SETTING AND TORSIONAL RECOVERY OF NYLON MONOFILAMENT AND ITS RELATION TO STRUCTURE

INTRODUCTION

Setting has been defined as a change in the stress-free form of fiber resulting from a deformation and subsequent chemical or physicochemical treatments prior to the release of the fiber. Setting can be accomplished by the means of heat, moisture, or chemical compounds and is known as heat setting, cohesive setting, or chemical setting. Setting of thermoplastic fibers in heat and in solvents[2] has been studied by a number of research workers. Ribnick, Weigmann, and Rebenfeld[1,3] have done extensive work on the effects of solvents on the mechanical properties of polyester yarns. Polyester yarn was set in various solvents at 21°C for 16 h, but no twist was given to the specimen. Dynamic shrinkage of the polyester yarn has also been studied by these workers[3] but again without twist.

Recently, heat-setting behavior of nylon and polyester monofilaments in torsion has been investigated by Arghyros and Backer[5] and Buckley, Hearle, and Mandal,[4] who have reported an anomalous behavior of these monofilaments during heat setting. Under certain conditions when single filaments are cooled and released after heat set in torsion they are found to exhibit "over twist." Feughelman and Mitchell[7] have observed this phenomenon earlier with wool fibers after wetting and drying them and also following cystine reduction. Krause[8] has examined the torsional behavior of nylon textured yarns produced by the false twisting technique employing a method in which the rotation of a free hanging filament is noted at temperatures ranging from 20° to 200°C.

We report here results of a simple experiment in which nylon monofilament has been set in torsion under constant tension in various solvents; the results suggest that in these samples, there are many exceptions to the trend noticed by the research workers.

EXPERIMENTAL

Commercial nylon 66 drawn monofilament of 45 μm (15 den. 1.66 tex) supplied by M/s. J.K. Synthetics Ltd. was used. The procedure for twisting the nylon monofilament, setting it in various solvents, and measuring the recovery was as follows: The twisting head of the twist tester was used and the nylon monofilament was fixed to the chuck. A T-shaped vane of mass 1.6 g equivalent to a tension of 8.8 K N.m/kg (0.1 gf/den) was fixed to the lower end of a 100-mm length of nylon monofilament with the T vertical. The rotation of T vane was arrested while twisting by inserting two forks. The twisting head was rotated at a constant rate, namely, 1 radian/cm/s to give twist in the cold state. This was done with a view to ensuring that the magnitude of shear strain provided was identical to all the specimens. Twist was imparted in the specimen by arresting the rotation of each arm of the T vane by passing the forks through it.

Setting of the cold-twisted nylon monofilament was accomplished by moving a measuring cylinder containing the required solvent upward such that the fork, T vane, and filament were all immersed in it for 300 s. Ten tests were carried out for each specimen for a particular level of twist and solvent.

Recovery after setting the nylon monofilament was measured by raising the forks to release the T vane and measuring the rotation of the vane by a protractor concentric with the specimen. Oscillations due to draughts were avoided by closing the apparatus with a perspex chamber during recovery measurements.

Setting efficiency in torsion in different solvents and at different twist levels was calculated as follows:

$$\text{Setting efficiency} = \frac{N_t - N_r}{N_t} \times 100 \qquad (1)$$

where N_t = number of turns inserted, N_r = number of turns removed. This is no more than the ratio of set twist to original twist.

The contraction of the nylon monofilament following cold twisting was measured by lowering the specimen in the desired solvent contained in a measuring jar and allowing it to remain there for a period of 300 s. It was then removed and a traveling microscope was used to measure the length of the twisted nylon monofilament between the chuck of the twist tester and the tip of the T vane. Twenty readings were taken for each twist level and the mean was considered to represent the contraction of the twisted nylon monofilament in the various solvents.

The sequence of the solvent setting experiments can be summarized as follows:

a. The nylon monofilament was mounted on the chuck of the twisting head and suspended free to untwist, to remove any producers twist remaining in the spool and its length L_0 was measured.

b. The vane was arrested and the twisting head was rotated at a constant rate of 1 rad/cm/s to insert the twist in the specimen under an axial tension of 8.83 K N.m/g (0.1 gf/d) which is the weight of the vane. The new length L_1 was measured to obtain twist shrinkage.

c. The specimen was set in the desired solvent at 25°C for 300 s.

d. The nylon monofilament was removed from the solvent.

e. The T vane was released and its rotation after a period of 300 s was noted.

f. The length L_2 of the specimen was measured after setting it in the solvent for 300 s.

Twist shrinkage was measured from the following formula.

$$\text{Twist shrinkage} = \frac{L_0 - L_1}{L_0} \times 100 \tag{2}$$

where L_0 = original length of the specimen
L_1 = length after twisting
Contraction was measured by using the following formula

$$\text{Contraction} = \frac{L_1 - L_2}{L_1} \times 100 \tag{3}$$

Thus, the method followed in the measurement of torsional recovery is similar to the one used by Mandal[6] and Buckley, Hearle and Mandal.[4]

The shrinkage of the nylon monofilament was measured by inserting it under a tension of 1 g in a capillary tube of 10 cm length and of diameter slightly bigger than that of the filament. The filament projecting out is cut on both sides and the capillary tube was set in the desired solvent for 120 min.

The length of the specimen inside the capillary tube was measured and shrinkage was calculated. This, in essence, is the principle of the method followed by Lopatain.[11] Ten tests were carried out in each of the solvents.

RESULTS

Table I shows the free shrinkage of filaments in the various solvents.

The free shrinkage values are more or less in agreement with the values obtained by Rukavtsev and Smirnov.[9] The twist shrinkage has been found to follow the pattern as obtained by Buckley, Hearle, and Mandal[4] and Zurek et al.[10] and not the trend noticed by Arghyros and Backer.[5]

Table II shows the setting efficiencies of nylon monofilament in the various solvents. It will be noted that the setting efficiencies of nylon monofilament are maximum in phenol and minimum in hydrochloric acid; values of intermediate setting efficiencies have been observed with formic acid and sulfuric acid. The increase in setting efficiencies in phenol can be attributed to an increase in crystallinity and plasticizing effect, as evidenced from Table III. It may be noted that the setting efficiency in torsion is almost constant at all twist levels in a particular solvent. It is also interesting to note that in no case was the setting efficiency higher than 80%; in other words, the anomalous behavior noticed by Buckley et al.[4] and Arghyros and Backer[5] has not been observed.

TABLE I
Free Shrinkage of Nylon Monofilament

S. No.	Solvent used	Original length mm	Length after setting for 120 s	Shrinkage %
1.	Phenol 3%	100	87.00	13.00
2.	Formic acid 30%	100	91.30	8.70
3.	Sulfuric acid 14%	100	92.80	7.20
4.	Hydrochloric acid 8%	100	93.75	6.25

TABLE II
Setting Efficiencies and Contraction of Nylon Monofilament Twisted to Various Levels and Set in Solvents

S. No.	Solvent	No. of turns inserted in 100 mm of yarn (N_t)	No. of turns removed (N_r)	Contraction after 5 min (mm)	Setting efficiency $\dfrac{\text{Set twist} \times 100}{\text{Original twist}}$ $\dfrac{(N_t - N_r)}{N_t} \times 100$
1.	Phenol (3%)	10	1.85	0.65	81.50
		20	5.00	0.87	75.00
		40	10.00	0.77	75.00
		80	19.00	0.70	76.00
		120	30.00	0.45	75.00
		160	43.00	0.40	73.00
		200	47.80	0.20	76.00
		> 200	—	—	—
2.	Formic acid (30%)	10	4.60	0.55	54.00
		20	8.50	0.90	57.00
		40	13.40	0.73	66.00
		80	26.00	0.50	67.00
		120	38.00	0.45	68.00
		160	52.00	0.35	67.00
		200	65.00	0.25	67.00
		240	77.00	0.15	67.00
		> 240	—	—	—
3.	Sulfuric acid (14%)	10	8.00	0.35	20.00
		20	15.80	0.62	21.00
		40	31.00	0.50	22.00
		80	61.90	0.38	23.00
		120	92.30	0.20	23.00
		140	105.00	0.12	25.00
		> 140	—	—	—
4.	Hydrochloric acid (8%)	10	8.50	0.30	15.00
		20	16.70	0.50	16.00
		40	33.00	0.39	17.00
		80	64.50	0.28	19.00
		120	100.50	0.19	16.00
		> 120	—	—	—

TABLE III
Density and CDT Values of Treated Materials

	Density g/cc	CDT/s
Untreated	1.14	13.0
Treated in phenol 3%	1.20	19.5
Treated in formic acid 30%	1.18	18.1
Treated in sulfuric acid 14%	1.15	16.0
Treated in hydrochloric acid 8%	1.13	14.2

The contraction percentage of the filament shows that it is very low; an interesting trend noticed is that it is maximum at a twist level of 20 turns/100 mm in all the solvents and then shows a gradual fall and above a certain twist level there is no shrinkage. The twist level beyond which the shrinkage is nil or the same length has been obtained seems to depend upon the kind of solvents used. For instance, it is above 200 in respect of phenol, 240 in the case of formic acid, 140 in the case of sulfuric acid, and 120 in the case of hydrochloric acid and it appears that the reduction in contraction percentage above 20 turns per 100 mm is partly due to creep of the filament due to the axial tension of 8.83 K N.m/kg (0.1 gf/den) which is the weight of the vane. The contraction percent is equivalent in formic acid and phenol and minimum in hydrochloric acid. It is pertinent to note that Alexander and Sturley[12] have found that the breaking extension of the 15 denier nylon monofilament is effectively constant over the range of twists 3/4 to 70 t.p.i. (i.e., from 3 turns/100 mm to 280 turns/100 mm). Hence, there are strong grounds to believe that creep should be the principal reason for the increase in contraction up to 20 turns and a reduction thereafter.

Further experiments are conducted in different modes of deformation such as bending and bending-cum-torsion and the results will be reported later.

References

1. A. S. Ribnick, H. D. Weigmann, and L. Rebenfeld, *Text. Res. J.*, **42**, 720 (1972).
2. A. B. Deasai and G. L. Wilkes, *J. Polym. Sci.*, **46**, 291 (1974).
3. A. S. Ribnick and H. D. Weigmann, *Text. Res. J.*, **43**, 316 (1973).
4. C. P. Buckley, J. W. S. Hearle, and R. Mandal, *J. Text. Inst.*, **76**, 264 (1985).
5. S. Arghyros and S. Backer, *Text. Res. J.*, **52**, 295 (1982).
6. R. Mandal, Ph.D. Thesis, UMIST, 1976.
7. M. Feughelman and T. W. Mitchell, *Text. Res. J.*, **39**, 1162 (1969).
8. H. W. Krause, *Bulk, Stretch, Texture*, Textile Institute, (1966).
9. G. I. Rukavtsav and L. S. Smirnov, *Legka i Tekstilnaya Promyshlennost*, **3**, 33 (1969).
10. W. Zurek, R. Cislo, and E. Kowalska, *Text. Res. J.*, **46**, 389 (1976).
11. G. Lopatain, *J. Appl. Polym. Sci., Appl. Polym. Symp.*, **31**, 127 (1977).
12. F. J. Alexander and C. H. Sturley, *J. Text. Inst.*, **1**, 43 (1952).

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