Pawan Kumar, Sujit Kumar Sinha and Subrata Ghosh
Department of Textile Technology, National Institute of Technology, Jalandhar-144011, Punjab, India

Elastic Performance Coefficient and Recovery of Modified Polyester/Polyvinyl Alcohol Ring Spun Yarn

Koeficient elastične učinkovitosti in elastični povratek modificirane poliester/polivinil alkoholne prstanske preje

Original Scientific Article/*Izvirni znanstveni članek*
Received/*Prispelo* 10-2014 • Accepted/*Sprejeto* 11-2014

Abstract
The structural modification of yarn is opening up new fields of application. In the present study, the structure of polyester/polyvinyl alcohol (PVAL) blended ring spun yarns was modified with a dissolution of PVAL, while the yarns were prepared using various percentage of the PVAL fibre. The elastic recovery and elastic performance coefficient (EPC) were measured before and after the dissolution of PVAL for a comparative assessment. Fibre fineness and twist multiplier were also selectively altered to study the effect. The experiments were carried out to study the elastic recovery at 2% and 4% extension, while EPC was calculated using 30% and 50% of breaking load of respective yarns. The t-test result confirmed some significant difference in EPC and recovery behaviour of the yarns on modification through the removal of PVAL. Fibre fineness and applied twist were found to influence the behaviour. Modified yarns were found to exhibit improved elastic recovery properties.
Keywords: elastic recovery, elastic performance coefficient, polyester and PVAL fibres, ring spun yarn

Izvleček
Spremembe v strukturi preje odpirajo nove možnosti uporabe. V raziskavi smo strukturo prstanske preje iz mešanice vlaken poliester/polivinil alkohol (PVAL) modificirali z odtopitvijo PVAL-a, pri čemer so preje vsebovale različen odstotek PVAL vlaken. Elastični povratek in koeficient elastične učinkovitosti sta bila za primerjavo izmerjena pred in po odtapljanju PVAL-a. Da bi preučili učinek, smo spremenili tudi finočo vlaken in koeficient vitja. Za preučitev elastičnega povratka so bili poizkusi izvedeni pri 2- in 4-odstotnem raztezku, medtem ko je bil koeficient elastične učinkovitosti izračunan pri uporabi 30 % in 50 % pretržne obremenitve prej. Rezultati t-testa so potrdili znatne razlike v koeficientu elastične učinkovitosti in elastičnem povratku prej, ki so bile modificirane z odstranitvijo PVAL-a. Ugotovljeno je bilo tudi, da finoča vlaken ter koeficient vitja vplivata na elastično obnašanje prej. Modificirane preje so imele izboljšane vrednosti elastičnega povratka.
Ključne besede: elastični povratek, koeficient elastične učinkovitosti, poliesterna in PVAL vlakna, prstanska preja

1 Introduction

The structure of a spun yarn governs its mechanical properties. Any structural change leads to a change in its properties [1] and expected to widen its scope of application. Structure of a yarn can be modified during and/or post manufacturing process. Such modification can be brought about either by mechanical or by chemical process or by combination of the processes. One of the ways of post manufacture modifications can be a suitable treatment. Such modification in yarn structure not only changes the aesthetic properties but strongly influences other physical and mechanical properties of the yarn and

Corresponding author/*Korespondenčni avtor:*
PhD Sujit Kumar Sinha
E-mail: sinhask@nitj.ac.in

DOI: 10.14502/Tekstilec2014.57.264–272

in the products made out of it. Textile products are generally subjected to stress and strain of repetitive nature and such modification may affect its time dependent behaviour or even influence the useful life. The mechanical failure of a material as a result of repeated loading and unloading occurs if the structure is incapable of absorbing and dissipating the imparted energy without the occurrence of failure as either a permanent deformation or an actual rupture of the components, depending upon the end-use requirement [2].

The elastic recovery plays a special role as one of the mechanical properties of yarn [3]. It is a time-dependent phenomenon, which is not only dependent on the structure but also on the duration, level of stress and level of strain on which the material is subjected to. The longer it is held at a given extension, the lower is the level of recovery [4, 5]. Both shape retention and durability of a textile material are likely to be affected due to the repetitive nature and level of applied stress causing delayed elastic and plastic after effects.

The ability of a material to retain its original properties after repeated use, hence the reproducibility of stress-strain properties exhibited by a material following cyclic loading and unloading is very important and is defined as its elastic performance. Precisely, the degree to which any material duplicates perfectly elastic material has been termed as elastic performance coefficient. The elastic performance coefficient reflects the effect of immediate-elastic recovery, primary-creep, and secondary-creep deflections [6, 7]. High immediate elastic recovery at low average tensile strain is an important property in determining the crease recovery of the fabric. Sett [8] has shown the yarn compactness, fibre orientation and fibre mobility/rearrangement to be the key factors in governing viscoelastic behaviour and elastic recovery of jute blended yarn. Chattopdhyay [9] reported that a yarn with poor structural integrity consumes less energy during deformation and accordingly the recoverable energy is also less.

A low recovery and high permanent set for air jet spun yarn while higher recovery and less permanent set for ring yarn compared to rotor spun yarn was reported by Tyagi [10, 11]. A significant effect of add on finish on recovery properties for air jet spun yarn was also reported by Tyagi [12]. Guthrie [13] while studying elastic recovery of viscose rayon fibres have found its dependence on the time of applied extension and on the time allowed for their recovery. A higher delayed elastic recovery for rotor spun yarn while higher permanent set for MJS yarn was reported [14]. Manich [15] reported fibre orientation in yarn structure to result better elastic characteristics and higher permanent set.

With the removal of one component in a blended yarn, elastic behaviour is expected to be decisively changed with possible internal structural modifications. Such removal is expected to influence moisture management behaviour and likely to alter the mechanical characteristics of yarn.

In the present study, an attempt has been made to study the effect of structural modification through removal of one component on the recovery behaviour of blended yarns.

2 Materials and methods

2.1 Material

The detail of material and process is given in Table 1. Yarn was spun on cotton spinning system while the blending of fibres was done at blow room to ensure homogeneity in mixing.

Table 1: Material preparation

Material and process	Fibre and process parameters
Fibre specifications	PET(1.0, 1.2 and 1.4 den, 38 mm length) and PVAL (1.4 den, 38 mm length)
Blend ratio	80/20, 85/15, 90/10
Resultant yarn count after dissolution	17.4 tex [With 23.9(2.5#), 28.2(3.0) and 33.5 (3.5) TM in turn per cm x tex$^{1/2}$]
Dissolution of PVAL	0.5% formic acid, 90 °C temp., for 60 min., followed by hot wash
Conditioning of sample	27±2 °C, 65% ± 5% RH

TM in turns per inch/$N_e^{1/2}$

The yarns were divided into two groups. One of the groups was taken for treatment to remove PVAL and will be referred as modified yarn. The parent yarn and the modified yarn after dissolution of PVAL are designated as X and Y yarn respectively. Though dissolution of PVAL renders the yarn to virtually a homogenous yarn but in the discussion both the yarns will be referred as blended yarn.
Factorial design used to prepare the sample is given in Table 2. Twenty seven types of yarns were prepared for the study.

Table 2: Full factorial design with different factors and levels

Factors	Levels		
Polyester fibre denier	1.0	1.2	1.4
% PVAL in blend	10	15	20
TM	2.5	3.0	3.5

2.2 Testing methods

Conditioning and mass irregularity
The yarns were conditioned at a tropical atmosphere of 27 ± 2 °C and at 65 ± 5% RH. The mass irregularity was measured using UT-3 evenness tester and was found to lie between 11.5 to 12.4% (cut length of 1 mm).

Elastic recovery
The recovery parameters of yarns were determined following ASTM D1774-79 standard [16]. The immediate elastic recovery (IER), delayed elastic recovery (DER), and permanent set (PS) together representing elastic recovery behaviour were obtained at two extension levels of 2% and 4%. Thirty observations were taken for each yarn sample to get result at 95% confidence limit. A typical extension recovery curve is shown in Figure 1. The yarn was extended up to a predetermined level 'G' and immediately retracted up to 'O', the origin though point 'C' on tex/2 g load line. After allowing the yarn to relax for 3 min, it was again extended till it crossed the tex/2g load line at 'B'. Recovery parameters were calculated from the following equations:

$$IER = \frac{CD}{AD} \times 100, \quad DER = \frac{BC}{AD} \times 100,$$
$$PS = \frac{AB}{AD} \times 100 \qquad (1)$$

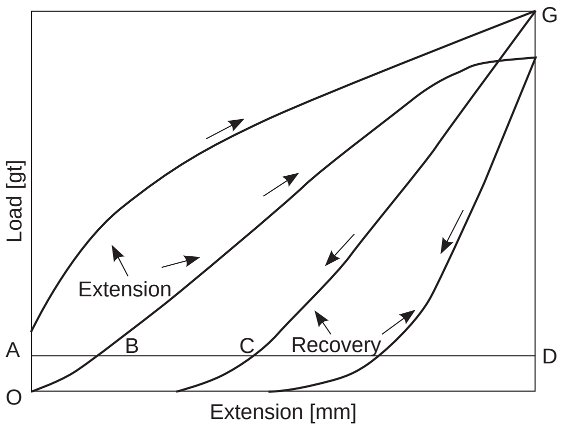


Figure 1: Evaluation of elastic recovery components

Elastic performance coefficient
In order to calculate EPC, the yarns were subjected to 10 cycles of loading on Zwick UTM. A traverse rate of 120 mm/min was used while two levels of conditioning loads, viz; 30% and 50% of average breaking load of respective yarns were used. A typical repeated load-deflection diagram (initial and conditioned cycles) is shown in Figure 2. On the basis of the diagram [6] EPC was calculated by using the following equation:

$$EPC = \frac{a_c^2 A_{Rc} A_{L0}}{a_0^2 A_{Lc}^2} \qquad (2)$$

where A_{L0} is area under loading curve of 1st cycle, A_{Lc} is area under loading curve of last cycle, A_{Rc} is area under unloading curve of last cycle, a_0 is deflection length of loading curve of 1st cycle and a_c is deflection length of unloading curve of last cycle.

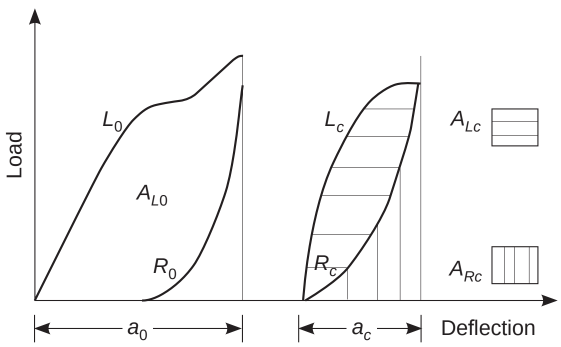
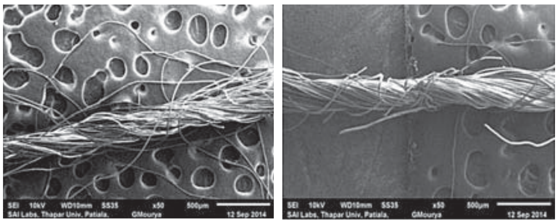


Figure 2: Load deflection diagram of initial and conditioned cycle

3 Results and discussion

3.1 Observed structural changes

In order to study the changes in the structure scanning electron microscope (SEM) images of both X and Y yarns were taken. Typical SEM images are given in Figure 3.



a b

Figure 3: Scanning electron microscope images: a – a modified yarn after dissolution of PVAL (Y yarn); b – the parent yarn (X yarn)

Following observations are made from the images:

a) the removal of PVAL has led to a reduction in the diameter of the yarn,
b) the angle of helix has reduced,
c) voids have been generated within the structure thereby causing slackness in fibres.

The reduction in diameter, helix angle and generation of voids can significantly alter the arrangement and configuration of fibres in the structure. Such a change not only expected to change the inter fibre cohesion but also the stress distribution pattern in the constituent fibres whenever the structure is subjected to loading.

3.2 Statistical treatment

A pair wise t-test for the results was carried out. The result at 95% confidence limit is given in Table 3.

3.3 Mechanisms of recovery in staple yarn

A material which offers good immediate elastic recovery can contribute to crease resistance, wrinkle resistance, fatigue resistance and finally can provide better comfort characteristics [17]. Elastic recovery represents recovery of the material on withdrawal of load and when a staple fibre yarn is subjected to loading its elastic recovery on withdrawal of load is expected to be influenced by:

a) the property of constituent fibres,
b) composition and arrangement of fibres in the yarn,
c) frictional characteristics of the constituent fibres,
d) fibre packing and hence compactness and inter-fibre cohesion,
e) ability of structure to maintain its integrity,
f) imperfections including voids and looseness in the structure.

When one component of a blended yarn is removed, it is expected to influence most of the factors cited above. Accordingly, the effect is expected to be reflected in the tensile recovery properties

Table 3: t-test result of X and Y for elastic recovery and EPC

Factors	Properties	IER		DER		PS		EPC	
	Treatment Levels	2%	4%	2%	4%	2%	4%	30%	50%
Fibre denier	1.0	s	ns	s	ns	ns	ns	ns	ns
	1.2	s	ns	s	ns	ns	ns	s	ns
	1.4	ns	ns	s	ns	ns	ns	ns	ns
Blend (%)	10	s	ns	ns	ns	ns	ns	ns	ns
	15	ns	ns	ns	ns	ns	ns	ns	ns
	20	ns	ns	ns	ns	ns	ns	s	ns
TM	2.5	s	ns	s	ns	ns	ns	s	ns
	3.0	ns	ns	s	s	ns	ns	s	ns
	3.5	ns	s	ns	s	ns	ns	ns	ns

Legend: s-significant, ns-non significan as well. When load is applied in a yarn, the stress will develop in it due to the stretching of constituent fibres. The level of stress and its distribution in individual fibres, however, may be influenced by the radial position of fibre and its arrangement and configuration in the structure. Removal of component is likely to change the radial position of a fibre due to its freedom of radial movement in the structure.

When a load is applied, the extension in a yarn may occur due to one or more of the following reasons:

a) straightening of the fibre,
b) stretching of individual fibres and their eventual breakage,
c) slippage of individual fibre.

The generation of stress and level of induced strain energy will depend on the mechanism involved in the extension of the yarn. Slippage and breakage of fibres lead to irrecoverable extension, though straining of constituent fibres will help the structure to recover due to induced strain energy. In case of fibre breakage, a loss in strain energy is imminent. Accordingly the structure cannot recover to its original length. Similarly extension due to slippage of fibre is also irreversible and causes loss in energy.

The ability of a material to recover is dependent on its capability of absorbing energy imparted through application of stress and of releasing this energy on removal of the stress without causing any major structural changes in the yarn viz; geometric and inherent.

Geometric changes refer to the changes which do not cause translation of the component fibre, while the inherent change refers to the locational change of the constituent fibres [6]. In the former case, the system can use the elastic energy to regain its original position while in the later, translation of fibre causes loss in energy and hence it cannot come back to its original position.

The deformation which takes place due to the alteration of internal structure of material is difficult to recover. The geometric form of a material also has a definite effect on both the magnitude and distribution of applied external loads.

Elastic property depends upon the inherent elastic characteristics of fibres, yarn count, and yarn twist. Any deviation in the elastic characteristic under tensile load arises purely as a result of changes in the stress distribution amongst the fibres only because of the geometry [18, 19].

Yarn twist can also influence the distribution of stress in a yarn, as it changes the radial position and helix angle of fibres. Higher the yarn twist the greater is the fibre tension for a given load. It implies that the load on individual fibre for particular load is a function of helix angle. The distribution of stress (f) has been given by the following equation [20]:

$$f = \frac{A}{1 + 4\pi^2 N^2 R^2} + \mathrm{B} \qquad (3)$$

where N is the yarn twist (turns/cm), R is the yarn radius (cm), A and B are constants, and determined from the stress strain diagram of individual fibre.

3.4 Elastic recovery

Immediate Elastic Recovery

The immediate elastic recovery (IER) refers to the ability of the textile material to recover from deformation immediately on withdrawal of load and is measured by the recovered length with respect to the total extension imposed. Depending on the structure, a yarn recovers to different extent and at different speed. IER is ideally associated with displacement of the constituent fibres from their position of equilibrium and with their spontaneous and immediate return on withdrawal of load. Slackness in the structure, ensuring less resistance can help such recovery, if the loading does not cause the extension to exceed the yield point. IER will be better if the breakage and/or translation of the fibres can be prevented.

It is observed from the Figure 4 that IER of Y is always higher irrespective of level of extension, fibre fineness, blend ratio and twist multiplier. The IER of Y decreases with coarse fibre, increased blend ratio and twist multiplier.

IER increases as openness of yarn structure increases on dissolution of one component while the parent yarn X is relatively compacted. The level of stress in individual fibre on application of load will be dependent on its radial position. A fibre travelling through a longer path is already at a higher stress level. It is also possible that loading may cause extension to such fibres beyond yield point causing a reduction in IER. In a compacted structure possibility of damage to such fibre is more while in a loosened structure the possibility of damage to the fibre at same radial position is less due to the accumulation of slackness in fibre. Dissolution of PVAL led to a more open structure and additional openness provides enough space to the fibres for rearrangement in the structure. The openness may also help fibre straightening protecting them from any appreciable breakage and/or displacement. Readjustment of fibres in a loosened structure may prevent the fibre extension exceeding a limit causing loss in elastic energy. Openness in the structure can also offer less hindrance in recovery leading to higher IER.

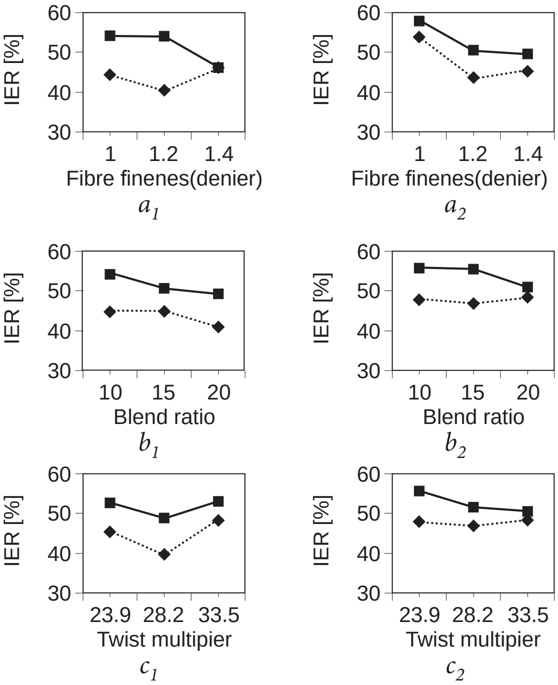


Figure 4: Effect of fibre fineness, blend ratio and twist multiplier on IER; a_1, b_1 and c_1 – IER at 2% extension; a_2, b_2 and c_2 – IER at 4% extension
X, Y

Delayed Elastic Recovery

The delayed elastic recovery (DER) refers to the ability of the textile material to recover from deformation with time. DER can be seen as hindered elastic recovery as some of the displaced fibres continue to return spontaneously for some time. After withdrawal of load the inter fibre cohesion/entanglement and stored elastic energy together can help in restoration. In an entangled and compacted mass of fibres, the mutual support can help in regaining original configuration. Such mutual interaction may even help a fibre at lower energy level to restore its original configuration. In a relatively open structure, where the inter-fibre cohesion reduces, the displaced/extended fibres get less assistance from the surrounding fibres in the recovery process. The recovery is expected to be mainly by virtue of stored elastic energy. Hence on removal of a component the increased opening of the structure does not facilitate time dependent recovery much.

It is observed from the Figure 5 that Y yarns show relatively lower DER irrespective of the level of extension, fibre fineness, blend ratio and twist multiplier. The value of DER at both extensions for Y yarns, were increased with coarser fibre and higher blend ratio, while it remains unchanged with twist multiplier at lower extension. However, at a higher extension the DER reduces with increase in twist multiplier.

On removal of a component the compactness of the structure and hence inter fibre cohesion reduces. Reduction in inter fibre cohesion does not support in time depended recovery and hence DER reduces for the modified structure (Y).

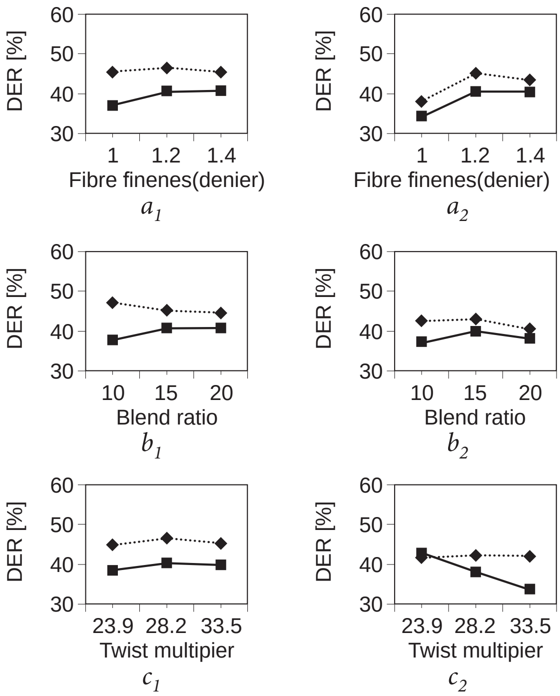


Figure 5: Effect of fibre fineness, blend ratio and twist multiplier on DER; a_1, b_1 and c_1 – DER at 2% extension; a_2, b_2 and c_2 – DER at 4% extension
X, Y

As the level of extension increases from 2% to 4%, DER of modified polyester yarn decreases for most of the cases. At small strain the developed stress in the yarn is expected to be less and hence the possible deformation in constituent fibres in the structure is also less. When the level of strain is less the extent of irrecoverable deformation is expected to be less. However, at low level of strain, the imposed strain energy in the structure and in the constituent fibres is also expected to be less which may affect DER. Accordingly, at higher strain, the amount of stress will increase and lead to higher deformation which may not be recovered even with time despite higher level of strain energy. At higher strain, non-recoverable fibre strain may also add to the deformation in the structure. Hence delayed elastic recovery at lower strain level is more than that at higher strain level. The DER is hence, influenced by the level of imposed strain energy, deformation in the yarn structure and deformation in the constituent fibres.

Permanent Set

The permanent set (PS) refers to the change or deformation in structure of the textile material which cannot be recovered at all. This may cause remarkable change in the shape of textile product after use and hence undesirable.

Though PS can also exist at lower load but is generally detected after the structure exceeds its elastic limit. It is caused due to irreversible shift of constituent fibres. Such a shift is expected to be influenced by

a) displacement of individual fibres,
b) straightening of slack fibres without imposing strain and its subsequent failure to restore to the preloading configuration,
c) stabilization of the rearrangement of fibres due to load application and hindrance in recovery offered by the modified structure.

It is observed from the Figure 6 that yarns Y result lower permanent set than X in all cases under study irrespective of level of applied extension. The inter fibre cohesion in an opened structure being less the restoration of configuration become more difficult.

The PS in the opened structure shows a tendency to increase. On removal of a component, stress is distributed among less number of fibres which may incidentally cause more deformation in fibres. When coarser fibres are used, the number of fibres further reduces thereby increasing the stress per fibre. So use of coarser fibre leads an increase in load per fibre and hence the PS is more. Slackness in the structure changes the stress distribution pattern in the constituent fibres. The geometric position of the fibres might show more change than the inherent properties of the fibres. Hence, the PS is low.

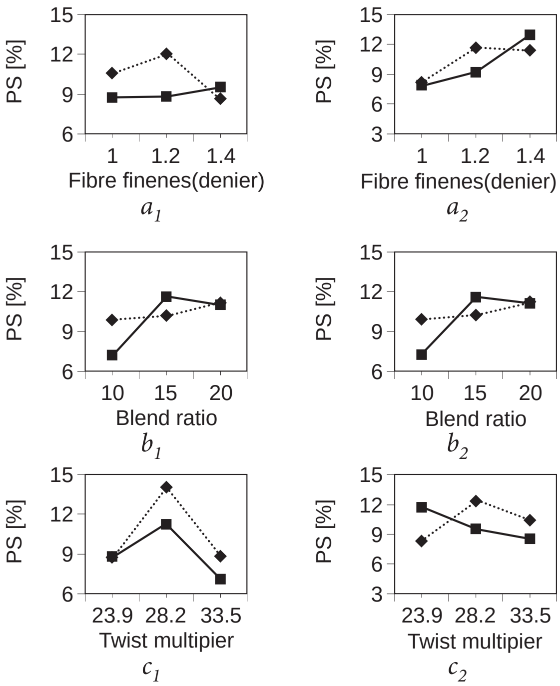


Figure 6: Effect of fibre fineness, blend ratio and twist multiplier on PS; a_1, b_1 and c_1 – PS at 2% extension; a_2, b_2 and c_2 – PS at 4% extension

X, Y

3.5 Elastic Performance Coefficient

Though the elastic performance coefficient (EPC) refers to the ability of the textile material to recover from deformation on repeated loading, the degree to which material can duplicate perfect elastic material has typically been termed as elastic performance coefficient.

The results are represented in Figure 7. It is observed from the figure that the EPC of the yarn after removal of one component improved compared to that of the parent yarn. With increase in the applied load the difference in EPC reduced. The fibre fineness, blend ratio and applied twist had also influenced EPC. EPC improved with the use of finer fibre and 15% PVAL blended yarn resulted highest value both for parent and modified yarn. However, at higher conditioning load, EPC is higher in yarn with lowest percentage of PVAL. The twist level, however led an initial increase of EPC and then a fall.

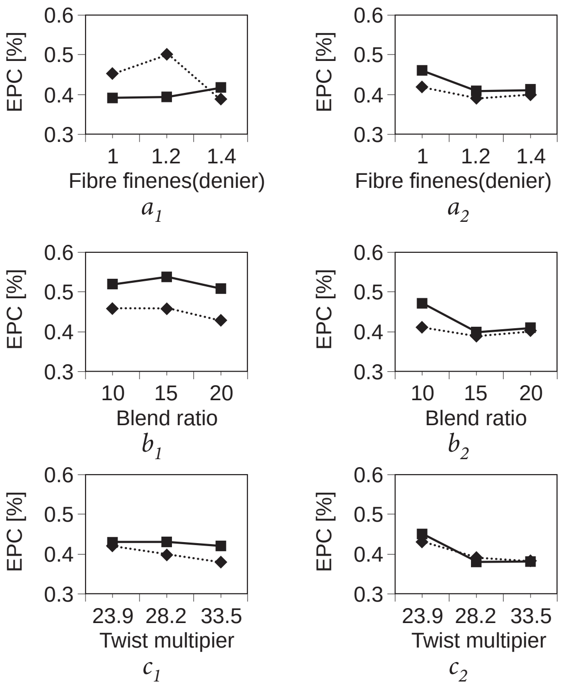


Figure 7: Effect of fibre fineness, blend ratio and Twist multiplier on EPC; a_1, b_1 and c_1 – PS at 2% extension; a_2, b_2 and c_2 – PS at 4% extension

····◆···· X, —■— Y

On loading, the level of stress in each fibre will be dependent on their respective radial position. Fibres away from the central position will experience higher stress. When the structure is compact, the possibility of readjustment is less. If some additional spaces are created in the structure by removing one of the components the remaining fibres will have a scope to change the radial position and hence level of stress will be reduced on application of load. The additional spaces created in the structure allow slackness to accumulate in fibres. It is possible for such fibre to withstand to higher level of load without undergoing any inherent deformation. This leads to the area under loading and recovery curve to change and hence the removal of PVAL leads to an improvement in EPC.

The EPC was also found to be influenced by fibre fineness, blend ratio and applied twist. In the parent yarn no significant change in EPC was observed while it declined in modified yarn as the fibre became coarser. For a particular count, the number of fibres in the cross-section will be more when finer fibres are used. Accordingly, higher number of load sharing components (leading to reduction in load/fibre) and slackness in the structure might have caused less stretching of the fibres. This leads to the minimization of deformation of the structure and of constituent fibres resulting better recovery.

The EPC of modified yarn (Y) is higher when EPC is calculated at lower load. When the applied load increases the difference in EPC of X and Y reduces. In the modified yarn it is higher at 15% PVAL blend at lower conditioning load. It is higher at 10% blend in at higher conditioning load. Locational change of the fibres and possibility of inherent change in properties of fibre at higher conditioning load are responsible for minimum difference in EPC at higher load.

A marginal reduction in EPC at higher twist may be attributed to the higher internal stresses in the individual constituent fibres than those in the fibres in yarn at lower twist. The conditioning load essentially is the sum of the components of fibre loads parallel to the yarn axis. So at higher twist an increase in stress on individual fibre leads to the possibility of secondary creep to dominate and hence the EPC reduces. Change in helical position due to the removal of PVAL and subsequent creation of space in the structure have caused some slackness. In such a case, even a low level of elastic energy can also help in recovery due to less resistance from inter fibre contact and accordingly EPC is higher.

4 Conclusions

Elastic recovery and elastic performance coefficient can be influenced by the properties of fibres, yarn composition and twist. Fibre fineness, twist and PVAL% in parent yarn and its dissolution in modified yarn resulted considerable influence on elastic recovery and elastic performance coefficient. From the study, following conclusions can be made:

- the parameters, fibre fineness, twist multiplier and blend ratio were found to influence both elastic recovery behaviour and EPC.
- it is evident from the Figures 4–6 that modified yarn has higher immediate elastic recovery and lower delayed elastic recovery and permanent set indicating modified yarn has more ability to recover with application of stress.
- similarly, a look on the figure 7 reveals that the modified yarn has higher elastic performance coefficient indicating that higher ability to withstand and recover with repeated stress application.
- dissolution of PVAL seems to have caused by a reduction in yarn diameter.

- structure of the modified yarn becomes more open with reduction of helix angle.
- The generated voids in the structure can reduce inter fibre cohesion which can alter the stress distribution pattern in the yarn. The stress distribution pattern is also expected to change due to the change in radial position of fibres.

References

1. *Structural mechanics of fibres, yarns and fabrics*. Edited by J. W. S. Hearle, Grosberg, P., Backer, Stanley. New York : John Wiley and Sons Inc., 1969, 175–207.
2. PLATT, M. Milton. Mechanics of elastic performance of textile materials. *Textile Research Journal*, 1950, **20**(1), 1–15.
3. *The structure of yarn*. Edited by Witold Žurek. Warsaw : Foreign scientific publications department of the national centre for scientific, technical and economic information, 1975, 175–178.
4. SUSICH, George, BACKER, Stanley. Tensile recovery behaviour of textile fibers. *Textile Research Journal*, 1951, **21**(7), 482–509, doi: 10.1177/004051755102100704.
5. *Physical properties of textile fibres* 8th edition Edited by J. W. S. Hearle, W. Morton, W. E. Cambridge. England : CRC Press, Woodhead Publishing, 2008, 338–347.
6. HAMBURGER, J. Walter. Mechanics of elastic performance of textile materials: Part I. Development of an elastic performance coefficient in tension. *Textile Research Journal*, 1948, **18**(2), 102–113, doi: 10.1177/004051754801800204.
7. HAMBURGER, J. Walter. Mechanics of elastic performance of textile materials: Part II The application of sonic techniques to the investigation of the effect of viscoelastic behaviour upon stress-strain relationship in certain high polymers. *Textile research Journal*, 1948, **18**(12), 705–743, doi: 10.1177/004051754801801201.
8. SETT, S. K., MUKHERJEE, A., SUR, D. Tensile characteristics of rotor and friction spun jute blended yarn. *Textile Research Journal*, 2000, **70**(8), 723–728, doi: 10.1177/004051750007000810.
9. CHATTOPADHYAY, R., SINHA, S. K. Studies on structural integrity of polyester – cotton friction spun yarn by cyclic extension test. *Fibres and Polymers*, 2011, **12**(2), 268–274, doi: 10.1007/s12221-011-0268-0.
10. TYAGI, G. K., GOYAL, A., PATNAIK, A. Elastic recovery properties of polyester jet-spun yarns. *Indian Journal of Fibre and Textile Research*, 2002, 352–357.
11. TYAGI, G. K., SHARMA, Dhirendra. Performance and low-stress characteristics of polyester--cotton MVS yarns. *Indian Journal of Fibre and Textile Research*, **29**, 2004, 301–307.
12. TYAGI, G. K., GOYAL, A., SINGH, A. Effect of add-on finish and process variables on recovery properties of jet-spun polyester yarns. *Indian Journal of Fibre and Textile Research*, 2004, **29**, 44–48.
13. GUTHRIE, J. C., NORMAN, S. Measurement of the elastic recovery of viscose rayon filaments. *Journal of the Textile Institute*, 1961, **52**(11), 503–512, doi: 10.1080/19447016108688590.
14. TYAGI, G. K., GOYAL, A., Chattopadhyay, R. Low stress and recovery characteristics of tencel blended ring, rotor and MJS yarns. *Indian Journal of Fibre and Textile Research*, 2013, **38**, 331–339.
15. MANICH, M. Albert, DE CASTELLER, M. D. Elastic recovery and inverse relaxation of polyester staple fibre rotor spun yarns. *Textile Research Journal*, 1992, **62**(4), 196–200, doi: 10.1177/004051759206200403.
16. *Standard test method for elastic properties of textile fibres*. ASTM, 1774–94, 455–459.
17. HAMBURGER, J. Walter, PLATT, M. Milton, MORGAN, M. Henry. Mechanics of elastic performance of textile materials: Part X Some aspects of elastic behaviour at low strains. *Textile Research Journal*, 1952, **22**(11), 695–725, doi: 10.1177/004051755202201101.
18. PLATT, M. Milton. Mechanics of elastic performance of textile materials: Part IV Some aspects of stress analysis of textile structures-staple fibre yarns. *Textile Research Journal*, 1950, **20**(8), 518–538, doi: 10.1177/004051755002000801.
19. PLATT, M. Milton. Mechanics of elastic performance of textile materials: Part VI Influence of twist on modulus of elasticity. *Textile Research Journal*, 1950, **20**(10), 665–667, doi: 10.1177/004051755002001001.
20. HAMBURGER, J. Walter, PLATT, M. Milton. An engineering approach to the analysis and design of textile structures. *Journal of the Textile Institute*, 1953, **44**(8), 475–512, doi: 10.1080/19447015308687858.