10.24 | 8.88 | 9.01 | 8.86 | 9.07 | 9.34 | 9.69 |
| Breaking tenacity (f_b), cN/tex | | 65.50 | 32.34 | 34.54 | 35.28 | 28.91 | 30.50 | 32.64 |
| Work at break (W_b), N·mm | | 225 | 318.3 | 344.6 | 350.3 | 301.1 | 321.9 | 355.9 |
| Loop strength (F_l), N | | 9.35 | 25.72 | 26.60 | 26.71 | 23.51 | 25.28 | 27.73 |
| Relative loop strength (R_L), % | | 53.68 | 89.76 | 86.92 | 85.46 | 91.81 | 93.56 | 95.89 |

0.25 cN/tex. All the tests were processed with *testXpert®* software.

In the tensile tests up to break the indices of the following parameters were obtained averaging 30 individual measurements:

- breaking force (F_b) and elongation at break (ε_b);
- breaking tenacity ($f_b = F_b/T$) in cN/tex;
- work of break (W_b);
- loop strength (F_l);
- relative loop strength ($R_L = 100 \cdot F_l/2F_b$) in %.

Viscoelastic properties of the yarns may be distinctly affected by the yarn thermosetting. To reveal the influence of thermosetting on the yarn viscoelastic properties the tests were provided for the raw PES yarn and for air-textured PES/PES threads manufactured without thermosetting (coded as 13, see Table 1) and the yarn thermoset (coded as 7), i. e., both of them manufactured at identical specified parameters: air pressure of $7(\times 98.9)$ kPa, and overfeed of 15 %. Stress relaxation and recovery data were measured at three different strain levels $\varepsilon_t = 1\%$, 2% , and 5% .

The yarn tensile force decrease $F(t^*)$ during stress relaxation was measured at constant strain ε_t over the period of time $t^* = 1000$ s. It is worth to notice here that dimensions of the specimen do not change during stress relaxation test, so, specimen stress is proportional to the tensile force. Relative relaxed force (F_{rel}) was used as the inverse index of relaxation intensity:

$$F_{rel} = \frac{F_{1000}}{F_0} \cdot 100, \% \quad (1)$$

where: F_{1000} is force at $t^* = 1000$ s; F_0 is force at $t^* = 0$, i. e., at the moment when the upper limit of strain ε_t was reached in extension.

After the end of relaxation the yarn specimens were fully retracted, and the tensile hysteresis was measured. The following data (averaged of 5 individual measurements) were obtained:

- elastic strain (ε_e);
- total work of extension (W_t);
- work of retraction (W_r).

Elastic recovery (D_E) showing ability of the yarn to recover immediately after removal of the imposed strain was obtained in percentage of the total strain:

$$D_E = \frac{\varepsilon_e}{\varepsilon_t} \cdot 100, \% \quad (2)$$

Toughness index (I_T) was used to evaluate recovery power of the yarns:

$$I_T = \frac{W_r}{W_t} \cdot 100, \% \quad (3)$$

RESULTS AND DISCUSSIONS

Stress-strain properties. Stress-strain curves of raw polyester yarn and two PES/PES air-textured threads are shown in Figure 1, while the indices obtained from tests provided up to specimens break are presented in Table 2. The shape of PES/PES thread stress-strain curve is similar to curve of the raw PES yarn: slope of the curve is high in the initial phase of extension. Second phase of extension begins somewhere at 2% strain where the slope of a curve becomes distinctly lower tending again to increase somewhere in the range of 6% strain.

As it is seen in Table 2, breaking tenacity of the PES/PES air-textured threads is just about one half of breaking tenacity of the raw polyester. In view of Rengasamy at al. [3, 4] the decrease in breaking tenacities

of synthetic threads after air-texturing is due to specific core-wrap structure of air-textured threads (in extending the wrap yarn bears fewer loads than the core yarns, so they less contribute to breaking force of the entire air-textured thread) and due to disordering of single filaments of the core yarns during air-texturing. It should be definitely pointed up that rupture of all PES/PES air-textured threads, despite of their core-wrap structure, was of catastrophic nature. Comparing textured PES/PES thread after thermosetting and the thread as received, it is seen that thermosetting results are in slight increase of the thread breaking tenacity and corresponding decrease of its elongation at break.

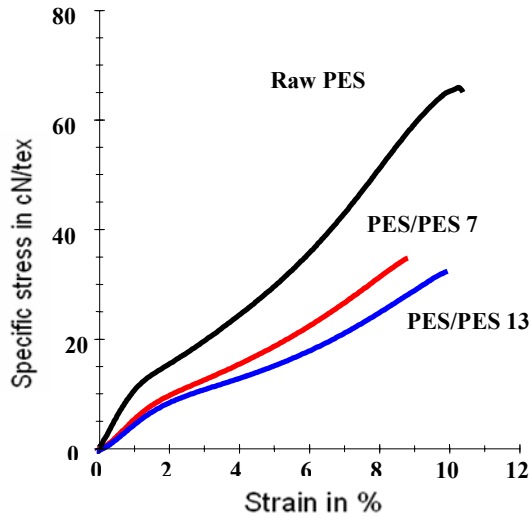


Fig. 1. Stress-strain curves of raw PES and air-textured PES/PES sewing threads

In the process of yarn thermosetting the intermolecular tension is relaxed which occurs when filaments (polymer macromolecules and fibrils at the same time as well) form loops. Hence, elongation at break of the yarns manufactured without thermosetting is determined by elongation of polymer macromolecules themselves [9]. The PES/PES threads manufactured with thermosetting had also higher index of work at break. Lower air pressure and overfeed values are also the advantageous factors in respect of air-textured thread fastness.

When testing yarns in loop, strength of the raw polyester yarn substantially decreases. It comprises only 54 % of the straight twofold thread strength. As to air-textured PES/PES threads, it is evident from the data shown in Table 2 that they are pretty less responsive to loop testing if comparing with straight thread test. Furthermore, relative loop strength of thermoset air-textured threads is less than that of the yarns manufactured without thermosetting. Possibly, additional cross-linking in the fibre structure during thermosetting may restrict relative inter-displacements of fibre cross-section layers in bending and, in turn, to produce higher stress concentration in a fibre cross-section during loop test leading to break at lower values of transversal forces. Air pressure and overfeed of the wrapping yarn also show to have noticeable influence to relative loop strength. With decrease of air pressure for threads manufacturing with thermosetting the evident tendency is seen for relative loop strength to decrease. Behaviour of threads air-textured without thermosetting is different: with

decrease of air pressure and overfeed the thread relative loop strength increases.

Viscoelastic properties. The curves of stress relaxation of the PES yarn and PES/PES sewing threads are presented in Figure 2 and Figure 3 in the form of relative force decrease over the logarithmic time scale. It is evidently seen that the character of force decrease is very different at various levels of the imposed strain. Stress decrease of the raw PES is low at the beginning of relaxation (up to the time 1 s) at 1 % strain while it intensifies onwards. Relaxation at higher strains is intense over the all time scale. Relative relaxed force drops to 72 % at 2 % strain but relaxation at 5 % strain again becomes less intensive. For air-textured threads the intensity of stress decrease at 1 % strain is approximately the same over all logarithmic time scale and the intensities at 2 % and 5 % do not differ so much as in the raw PES yarn. Comparing intensities of stress decrease in PES/PES threads textured with and without thermosetting it is seen that almost at each level of strain the curves of relative force of threads No7 and No13 are quite close to each other. So, thermosetting of threads does not markedly influence relaxation behaviour of air-textured threads. Indices of viscoelastic properties of the threads are shown in Table 3.

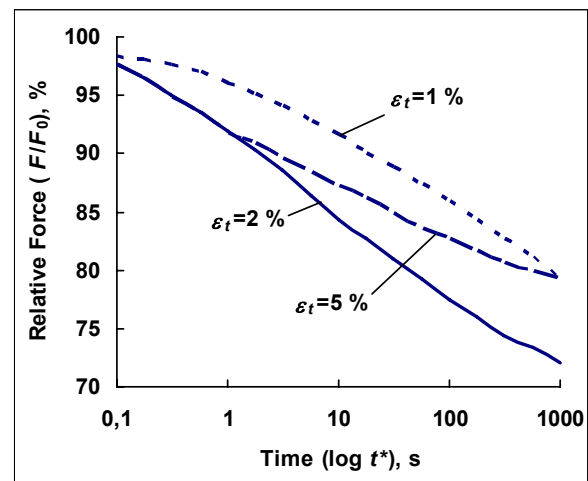


Fig. 2. Relative stress relaxation of raw PES yarn at different total strains ϵ_t

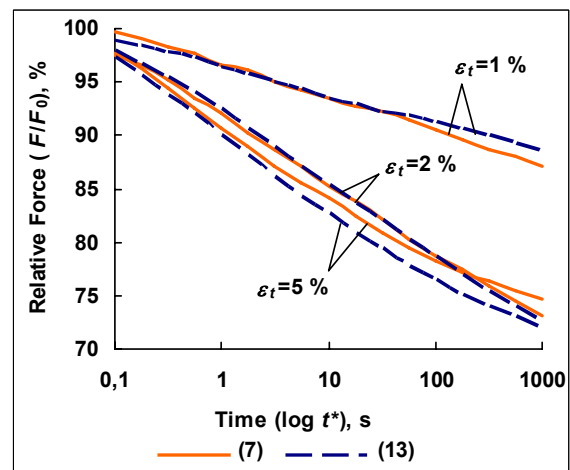


Fig. 3. Relative stress relaxation of air-textured PES/PES sewing threads (codes 7 and 13) at different total strains ϵ_t

Table 3. Indices of viscoelastic properties of the investigated yarns

| Parameter | Type of thread | Raw PES yarn at $\varepsilon_r =$: | | | Air-textured PES/PES sewing threads at $\varepsilon_t =$: | | | | | |
|---------------------------------------|----------------|-------------------------------------|-------|-------|--|-------|-------|----------------------------|-------|--------|
| | | | | | with thermosetting (7) | | | without thermosetting (13) | | |
| | | 1 % | 2 % | 5 % | 1 % | 2 % | 5 % | 1 % | 2 % | 5 % |
| F_0 , N | | 1.34 | 1.97 | 3.806 | 2.12 | 4.22 | 8.27 | 2.10 | 4.08 | 6.97 |
| F_{1000} , N | | 1.06 | 1.42 | 2.97 | 1.850 | 3.091 | 6.196 | 1.882 | 2.967 | 5.018 |
| Elastic strain (ε_e), % | | 0.72 | 1.12 | 3.06 | 0.77 | 1.37 | 3.39 | 0.78 | 1.4 | 2.8 |
| Elastic recovery (D_E), % | | 72 | 56 | 61 | 77 | 68.5 | 67.8 | 78 | 70 | 56 |
| Work of extension (W_e), N·mm | | 3.57 | 12.17 | 55.81 | 4.52 | 21.90 | 118.5 | 4.40 | 21.56 | 106.41 |
| Work of recovery (W_r), N·mm | | 1.95 | 3.44 | 16.25 | 2.83 | 7.31 | 28.79 | 2.94 | 7.31 | 19.90 |
| Toughness (I_T), % | | 54.62 | 27.09 | 29.12 | 62.61 | 33.38 | 24.29 | 66.82 | 33.91 | 18.7 |

Elastic recovery of the textured threads is better than that of raw PES. With increase of total strain level, elastic recovery of the air-textured threads decreases, but after thermosetting the threads show to have more stable elastic recovery power at higher levels of strain.

Work of extension and work of recovery of all the investigated threads increase, increasing the level of strain. To extend textured threads, it is necessary to apply almost twice more work than to extend raw polyester thread. More work of extension as well as work of retraction is necessary for threads produced with thermosetting, because the crimped structure of filaments remains after thermosetting, so this structure is more resistant to extension impact.

When the strain levels are 1 % and 2 %, thread No 13 produced without thermosetting has approximately the same amount of toughness as the thread No7 produced with thermosetting. Toughness of the thermoset thread No7, however, becomes higher when strain level reaches 5 %. In general, despite toughness of the tested threads decreases applying higher level of strain, the thermosetting improves elastic power of air-textured yarns at higher strains.

CONCLUSIONS

Mechanical properties of PES multifilament yarns are markedly changed by air-texturing. Breaking tenacities of PES/PES air-textured sewing threads are markedly less than that of the raw PES thread. This is due to core-wrap structure of the air-textured threads and the disordering of filaments of core threads during air-texturing. PES/PES threads are pretty less responsive to loop testing if comparing with straight thread test than the raw PES yarn. Air-pressure and overfeed in texturing are influential factors in respect of stress-strain properties and loop strength of air-textured PES/PES sewing threads consisting of two core yarns and one wrap yarn. Their influence is markedly affected by thread thermosetting: lower air pressure and overfeed values are advantageous factors while texturing without thermosetting but they are disadvantageous ones while texturing with thermosetting. The thermosetting of threads does not markedly influences relaxation behaviour of air-textured PES/PES threads but

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