Rimvydas Milašius,
Ginta Laureckiene

Kaunas University of Technology,
Faculty of Mechanical Engineering and Design,
Department of Materials Engineering,
Studentu Str. 56, LT-51424 Kaunas, Lithuania
E-mail: ginta.laureckiene@ktu.lt

Prediction of Long-lasting Relaxation Properties of Polyester Yarns and Fabrics

Abstract
Relaxation properties are very important for various kinds of textiles and especially for technical ones. Technical textiles in their usage sometimes undergo stress for a long time and their behaviour after which is very important for prediction of the possibility for their further usage. For the prediction of such properties and long-lasting relaxation investigation, the relative stress relaxation P/P0, which characterizes the rate of relaxation, is used. In the present paper it was found that this rate cannot be described as a linear dependency on the logarithm of the time – in a certain time the character of the rate changes. Such a phenomenon is clearly visible for multifilament polyester yarns as well as for woven fabrics from them. The time in which the character of the rate of relaxation changes is herein proposed to be named as the break-point of the relaxation process. In our work it was found that the break-point of polyester (PET) yarns and fabrics exist after 100 seconds. It was also discovered that the rate of relaxation in the log(t) scale can be described by two straight lines and the values of relaxation in the long term can be predicted by the rate of relaxation of the second linear dependency. A method which allows to predict the relaxation process up to 200,000 seconds after testing till 500 seconds is presented. The reliability of such a prediction is lower than 2%.

Key words: *stress relaxation, polyester yarn, textile.*

Introduction

Relaxation properties are very important for various kinds of textiles and especially for technical ones. Technical textiles in their usage sometimes undergo long-lasting stress and their behaviour after which is very important for prediction of the possibility for their further usage. Long-lasting usage depends on the viscoelastic properties, which influence the behaviour during cycling fatigue, long-lasting and cycling stress, among others. For this reason the stress relaxation and other mechanical behaviour of various polymeric materials (textiles, leather, films etc.) were investigate, but usually researches investigate not very long-lasting relaxation, only for some hours [1 - 9]. But for usage, long-lasting relaxation is also very important. On the other hand, investigation of such long-lasting relaxation takes a large amount of time, and therefore it is not popular. However, the long-lasting relaxation and behaviour of materials, especially for technical application, are very important.

Numerous authors have investigated relaxation behaviour for some hours and tried to predict the behaviour for a much longer time [10 - 15]. After analysing these investigations it can be noted that the dependence of relative stress relaxation (P/P_0), which characterises the rate of relaxation, on the logarithm of the time (log(t)) is not linear. This phenomenon complicates long-lasting stress relaxation prediction for short time investigations.
The work presented in this paper focused on long-lasting relaxation prediction in a shorter time of investigation, which is a part of research also made earlier and is being carried out at the present time. Other authors also show the possibility to describe stress relaxation by two straight lines and explained such a phenomenon that fabrics may be characterised by two kinds of relaxation mechanism [10]. The point at which the stress relaxation behaviour changes its character can be named as the break-point of relaxation [11].

Other authors also found that the nature of the relaxation curve changes during the final stages and the initial relaxation was reported to be globally faster with a higher tensile relaxation rate. The change occurs after 200 s in all cases investigated [12]. The same phenomenon was also observed in papers [13, 14], but in both cases hybrid samples were investigated and both authors explained this phenomenon by the influence of two different components. On the other hand, such a phenomenon has also been observed not only for hybrid textiles but also for woven polyester fabrics [15]. The investigations of other authors show that the results of residual relaxation as well as the behaviour of textile at the time of relaxation depend not only on the conditions of experiments (level and speed of deformation etc.), which is very well known in research, but also on the various parameters of the textile structure [7]. This means that it is impossible to use the experimental results of investigations of one kind of textile for the behaviour prediction of another kind of textiles.
On the basis of experiments as well as theoretical consideration an assumption can be drawn that the so called break-point is characteristic for the material from which textiles are manufactured.

In this paper we try to prove the existence of such a break-point of stress relaxation and to describe the definite time of the break-point for polyester (PET) yarns and to find a similarity (or difference) between polyester yarns and woven fabrics made from them – i.e. to find out whether

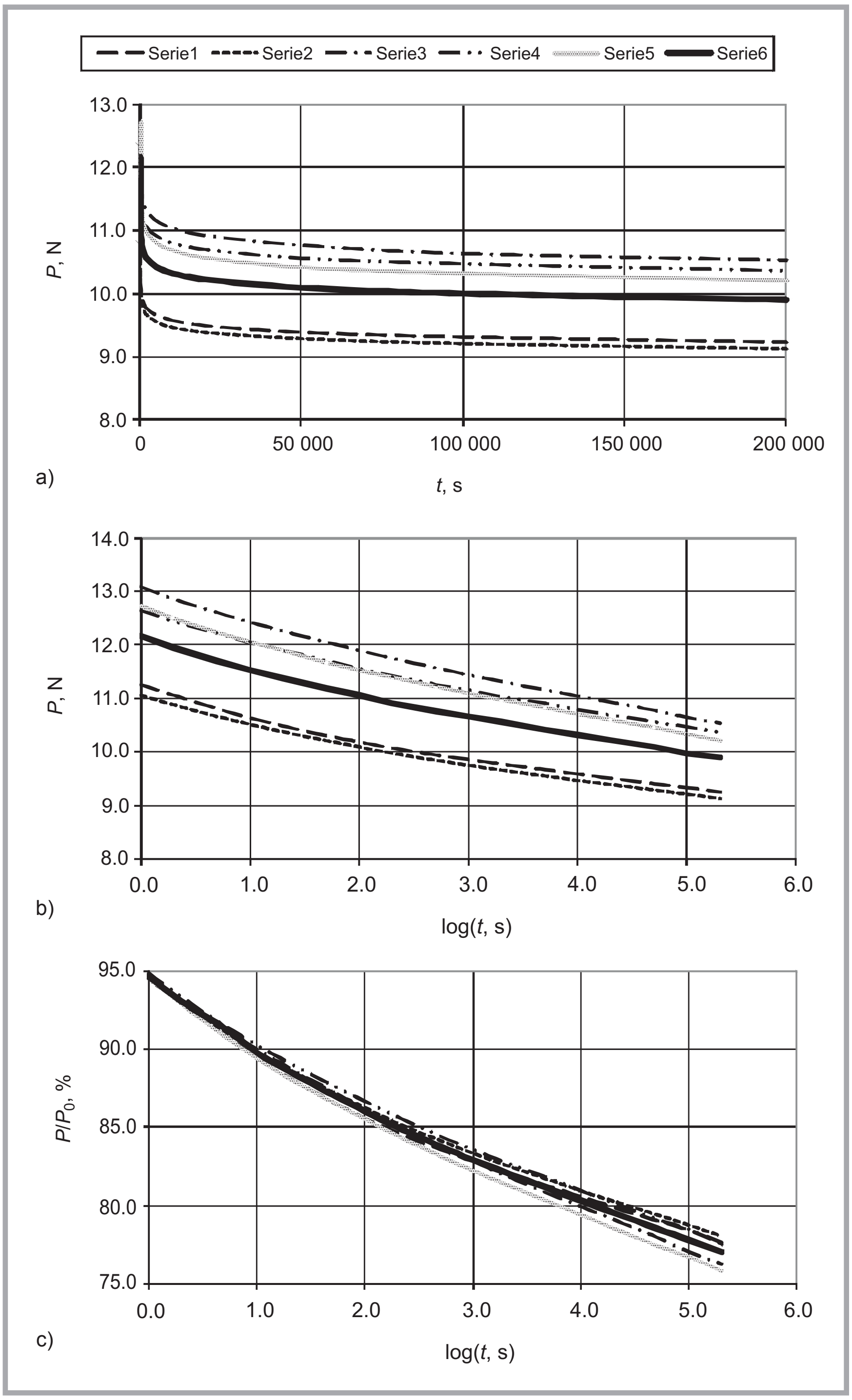

Figure 1. Stress relaxation curves of polyester yarns, a) curves in normal time scale, b) curves in logarithmical time scale, c) relative stress relaxation curves (in all Figures of Series 6 - the average curve).

the structure of the textile has an important influence on this phenomenon. Determination of the shortest time for stress relaxation tests for long-lasting stress relaxation prediction was also the goal of the present investigations. The break-point's existence and its location was determined using mathematical analysis of stress relaxation behaviour. The maximum relative error between experimental and calculated values (δ_{max}) for determination of this textile stress relaxation break-point was chosen.

Materials and methods

Polyester (poly-ethylene terephthalate - PET) multifilament 29.4 tex yarns (48 filaments, twisted 100 m^{-1}) were tested in a loading cycle. The tests were performed on a Zwick/Roell universal testing machine operated by the programme *testXpert®* at a gauge length of 500 mm, with tensile speed – 500 mm/min, and total testing time t = 200 000 s (about 55.5 h). The relaxation process of the materials was investigated by the fixed elongation method, i.e. test specimens were stretched up to 10% and stresses measured. The tests were carried out in a conditioned atmosphere of 20 ± 2 °C and 65 ± 2% relative humidity.

The stress relaxation was calculated as (P/P_0), where P_0 is the initial stress at a time of zero (t = 0) and P is the stress at subsequent times. The stress relaxation curve for a mathematical description was calculated from a series of experimental points, i.e. the stress relaxation value was measured after 1, 2, 5, 10, 20, 50, 100, 200, 500, 1000, 2 000, 5 000, 10 000, 20 000, 50 000, 100 000, 200 000 s for each curve. The curves were calculated as a related stress relaxation dependence on the logarithm of time.

By means of an earlier method presented, it was proposed to describe these experimental points with two straight lines [11]. The average curve of relaxation calculated from 5 relaxation curves was used for investigations. The related error between experimental values and those calculated by the straight line equation (δ) for all experimental points of the stress relaxation curve is calculated as:

$$\delta_i = \frac{(P/P_0)_e - (P/P_0)_c}{(P/P_0)_e} \times 100\% \qquad (1)$$

where: $(P/P_0)_e$ – experimental values of stress relaxation, $(P/P_0)_c$ – values of stress relaxation calculated by straight line equations.

The maximum related error between experimental values and those calculated by the straight line equation (δ_{max}) has been used for the investigations.

Experimental results and discussions

When a yarn or fabric is stretched at a constant rate of straining, an internal stress is set up gradually. When it is stretched to a given strain and held at the same strain, the stress decreases as time passes. The results of stress relaxation measurement under constant strain (10%) are presented in our paper. The results obtained under long-lasting relaxation (till 200 000 s) are presented in ***Figure 1***

(***1.a*** - in a normal time scale and ***1.b*** - in a logarithmical time scale).

The 6th curve is the average of the five tests of relaxation and all further calculations were made only with the average curve. As is seen from ***Figure 1.a***, the difference between the average curve and the experimental curves is not high - less than 1 N in all the processes, i.e. less than 9% from the average curve. This means that the average curve describes all experimental results very well. The shape of the relaxation process of all the tests is also very similar – no straight line in the logarithmical scale was obtained (see ***Figure 1.b***) and very close curves of relative relaxation were also attained (see ***Figure 1.c***).

As was noted earlier, the main goal of our investigations was to find the time when the process of relaxation changes, i.e. to find the time of the break-point of the relaxation rate. The relaxation process was divided into two parts – till 100 s and after 100 s (the 100 s point was chosen for both parts). The 100 s time for the break-point was also choosen in accordance with results obtained in earlier investigations of polyester woven fabrics (plain weave, 24.5 tex textured yarns in warp and weft, $S_1 = 340\ dm^{-1}$, $S_2 = 220\ dm^{-1}$) [11]. A description of the relaxation process using two straight lines is presented in ***Figure 2***.

As is seen from ***Figure 2***, two stright lines describe all relaxation processess very well; the coefficients of determination are quite high. Moreover the maximum relative error between experimental values and those calculated with one linear curve and two linear curves is much lower in the case of describing the relaxation process with two stright lines – describing with one linear curve δ_{max} = 1.48%, and describing with two linear curves δ_{max} = 0.26%. The cause of such a phenomenon can be various, one of the posible explanations for which can be changed in the macromolecular structure of the fibre material, and not due to variations in the macrostructure of textiles. It seems that this explanation is also confirmed by investigations with other kinds of textiles. Very close results were obtained earlier in an investigation of polyester woven fabrics manufactured even from another kind of yarn used in weaving, i.e. not from twisted multifilaments but from textured yarn [11]. The results obtained earlier are presented in ***Figure 3***.

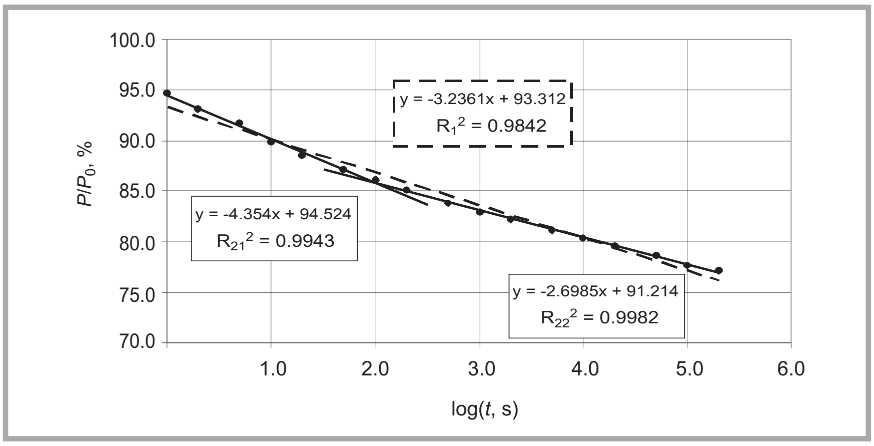

Figure 2. *Description of relaxation process of polyester yarn: 1 – described by one straight line, 2 – described by two straight lines (2_1 - line of first part (log t = 0 - 2), 2_2 – line of second part (log t = 2 - 5.3)).*

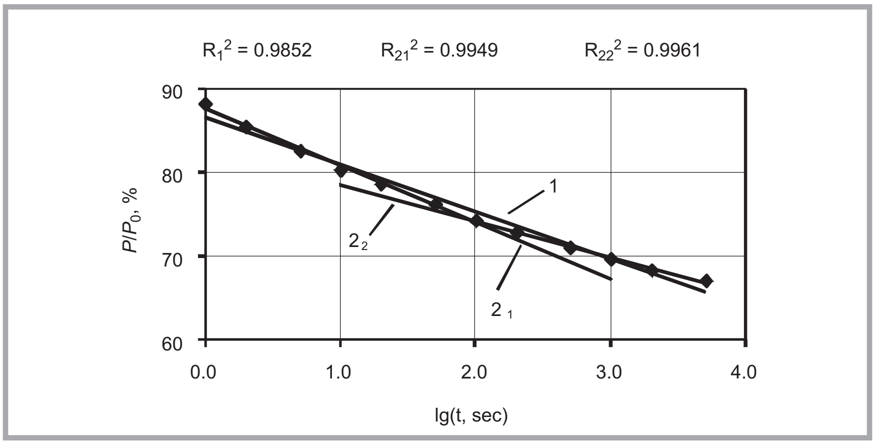

Figure 3. *Relative stress relaxation curve of polyester woven fabric: 1 –described by one straight line, 2 - described by two straight lines (2_1 – line of first part (lg t = 0 - 2), 2_2 – line of second part (lg t = 2 - 3.7))[11].*

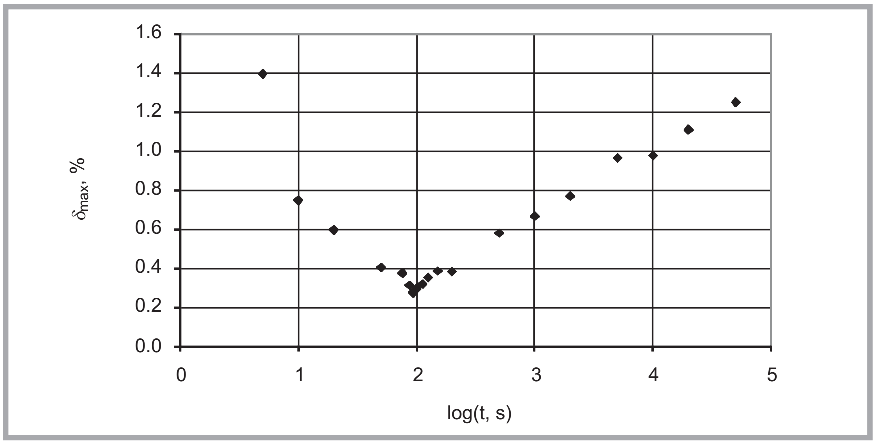

Figure 4. *Dependence of maximum relative error between experimental and calculated values (δ_{max}) for break-point selected.*

In the next step of our investigations we tried to specify the place (time) of the relaxation break-point. Additional calculations with break-points in the range of 100 s as well as in other places of relaxation were carried out. The results are presented in ***Figure 4***.

It is clearly visible from ***Figure 4*** that the lowest relative error is obtained in cases where the break-point is chosen in

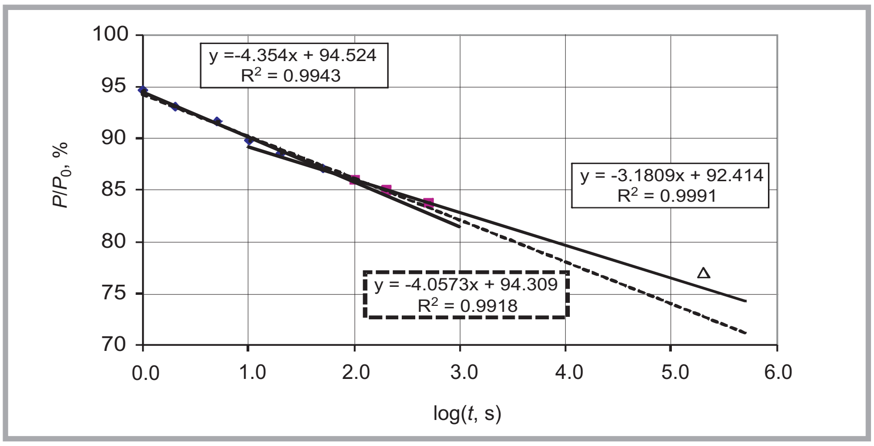

Figure 5. *Prediction of stress relaxation.*

the range of 100 s (log(t) = 2)). The best result is obtained when the break-point was chosen at 94 s, which is very close to 100 s, with differences being in the limits of errors. Thus we can say that the break-point of PET polyester yarn relaxation occurs at the same time as for woven fabrics, i.e. approximately after 100 s. Hence the structure of the textile material does not influence the place of the break-point. The same results were obtained for yarns as well as for fabrics.

In the next step of our investigations we tried to predict long-lasting relaxation results by experimental testing for a much shorter time. For this reason the experimental results only till 500 s were chosen. The relaxation process was described with two straight lines with the break-point at 100 s and without a break-point. In both cases the relative error after 200 000 s was also calculated, the results of which are presented in ***Figure 5***.

As is seen from ***Figure 5***, the maximum relative error between the experimental value and that calculated from experimental results till 500 s in the case of describing the relaxation process with two straight lines with the break-point at 100 s is much lower than in the case of predicting this value with one straight line (δ_{max} in the case of two straight lines is 1.98% and for one straight line - 5.54%). Hence it means that the method of predicting long-lasting relaxation presented, from results only till 500 s, is successful.

Conclusions

The results presented show the possibility to predict values of long-lasting relaxation after experimental investigations of a much lower time. Our experimental testing and method of describing the relaxation process with two straight lines show the existence of a break-point of the relaxation rate. This break-point for polyester (PET) textiles occurs after 100 s of relaxation. Long-lasting relaxation prediction using the method presented shows very accurate results and can be used for practical application. The results presented are valid for textiles from polyester (PET) and, of course, it does not mean that they can be used for the relaxation prediction of textiles from other polymers including other polyesters. Only after similar experimental investigations of the relaxation properties of other kinds of polymers as well as with other kinds of textiles (at first with knitted fabrics) and various structures thereof, and after a summary of all results, it will be possible to make more wider conclusions about the existence of the phenomenon of a break-point of the relaxation relations and explain how to use this phenomenon for practical application of long-lasting relaxation prediction for textiles from various raw materials. Such investigations will be the subject of our further tests. At this time we would only like to focus researches on a phenomenon which has not been analysed earlier and to show the possibility of predicting long lasting relaxations from the results of 500 s relaxations and by the method presented.

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