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Effect of add-on finish and process variables on recovery properties of jet-spun polyester yarns

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The influence of add-on finish and process variables on the recovery properties of jet-spun polyester yarns has been studied using the Box-Behnken design. It is observed that the add-on finish plays a key role in determining the immediate elastic recovery of jet-spun polyester yarns which tends to increase with the increase in level of add-on finish. Immediate elastic recovery hardly alters with spinning speed but it increases significantly with the increase in both first nozzle pressure and main draft. Both delayed elastic recovery and permanent set, on the other hand, invariably decrease with increasing main draft, and are considerably lower for the yarns spun with higher add-on finish than for the yarns spun without finish. An increase in spinning speed increases the permanent set but adversely affects the delayed recovery.

Keywords : Add-on finish, Air-jet spinning, Elastic recovery, Nozzle pressure, Polyester yarn

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1 Introduction

The tensile properties of jet-spun yarns are dependent on their structures. These are determined in a complex manner by the properties of raw materials and process parameters used. Yarns are subjected to stress, especially elongation of low magnitude, in the preparatory stages of weaving. Besides, yarns experience repeated small strains in the course of handling and are also subjected to rupture under high stress. The suitability of a jet-spun yarn during mechanical processing depends decisively on its ability to recover from strains. As a consequence, the elastic recovery and its variability is becoming an increasingly important factor for adequate functioning of yarns during post-spinning operations and for long-term storage. Though many studies on jet-spinning process have been performed with a view to provide some insight into the dependency of yarn properties on important process parameters and structural modifications to the nozzle[1-6], information with regard to the relation between recovery properties and processing factors is scanty. The behaviour of jet-spun polyester yarns at repeated application of small strain was, therefore, thought to be worth investigating. The present work was aimed at investigating the influence of four process variables, namely level of add-on finish, first nozzle pressure, main draft and spinning speed, on the recovery properties of MJS yarn with the help of Box-Behnken design.

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2 Materials and Methods

2.1 Preparation of Yarn Samples

Polyester staple fibres (length, 44 mm; fineness, 1.55 dtex; tenacity, 43.80 cN/tex; and breaking extension, 26.81 %) were hand opened and separated into three lots of 10 kg each. Fibre finish LV40 was dissolved in water and sprayed as uniformly as possible on two lots of polyester without extracting the original fibre finish. Two different add-on spin finish levels, viz. 0.08% and 0.16% (owf), were used. The conversion to drawn sliver was carried out by using a MMC carding machine and a Lakshmi Rieter's draw frame DO/2S. Three drawing passages were given and the linear density of finisher sliver was adjusted to 3.1 ktex for all the samples. The slivers were spun into 14 tex yarns on air-jet spinner 802MJS operating under normal mill conditions. As per the Box-Behnken design, the experimental combinations of the four variables were chosen. The four variables and their coded levels are shown in Tables 1 and 2 respectively. The other process parameters, namely second nozzle pressure, feed ratio, and the distance between the first nozzle and the nip of front roller, were kept constant at 3.5 kg/cm^2, 0.98 and 39.5mm respectively.

Table 1–Experimental plan for selected variables

Experimental combination No.	X_1 (Add-on spin finish)	X_2 (First nozzle pressure)	X_3 (Main draft)	X_4 (Spinning speed)
S_1	-1	-1	0	0
S_2	+1	-1	0	0
S_3	-1	+1	0	0
S_4	+1	+1	0	0
S_5	-1	0	-1	0
S_6	+1	0	-1	0
S_7	-1	0	+1	0
S_8	+1	0	+1	0
S_9	-1	0	0	-1
S_{10}	+1	0	0	-1
S_{11}	-1	0	0	+1
S_{12}	+1	0	0	+1
S_{13}	0	-1	-1	0
S_{14}	0	+1	-1	0
S_{15}	0	-1	+1	0
S_{16}	0	+1	+1	0
S_{17}	0	-1	0	-1
S_{18}	0	+1	0	-1
S_{19}	0	-1	0	+1
S_{20}	0	+1	0	+1
S_{21}	0	0	-1	-1
S_{22}	0	0	+1	-1
S_{23}	0	0	-1	+1
S_{24}	0	0	+1	+1
$S_{25\text{-}31}$	0	0	0	0

2.2 Tests

The recovery parameters of the yarns were determined using an Instron tensile tester (model 4411) according to ASTM D1774-79 procedure. The immediate elastic recovery (IER), the delayed elastic recovery (DR), and the permanent deformation (PS) were obtained for an initial extension level of 4%. Thirty observations were taken for each yarn sample. For each yarn sample, 500 mm long specimens were elongated at a extension rate of 200 mm/min. The yarn was extended up to a predetermined level 'B' and immediately retracted up to level 'O', the origin via point 'G' on tex/2g load line. After allowing the yarn to relax for 3 min, it was again extended till it crossed the tex/2g load line at point 'F'. Fig. 1 shows

Table 2–Variables and there levels used in experimental plan

Variable	Coded level -1	Coded level 0	Coded level +1
Spin finish (X_1), %	0	0.08	0.16
First nozzle pressure (X_2), kg/cm^2	2	2.5	3
Main draft (X_3)	30	35	40
Spinning speed (X_4), m/min	160	180	200

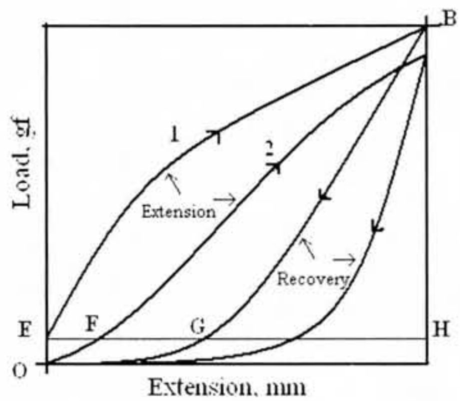

Fig. 1 – Load-elongation curves

the evolution of the tests. Recovery components were calculated from the following expressions :

$$IER = [GH / EH] \times 100$$
$$DR = [FG / EH] \times 100$$
$$PS = [EF / EH] \times 100$$

where E, F, G and H are the points shown in Fig. 1.

3 Results and Discussion

The test results were analysed using SYSTAT 10. The response surface equations for each recovery property were obtained. The response surface equations along with the calculated F-values and the correlation coefficients are given in Table 3.

3.1 Immediate Elastic Recovery

Relationships between the processing parameters and the immediate elastic recovery of jet-spun polyester yarns are shown in Fig. 2. Generally, the higher the add-on finish, the higher is the immediate elastic recovery. The observed trend is the expected consequence of the increased inter-fibre friction between the core fibres caused by higher add-on finish, which, in turn, restricts the slippage of fibres[7]. With increased first nozzle pressure, the number of wrapper fibres increases. Consequently, radial pres-

Table 3–Response surface equations[a]

Recovery property	Response surface equation	Correlation coefficient	Calculated F-ratio	Standard error
Immediate elastic recovery, %	$52.876+1.938X_1+0.998X_2+2.561X_3-1.331X_4+0.83X_1^2+0.572X_2^2-0.883X_3^2-1.118X_4^2$	0.918	30.892	0.856
Delayed elastic recovery, %	$18.509-0.639X_1-1.031X_2-1.037X_3-1.108X_4+0.964X_3^2+0.436X_4^2$	0.865	25.647	0.587
Permanent set, %	$28.623-1.298X_1-1.524X_3+2.439X_4-0.814X_1^2-0.686X_2^2+0.68X_4^2$	0.884	30.558	0.848

[a]Only significant terms considered (99% level of confidence)

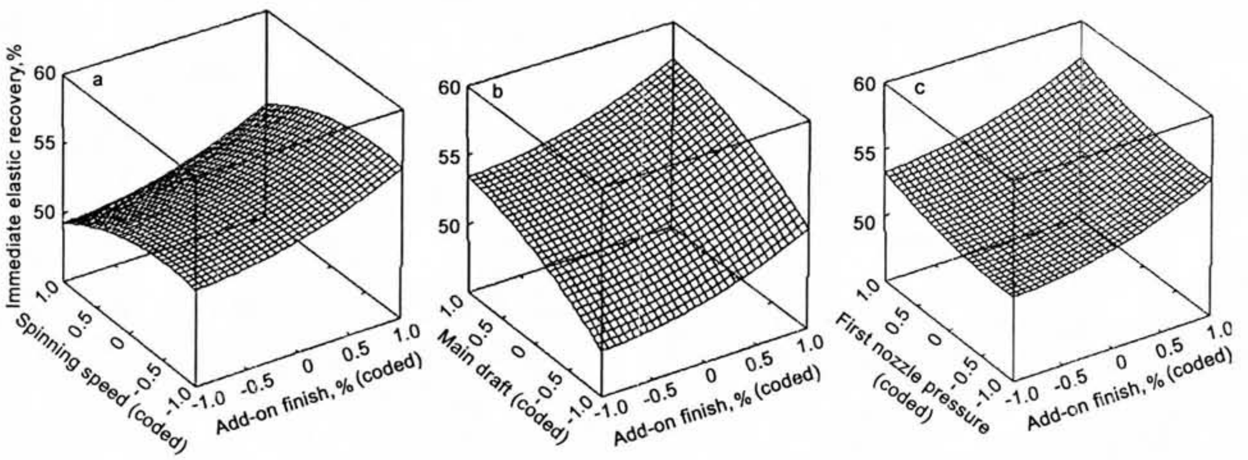

Fig. 2 – Effect of add-on finish and process variables on immediate elastic recovery

pressure on the core fibres also increases, leading to higher immediate elastic recovery. Higher immediate elastic recovery with increased first nozzle pressure has already been reported[8].

Fig. 2 shows that at higher levels of add-on finish and first nozzle pressure, a positive interaction exists between these variables, affecting immediate elastic recovery. Immediate elastic recovery is markedly higher when both these variables are higher. The main draft is another factor influencing immediate elastic recovery. As may be seen from Fig. 2 (b), the use of higher main draft leads to higher immediate elastic recovery; the increase in immediate elastic recovery is however noticeable at all levels of add-on finish. Very high levels of spinning speed do not increase immediate elastic recovery significantly rather they result in decreased immediate elastic recovery.

3.2 Delayed Elastic Recovery

The F-ratio, coefficient of correlation and response surface equation for delayed elastic recovery are given in Table 3. The correlation coefficient of 0.865 indicates good correlation between the process variables and the delayed elastic recovery. The spatial diagrams of the response surface are given in Fig. 3. It is apparent that the yarns produced with 0.16% add-on finish exhibit lower delayed elastic recovery than the yarns made without adding finish. As regards the delayed elastic recovery of yarns at different levels of first nozzle pressure, it is observed that the higher first nozzle pressure leads to a lower delayed elastic recovery. On increase in spinning speed, the delayed elastic recovery decreases for all levels of add-on finish. Delayed elastic recovery also decreases consistently with the increase in main draft up to 35 and then it stays constant.

3.3 Permanent Set

Fig. 4 shows the interaction effect of different process variables and the add-on finish on permanent set. In general, for jet-spun polyester yarns, there is higher permanent set around the intermediate level of first nozzle pressure. This is attributed to the fact that the optimum wrapping length would be achieved at

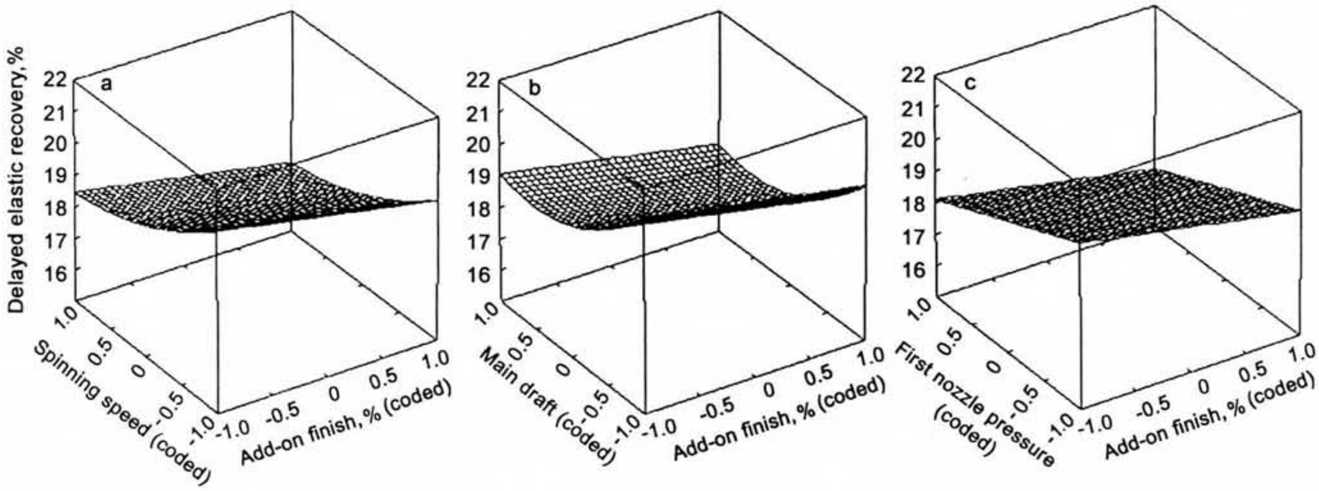

Fig. 3 – Effect of add-on finish and process variables on delayed elastic recovery

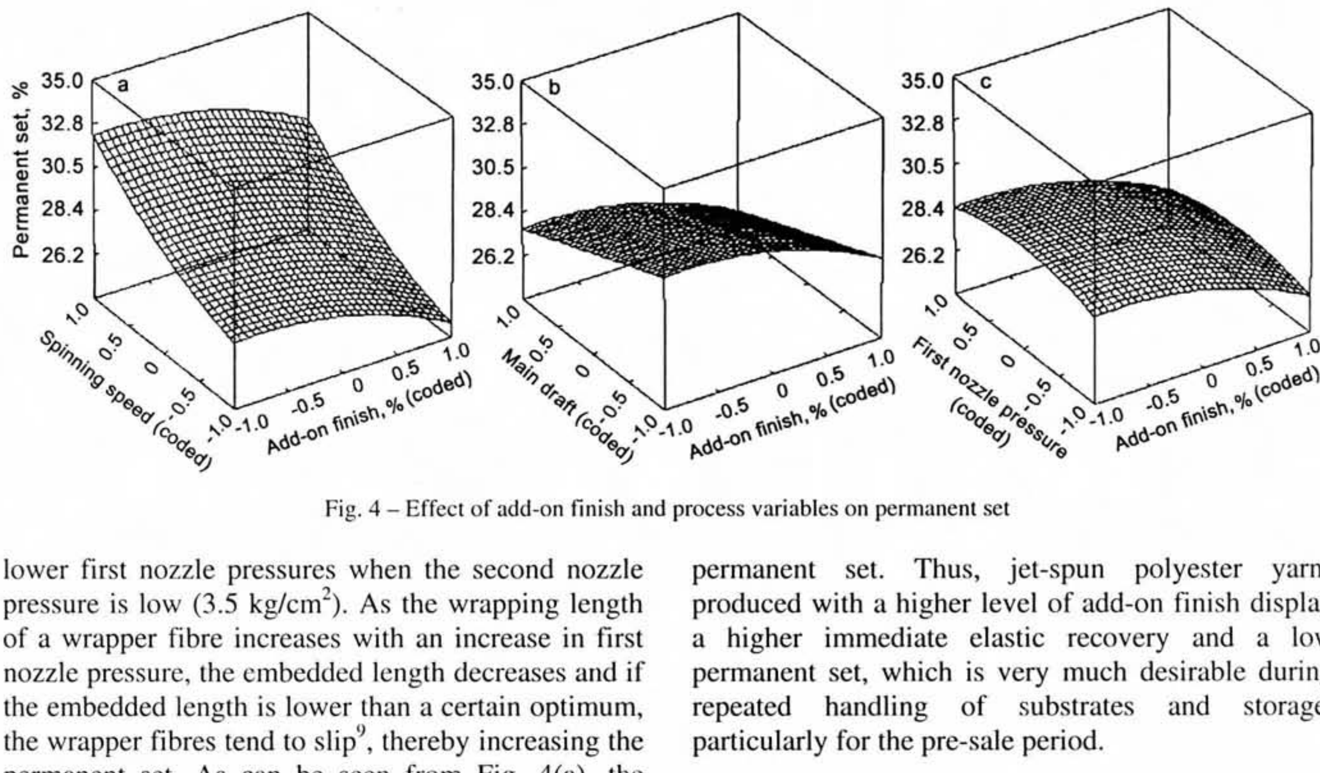

Fig. 4 – Effect of add-on finish and process variables on permanent set

lower first nozzle pressures when the second nozzle pressure is low (3.5 kg/cm^2). As the wrapping length of a wrapper fibre increases with an increase in first nozzle pressure, the embedded length decreases and if the embedded length is lower than a certain optimum, the wrapper fibres tend to slip[9], thereby increasing the permanent set. As can be seen from Fig. 4(a), the minimum permanent set is observed at 160 m/min spinning speed and it increases as the spinning speed is increased to 180 m/min.

The data show a sizeable decrease in permanent set with the increase in level of add-on finish. This behaviour is the outcome of higher fibre-to-fibre friction. The fibre-to-fibre friction, which effectively reduces the slipage of core fibres, increases with the increase in level of add-on finish, resulting in a lower permanent set. Thus, jet-spun polyester yarns produced with a higher level of add-on finish display a higher immediate elastic recovery and a low permanent set, which is very much desirable during repeated handling of substrates and storage, particularly for the pre-sale period.

4 Conclusions

4.1 Within the experimental range of process variables considered, the add-on finish markedly affects the immediate elastic recovery of jet-spun polyester yarns, which tends to increase with the increase in level of add-on finish. Immediate elastic recovery shows no significant change with the change in spinning speed but it increases considerably with the increase in both first nozzle pressure and main draft.

4.2 Delayed elastic recovery decreases initially when the main draft increases from 30 to 35 and it stays constant thereafter as the main draft is further increased to 40. Higher add-on finish, spinning speed and first nozzle pressure result in lower delayed elastic recovery.

4.3 With first nozzle pressure, the permanent set reflects no consistent trend. On the other hand, the permanent set is considerably higher in the yarns spun with higher spinning speed and it continues to decrease with the increase in main draft. For same spinning speed and main draft, when the add-on finish increases, the subsequent result is a decrease in permanent set.

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