Study on Physical Properties of Poly(ethylene terephthalate) Bi-shrinkage Yarns

Mahbobeh Mehran, Mohammad Ali Tavanaie*, and Saeid Fattahi

***Abstract*- Experimental and statistical properties of bi-shrinkage yarns (BSY) were studied by combining multifilament yarns of poly(ethylene terephthalate) containing partially oriented yarn and fully drawn yarn with different finenesses. In this procedure, different twists per meter (500, 1000, and 1500 tpm) were applied to different BSYs. Then tensile, shrinkage, and appearance properties of the samples were analyzed. The appearance properties of the BSYs showed that they are very similar to multifilament textured yarns. The most important factor affecting the BSYs properties is the filaments' number of yarns. The best mechanical, shrinkage, and appearance properties were observed in the samples containing two components with the same number of filaments (regular or microfilament yarns). Also, statistical studies showed the most important factor affecting the BSYs properties was filaments' number of yarns. Moreover, the number of twists per meter of BSY's is an effective parameter.**

***Keywords*: bi-shrinkage yarn, bulk, physical properties, poly(ethylene terephthalate), partially oriented yarn (POY), fully drawn yarn (FDY), microfilament yarn**

I. INTRODUCTION

Bi-shrinkage yarn (BSY) is a combination of two filament yarns with different shrinkage properties. Shrinkage of one component and resistance of the other after heat treatment provide different appearances and improve the handle of the fabric.

Producing combined yarn from two types of the mentioned filament creates properties like minimizing the negative features of each components, reducing the manufacturing costs, the effect of two-tone effect dye, increasing evenness, and expanding the application of the product.

Producing BSYs were started about 44 years ago with a two-stage procedure [1], and in recent years, the one-stage method with simultaneous melt-spinning has been developed. Today, BSYs are being produced in both one-stage and two-stage techniques.

BSY has the feature of "shrink bulk effect". The shrinkage of two components differs, and due to the differences in shrinkage, the component with more shrinkage is shrunk, and the component with low shrinkage exits from the surface of the filament yarn as small loops entirely, causing curls and waves and increasing in the bulk of the yarn [2,3]. This feature creates a unique handle and quality similar to the textured yarns. In the two-stage method, partially oriented yarn (POY) with high shrinkage combines with a fully drawn yarn (FDY) with low shrinkage.

BSYs can generally be produced through different two-stage methods using the following machines [1,4]:
- Draw-twisting machine,
- Draw-winder machine equipped with a hot-pin,
- Texturizing machine,
- Drawing or plying machines equipped with interlace jet.

In one-stage process, unlike the two-stage process (where, at first, a low shrinkage yarn is produced; then using that, a high shrinkage yarn is produced), the whole process is completed in one stage, so that each of the two filament yarns exits from two inside spinnerets at each position, passing through the related path turns into yarn with high shrinkage yarn and low shrinkage yarn. Then one of them is drawn with the drawing godets while another one is directly thread-up to final combining interlace jet. Finally, the filament yarn with different shrinkage is produced as a BSY. Although this process has been newly developed, it is affordable regarding the end cost of the production of yarn. However, this machine is costly, and in all working factories, there are needs for new investment, high expenses, and accepting complexities of a new process. Industrial production of this yarn by two-stage method has a long history, while its manufacturing by one-stage method has significantly developed over the last few years. However, there is a little

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information about the factors affecting the properties of these yarns due to their economic importance for the unique manufactures. In recent years, some researches were done on the structure and properties of this yarn, among which the effect of heat treatment [4-6], the thermal relaxation time, and changes in strain ratio [6] on the properties of the composite BSY were considered.

Tavanai *et al.* studied the effects of the type of heat treatment on BSY using a air-jet texturizing machine (two-stage method) [6]. This study showed that dry heat causes more shrinkage for BSY than other relaxation methods, including boiling water or superheated steam. In studying the effect of strain rate on the shrinkage of BSY, it was revealed that BSY shrinkage reduces with increasing the tensile ratio between the two components of shrinkage.

Chengtan *et al.* studied the effects of heat treatment with water steam on the tenacity of BSYs and reported that the way of yarn breaking varied before and after exposure to super-heated steam [5]. The tenacity of yarn increases as a result of being placed in a hot water steam.

Yuan *et al.* investigated the effect of heat relaxation and stabilization of steam on the rate of shrinkage and the tensile properties of BSY. They observed that thermal stabilization reduces the rate of shrinkage and improves the yarn's tensile properties. They also found that by increasing the relaxation temperature, BSY's shrinkage increases, and its apparent structure becomes bulkier with no significant change in the tensile properties [2].

Considering the lack of availability of information on the effect of twist and fineness of component yarns on the final combined yarn (BSY), this study was conducted in two-stage method via laboratory ring spinning machine to examine the possibility of producing BSY and to investigate the appearance and physical properties of these yarns and their fabrics. The studied parameters were changes in the number of twists per meter of BSY and in the numbers of the filament of their component yarns.

II. EXPERIMENTAL

A. Materials and Methods

High shrinkage components were selected as follows:

1. Regular PET yarn with partially orientation (POY, P_r), the linear density of 118 denier, and 36 filaments number.
2. Microfilament PET yarn with partially orientation (POY, P_m), the linear density of 120 denier, and 108 filaments number.

TABLE I
DRAWING MACHINE PARAMETER ADJUSTMENT

Parameter	Value
Draw ratio	1.7
Hot drawing temperature	90 ºC
Relaxation temperature	180 ºC
Drawing speed	400 m/min
Spindle speed	4500 rpm

TABLE II
COMPONENTS SPECIFICATION OF BSY'S

Components	Sample code
FDY108 + POY36	F_mP_r
FDY108 + POY108	F_mP_m
FDY36 + POY108	F_rP_m
FDY36 + POY36	F_rP_r
FDY108 + FDY36	F_mF_r

FDY: fully drawn yarn, POY: partially oriented yarn; 108 and 36 are the yarns filaments number

In order to prepare a low shrinkage component, the PET yarn samples were drawn to obtain fully drawn yarn (FDY) using an industrial drawing machine manufactured by Zinser Co. (Germany, model 520-2). The drawing machine's setting is according to Table I.

Fully drawn yarns (FDY, F_r) and (FDY, F_m) were obtained from P_r and P_m, respectively. Then they were combined using a ring machine manufactured by SER.MA.TES (SRL) Company (Italy, model 82BA). Three different twists per meter of 500, 1000, and 1500 were applied to determine the effect of twist number on the properties of BSY. Different types of produced yarns are presented in Table II with their identification codes. The fabric samples were knitted by a weft knitting single cylinder hosiery machine (3.5 in diameter, 120 needles) that was manufactured in a local company (Iran).

In order to investigate the BSYs' mechanical properties and shrinkage, the samples were tested according to the ISO 2062:2009 and DIN 53840 standards, respectively. Shrinkage of yarns was measured after heating the skeins of yarn at 130 °C and 10 min duration time. The Eq. (1) was used for shrinkage percent calculation. Each measurement was repeated five times, and then their average and coefficient of variants were presented.

$$\text{Sh}\ (\%) = (L_1 - L_2) / L_1 \times 100 \tag{1}$$

Sh (%), L_1, and L_2 mean shrinkage percent, initial skein length before heating, and contracted skein length after heating, respectively. The appearance of loops on the surface of BSY samples needs heat relaxation. The yarn and fabric samples were relaxed in a tensionless state in dry heat in an oven at 10 min and 130 °C. The surface observations were considered using a Dinolite digital camera with 200-fold magnification and 1.3-megapixel resolution.

TABLE III
INDICATION OF STATISTICAL INDEX FOR STUDIED SAMPLES' PROPERTIES

Properties	Index
POY's strength	X_1
FDY's strength	X_2
POY's elongation-at-rupture	X_3
FDY's elongation-at-rupture	X_4
POY's shrinkage	X_5
FDY's shrinkage	X_6
Twist factor	X_7
POY's share of filaments	X_8
BSY's strength	Y_1
BSY's elongation	Y_2
BSY's shrinkage	Y_3

The tensile and fabric friction tests were performed on the fabric samples based on the ISO 13934-1: 2013 and BS 3424-part 10 (method 12A), respectively.

B. Statistical Methods

Multiple regressions, collinearity diagnostic, and an extra sum of squares were applied as statistical methods for consideration of affective parameters.

A regression model that involves more than one regressor variable is called a multiple regression model. A sever problem that may dramatically influence the usefulness of a regression model is multicollinearity or near-linear dependence among the regression variables. Multicollinearity can also seriously affect the precision with which regression coefficients were estimated. Also the regression sum of squares can be partitioned into marginal single-degree-of-freedom components with the corresponding analysis-of-variance identity. For more details, see the book published by Montgomery *et al.* [7].

Also, to provide a model to predict the tensile behavior and the shrinkage of BSY, each of yarns quality properties was analyzed as follows:

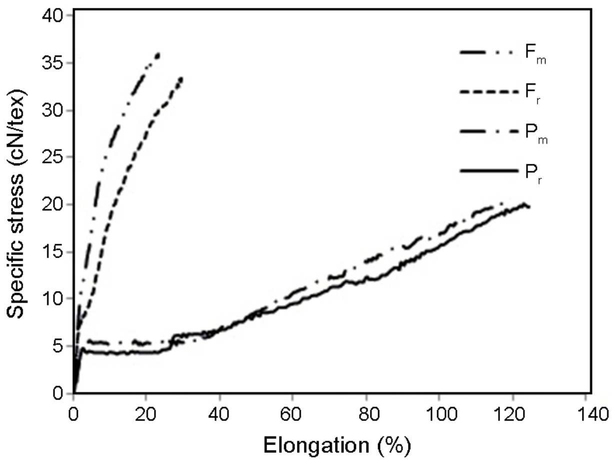


Fig. 1. Stress-strain curves of raw materials.

- Selection of variables using the stepwise method with the criteria of mean squared error (MSE) and R^2 coefficient of determination,
- Using a suitable model and estimating parameters for different properties,
- A relative importance of appropriate variables using the extra sum of squares.

Indication of the index for studied samples' properties is presented in Table III.

III. RESULTS AND DISCUSSION

A. Experimental Evaluation

A.1. Physical and Tensile Properties of BSY Yarns

Fig. 1 shows the stress-strain curves of raw materials. Accordingly, PET POY has an elongation-at-rupture much more than that of FDY and less strength than that of FDY. Microfilament yarns show higher strength than that of regular yarns. The raw materials' mechanical properties are presented in Table IV.

The results showed that after drawing POY, the resulted FDY has an elongation-at-break and shrinkage less than those of POY, and more strength than POY. These effects

TABLE IV
MECHANICAL PROPERTIES OF BSY'S COMPONENTS

Materials	Strength (cN/tex)	Elongation-at-rupture (%)	Shrinkage (%)
POY (microfilament), P_m	19.8 (7.5)*	117.2 (7.1)	53.8 (2.0)
FDY (microfilament), F_m	35.1 (7.0)	23.2 (5.9)	0.6 (1.3)
POY (regular), P_r	19.5 (6.8)	121.7 (4.7)	61.1 (0.1)
FDY (regular), F_r	33.5 (3.6)	29.3 (5.8)	0.8 (1.2)

* The values in the brackets indicate the coefficient of variation (C.V.%)

TABLE V
LINEAR DENSITY, REAL TWIST, AND TWIST FACTOR OF BSYS AND TWO-PLIED TWISTED YARN

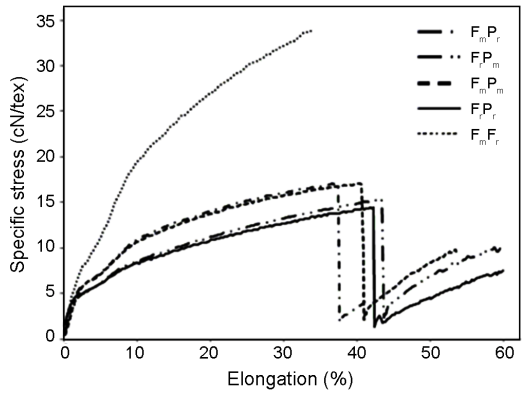
Measured properties	Linear density (dtex)			Real twist (tpm)			Twist factor		
Nominal twist (tpm) Sample code	500	1000	1500	500	1000	1500	500	1000	1500
$F_{(m)}P_{(r)}$	224.2	232.8	261.6	478	1016	1679	100.1	210.6	328.3
$F_{(m)}P_{(m)}$	224.8	242.2	279.8	460	1011	1759	97.0	205.4	332.5
$F_{(r)}P_{(m)}$	222.8	237.6	263.2	444	946	1526	94.1	194.1	297.4
$F_{(r)}P_{(r)}$	218.8	227.8	250.6	434	1029	1598	92.8	215.6	315.3
$F_{(m)}F_{(r)}$	168.8	176.6	185.6	396	891	1643	96.4	212.0	381.4

occurred due to the orientation of molecular chains in the direction of the fiber axis.

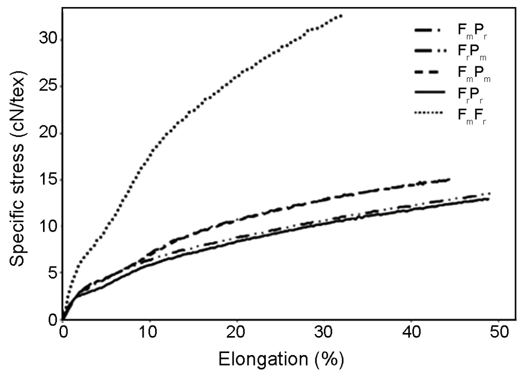
Table V shows the results of measuring the linear density, real twist, and twist factor of combined yarns.

The table shows that among the BSYs, the lowest linear density is for F_rP_r yarn that is due to the low linear density of this yarn's components compared to the other yarns. Among the BSYs, the highest linear density is related to the BSY yarn with two microfilament yarn components. The reason for this difference is the difference in the samples filaments fineness. The fineness of filaments introduces with the number of fibers included in each single yarn. It is evident that the finer filament results in less air trapped volume between the filaments. On the other hand, when the parallel and straight fibers are twisted, due to the lateral force generated, the fibers press each other from outside to inside, resulting in the evacuation of the air between them and thereby occupying less space. In other words, the contribution of air between the fibers decreases, and the fineness of yarn increases [8]. In regular yarns, where fineness of their filaments is low, the contribution of air among the filaments is more than that of microfilament yarns. As a result, by applying twist, the filaments in regular yarns discharge more air, and this causes an increase of the regular yarns' fineness than that of microfilament yarns after twisting.

Also, it is observed that by an increase of the twist, as expected, the yarn's linear density increases because the twist factor increases with increasing the twist, indicating the increase of filament angle with the axis of the yarn. Thus, by changing the filaments' angle relative to the axis of the yarn and locating more of their length in cross over the yarn, more length of POY and FDY is placed in the length unit of the yarn; this causes the increase of weight per unit length and thus the linear density of the yarn. There was no specific trend for twist factor changes in each independent twist, which is an indicator of the independent relationship between the twist factor and the fineness of yarn components in each applied twist.



(a)



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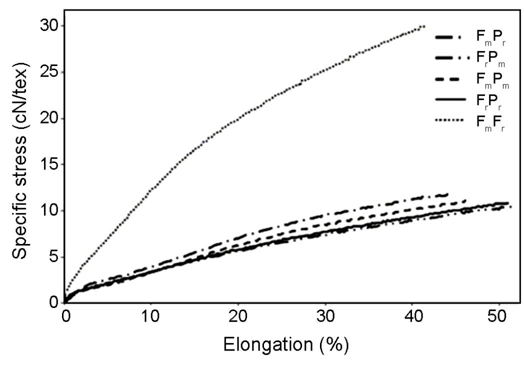


(c)

Fig. 2. Stress-strain curves of BSYs and 2-ply twisted yarn with three different twists per meter: (a) 500 tpm, (b) 1000 tpm, and (c) 1500 tpm.

Figs. 2a to 2c show the stress-strain curves of BSY and 2-ply twisted yarns with three different twists numbers. It is observed that BSYs' strength is less than that of 2-ply twisted regular yarns (F_rF_m) due to less strength of POY than FDY in all three twists; however, POY causes increased elongation-at-rupture of BSYs more than composite yarn from regular FDYs.

In the stress-strain curves of the sample twisted with 500 tpm, there are two points of rupture for each BSY that represent the rupture of yarn at two stages. Since in this twist per meter value, the filament interconnections is low, so at first, FDY is ruptured due to its higher resistance to load and lower elongation-at-break, and then POY is ruptured due to its higher elongation-at-break and lower resistance to load. Accordingly, this feature is not observed for F_mF_r yarn due to lower elongation-at-ruptures of both FDY components. Furthermore, all of the stress-strain curves of the BSYs with 1000 and 1500 twists per meter do not show a two-step rupture due to a higher twist per meter and their higher interconnection of the component yarns' filaments. Chengtan [5] also reported a similar result.

As mentioned in the previous sections, BSYs are a combination of two components with different shrinkages. Therefore, BSYs properties are affected by its components, while each component depending on its contribution to the yarn structure, can affect BSYs properties. In other words, when the number of filaments of two components is different in BSY, the effect of these components can vary too. A comparison between the curves of Fig. 2 shows that increasing the twist per meter causes to increase the fiber's angle with the vertical axis of the yarn and the elongation-at-rupture of the samples, while the strength of the samples reduces because the fiber is pulled away from the yarn's axis. Also, 2-ply twisted yarns with F_r components showed the most significant enhancement of the elongation-at-rupture, and the BSY with regular partially oriented yarn (F_mP_r) showed the lowest reduction of the breaking strength. The increased elongation is due to undrawn component (POY) with high elongation capability; if the contribution of this component (POY) is greater than or equal to that of BSY, the BSY's elongation-at-rupture increases with the increase of twist. Also, BSY with a more significant share of FDY will show a more breaking strength decreasing by increasing the twist due to the higher share of the FDY component on BSY's strength. Table VI shows the test results of tensile properties and shrinkage of BSYs.

The most important result of the tensile properties of the BSY is the effect of FDY on elongation-at-rupture. As can be seen in Table VI, the maximum elongation-at-rupture is 51.84% that is very different from a significant elongation-at-rupture of POY showing FDY's effect on the elongation of the BSY. The existence of POY (P_m or P_r) has caused BSY to show a higher elongation-at-rupture than the F_rF_m combined yarn. Table III shows that the conventionally drawn yarn (F_r), has a much higher elongation-at-rupture compared to drawn microfilament yarn component (F_m). Also, it is expected that among the BSYs with the same low shrinkage component yarn (FDY), the BSY with regular high shrinkage yarn component (P_r) has a higher elongation-at-rupture comparing to the BSY with high shrinkage yarn component (P_m) due to higher elongation to rupture of the P_r than P_m. Differences in the proportion

TABLE VI
ELONGATION-AT-RUPTURE, STRENGTH AND SHRINKAGE OF THE BSYS AND TWO-PLIED TWISTED YARN IN VARIOUS TWIST PER METER

BSY type	Share (%)		Elongation-at-rupture (%)			Strength (cN/Tex)			Shirinkage (%)		
	FDY	POY	500 tpm	1000 tpm	1500 tpm	500 tpm	1000 tpm	1500 tpm	500 tpm	1000 tpm	1500 tpm
$F_{(m)}P_{(r)}$	75	25	38.1 (9.7)*	43.5 (9.6)	44.1 (4.72)	16.9 (3.2)*	15.0 (4.0)	14.2 (3.9)	30.1 (1.3)*	22.2 (0.9)	16.2 (2.8)
$F_{(m)}P_{(m)}$	50	50	41.1 (7.2)	44.5 (8.3)	46.1 (6.0)	16.8 (3.1)	15.0 (5.6)	11.5 (4.6)	40.0 (0.8)	27.9 (0.9)	21.1 (0.9)
$F_{(r)}P_{(m)}$	25	75	42.6 (9.9)	51.6 (7.5)	51.8 (4.4)	15.0 (4.4)	13.7 (5.3)	10.8 (4.1)	50.7 (1.3)	28.8 (1.4)	28.1 (5.4)
$F_{(r)}P_{(r)}$	50	50	41.9 (7.4)	50.8 (7.4)	51.4 (5.1)	14.5 (4.1)	13.6 (4.5)	11.2 (5.2)	50.1 (0.9)	28.0 (0.4)	28.0 (1.1)
$F_{(m)}F_{(r)}$	75**	25**	33.8 (15.0)	34.9 (13.9)	41.6 (6.9)	33.2 (5.9)	30.5 (5.8)	25.1 (5.2)	0.6 (0.7)	0.8 (0.3)	1.4 (1.1)

* The values in the brackets indicate the coefficient of variation (C.V.%)

** Share of 75% is related to the number of microfilament FDY and share of 25% is related to the number of regular FDY of each component which affecting the elongation-at-the rupture of BSYs resulting in the opposite observation.

Comparing the values presented in Table VI for the F_rP_m and F_rP_r yarns further show that the increased elongation-at-rupture of F_rP_m BSY is due to more share of POY than FDY in BSY, while both have the same value in the F_rP_r. Moreover, it was expected that F_mP_m BSY's, compared to F_mP_r BSY's elongation-at-rupture, has higher elongation-at-rupture. However, this expected result was not observed due to the impact of components shares in elongation-at-rupture of the combined yarn.

According to Table VI, by the increase of the twist per meter, the elongation-at-rupture of the samples increases; while the sample's strength reduces. The BSY elongation-at-rupture increases due to the increase of the length of the filaments in each centimeter of the yarn. Hence, the applied tensile force was used for a little twist opening at first and then transferred to the filaments. So after an optimum value of the TPM, twisting is not able to increase the friction between the filaments, and the additional twist can change the angle between the BSYs' filaments and the yarn axis; thereby BSYs' strength is reduced.

According to Fig. 2, with the increase of the twist, the strength of the BSY and two-plied twisted yarn decreases. As previously mentioned, after an optimum value of the twists per meter, twisting is not able to increase the friction between the filaments, and the lateral force inserted from the extra twisting causes the yarn take a loop form (spring

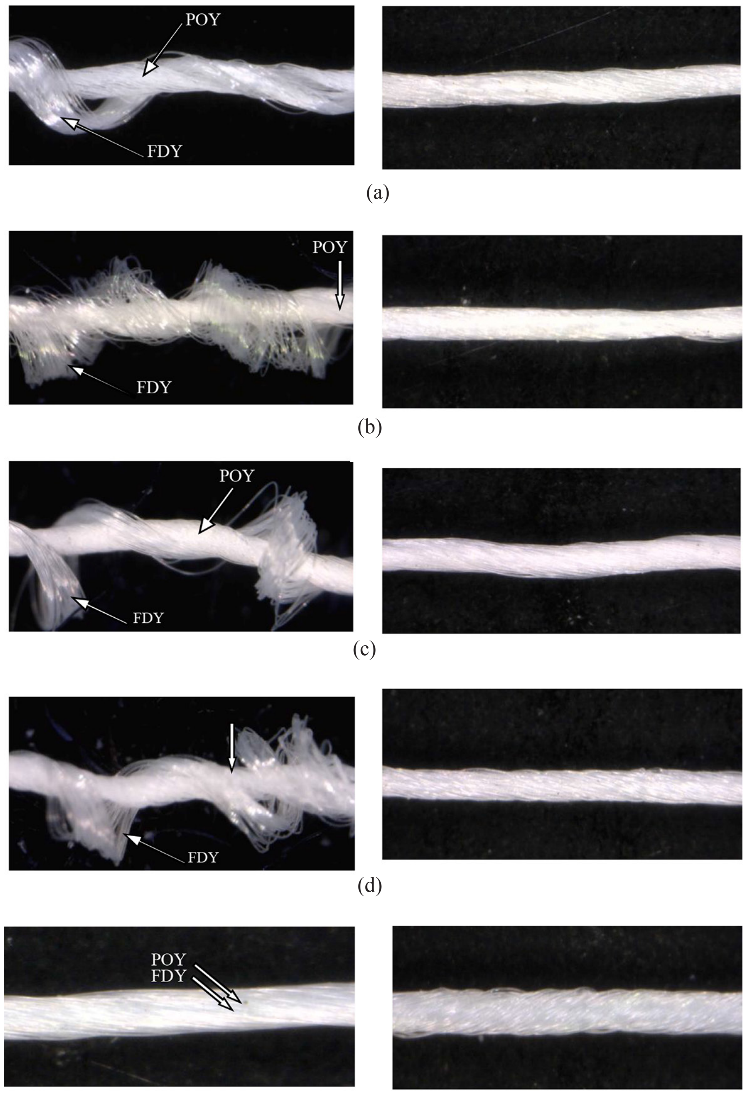


Fig. 3. BSY and 2-ply twisted yarn images before and after heating (right figures show the samples before heating and left figures show the samples after heating): (a) F_mP_r, (b) F_mP_m, (c) F_rP_m, (d) F_rP_r, and (e) F_rF_m.

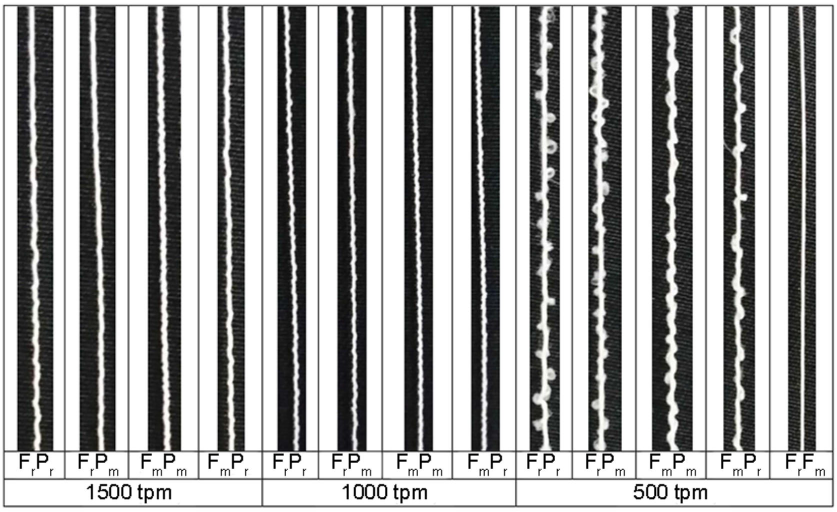


Fig. 4. BSY and 2-ply twisted yarn images with various twists per meter after heating.

form) along the yarn axis, and the strength is reduced [8].

In the study of the effect of twisting on the strength of BSY and two-plied twisted yarn samples, the maximum strength was observed in the yarns with F_m component while the values less than 17 cN/tex in the strength of the samples show a more significant impact of POY on BSY's strength. Interestingly, a dramatic reduction in the F_mP_m yarn's strength, compared to the F_mP_r yarn in 1500 tpm, better shows the effects of the twists on the strength of the BSY. This effect was observed because of the difference between the real and nominal rates of the twists. The difference between the nominal and real twists in nominal 1500 tpm is 100 tpm while the value in the 500 and 1000 tpm is about 18 tpm. Comparing the results of shrinkage (Table VI) shows that the increase of twists per meter reduces shrinkage, which is due to less involvement of two components in low twists, and so the possibility of easier shrinkage of the component with POY. In total, the highest shrinkages were observed for the BSYs with F_r component that represents the opposing effect of lower filament numbers of the non-shrinkable component (FDY) on BSY shrinkages. So, the yarn with less shrinkage component (FDY), which has higher shrinkage, shows more shrinkage.

Comparison of the BSYs, F_rP_m, and F_rP_r yarns revealed that F_rP_r yarn has higher shrinkage due to its P_r component, while the opposite result was observed. It is because of the share of each component on the properties of the BSYs, similar to the elongation-at-rupture.

The results suggest a dominant influence of the FDY component on BSY; therefore, the BSYs with F_r component show better shrinkage, and so BSYs containing F_r yarn component show a higher shrinkage. Also, the comparison of F_rP_r and F_rP_m BSYs indicated that F_rP_m has a higher shrinkage due to the more significant share of shrinking

TABLE VII
BREAKING FORCE, ELONGATION-AT-RUPTURE AND FRICTION COEFFICIENT OF THE FABRIC SAMPLES (500 tpm)

Sample	Properties		
	Breaking force (N)	Elongation-at-rupture (%)	Friction coefficient
$F_{(m)}P_{(r)}$	333.48 (7.7)*	28.05 (3.1)	0.44 (4.0)
$F_{(m)}P_{(m)}$	460.66 (3.5)	28.57 (9.0)	0.78 (5.7)
$F_{(r)}P_{(m)}$	345.08 (7.6)	27.78 (6.2)	0.52 (4.1)
$F_{(r)}P_{(r)}$	418.78 (3.5)	30.65 (3.4)	0.63 (1.9)
$F_{(m)}F_{(r)}$	435.34 (9.9)	25.62 (3.9)	0.35 (2.1)

* The data inside the brackets are coefficient of variants of the average values (C.V.%)

component in this yarn. Thus, contrary to expectation, the shrinkage of BSYs containing a high shrinkage POY component is not more than the others, and the contribution of each component of the yarn will have a higher impact on the BSY shrinkage.

In a study on the properties of BSY and two-plied twisted yarn, the minimum shrinkage and elongation-at-rupture and the highest strength were observed for the F_mF_r yarn consisting of two components with fully orientation of polymer chains (with low elongation-at-rupture, high strength, and insignificant shrinkage).

A.2. The Appearance of BSY Yarns

Fig. 3 illustrates the BSYs and two-plied twisted yarn surface images before and after heating. As shown, after heat setting of the BSYs, due to differences in the shrinkage of two components, high shrinkage component (POY) shrinks along the yarn axis, and fixes at the center of BSY; however, low shrinkage component (FDY) lies on the surface of the yarn as curls and waves, and forms loops on the BSY surface. This resulting in the form of high bulk appearance of the BSYs. These results are consistent with the findings of similar researches [5,6,9,10]. According to Figs. 3 and 4, two-component BSYs with different shrinkage formed a structure similar to that of air-textured yarns (contains loops (effect yarn) around the center yarn (core yarn)).

According to Fig. 3, the best bulk was created for the F_rP_r and F_mP_m BSYs because of the similarity of two-component yarn's contribution. In the above yarns, the contribution of filament components is equal; therefore, at the shrinkage of POY component, the resistance of FDY component leads to the removal of this component from the yarn center, and to cover the yarn's surface by loop, while in F_mP_r BSY, the resistance of FDY component due to the higher share of filament number, compared to the POY component, causes POY the component not to be able to be shrunk easily; as a result, the F_mP_r yarn's shrinkage is lower than that of other yarns with less bulk.

The less share of the filament number of FDY than POY in F_rP_m BSY would result in its lower resistance against the shrinkage of POY component and resulting in pulling out of greater part of the FDY through the BSY that covers the yarn in loops.

The evenest loops among BSYs, shown in Figs. 3 and 4, go to the F_mP_m, because of the number of filaments and the FDY's high fineness in the F_mP_m yarn which cause the FDY component to surround the POY component more even.

The overall study of the samples' surface appearance (Fig. 3) shows that the longer loops height was obtained for the BSY sample with 500 tpm. Also, with increasing the number of twists, the loop length reduces, and the yarn gets more curvy and wavy with less bulk. This is because of the more interconnection and compactness of components in more twists per meter. The filaments compactness results in restriction of the shrinkage and less freedom of the FDY filaments to get out of the surface of the yarns. According to Fig. 4, increasing the twist has the most impact on F_rP_m yarn bulk. In other words, the twist increases by increasing the proportion of the number of filaments in the yarn properties, causing a decrease of F_rP_m yarn's bulk, and resulting in eliminating the effect of peachy skin of the final textile. Thus, to create and maintain a famous peach skin handle, a low twists per meter (about 500 tpm) is recommended.

A.3. The Appearance of Fabrics Knitted with BSY Yarns

To study the effects of BSY on the fabrics' mechanical

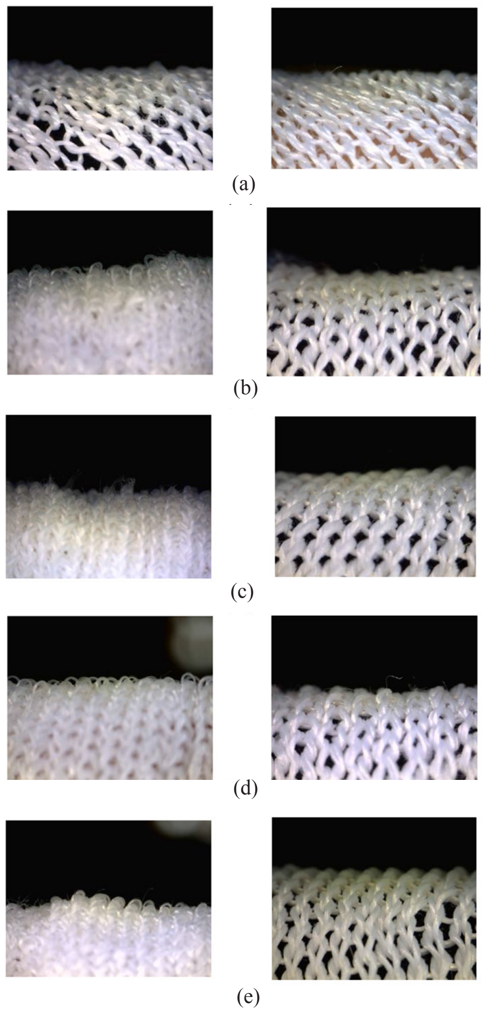


Fig. 5. Images of fabrics knitted using BSYs and 2-ply twisted yarn before and after heating. (Right images show the fabrics before heating and left images show the fabrics after heating): (a) F_rF_m, (b) F_mP_r, (c) F_mP_m, (d) F_rP_m, and (e) F_rP_r.

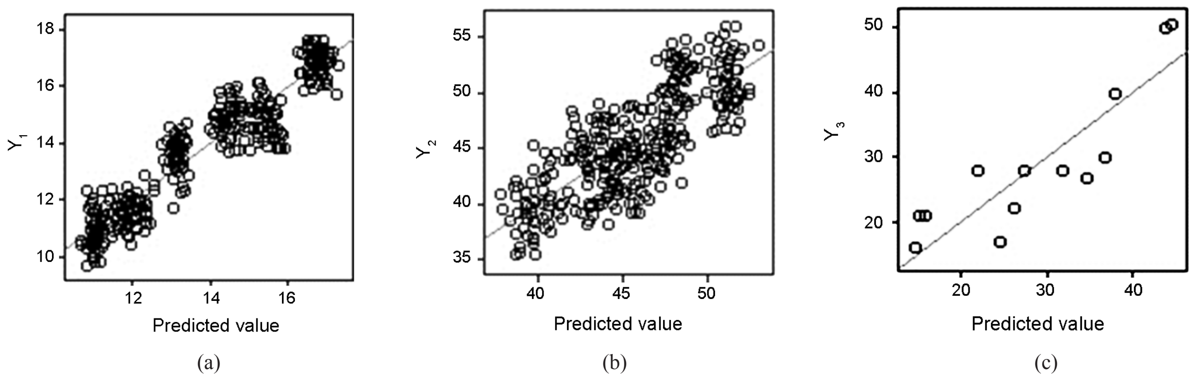
TABLE VIII
PARAMETER ESTIMATES FOR Y_1 AND Y_2

Variable	Parameter estimate		T-value		P_r>|t|		VIF	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
Intercept	15.93	48.74	24.58	18.85	<0.0001	<0.0001	0	0
X_2	0.165	-0.80	8.38	-8.34	<0.0001	<0.0001	1.560	1.51
X_4	-0.103	0.50	-8.94	8.94	<0.0001	<0.0001	1.775	1.70
X_7	-0.021	0.03	-47.46	16.94	<0.0001	<0.0001	1.006	1.005
X_8	-0.015	0.04	-4.72	3.56	<0.0001	0.0004	1.880	1.8

properties, Table VII shows the mechanical properties of the knitted fabrics using the yarn samples. Interestingly, it is observed that the elongation-at-rupture of the knitted fabrics is not dependent on the elongation-at-rupture of the BSY. The fabrics produced with the BSY containing similar fineness components (both components are micro or regular) have the highest breaking load. Also, breaking load of the knitted fabrics with both microfiber yarn (F_mP_m) components was higher than that of the knitted fabrics produced using the two-plied twisted yarn with both fully drawn yarns (FDY). It can be concluded that producing the BSYs using this method not only does not affect decreasing the fabrics' tensile properties, but also with the right selection of BSY components, better breaking load of the final fabric can be attainable. The friction test results showed that the knitted fabrics with BSYs, which have the similar number of filaments, have more roughness than the others due to the more bulk and/or loop number of their BSY components. Hence, peach skin handle, which is the main goal of this production, is possible using two components of the BSY with similar filament number.

Fig. 5 depicts the images of fabrics knitted using BSYs before and after heating. Fig. 5 clearly shows that the heat applied causes the appearance changes to create shrinks of POY and loops of FDY around it (bulky shape). Also, the knitted fabric produced with BSY (example: F_mP_m) creates bulkier fabric comparing to knitted fabric produced with two-plied twisted yarn (F_mF_r) due to the higher shrinkage of its POY component. As expected, the maximum amount of volume (bulk) in the fabric made with BSY contained the same finesse of components. Also, the fabric made with F_rP_r yarn has the highest loops due to the properties of the composite yarn.

The effect of two yarn components with different shrinkages on the appearance of the final fabrics is observed with a comparison of the fabrics made with F_mF_r yarn and BSY. The knitted fabrics made with BSY before heating appear the same as those from F_rF_m, but after heating due to the shrinkage of POY, the FDY component loops on the surface of the fabric causes soft handle and similar appearance as that of made with textured yarns. These results indicate that the appearance properties are very similar to those of fabrics made with textured yarns. So this self-texturing method by selecting the suitable yarn components shows the excellent potential to replace the conventional texturizing methods such as false-twist, air-jet, or stuffer box texturizing methods.



(a) (b) (c)

Fig. 6. Plot of Y_1, Y_2, and Y_3 and predicted Y_1, Y_2, and Y_3.

TABLE IX
SUMMARY OF STEPWISE SELECTION FOR Y_1 AND Y_2

Step	Variable entered	Partial r-square		Model r-square	
		Y_1	Y_2	Y_1	Y_2
1	X_7	0.76	0.28	0.76	0.28
2	X_8	0.08	0.21	0.84	0.50
4	X_4	0.01	0.03	0.88	0.53
3	X_2	0.02	0.07	0.86	0.61

TABLE X
PARAMETER ESTIMATES FOR Y_3

Variable	Parameter estimate	T-value	P_r>|t|	VIF
Intercept	37.77	12.22	<0.0001	0
X_6	21.98	15.95	<0.0001	1.03
X_7	-0.11	-5.53	<0.0001	1.03

TABLE XI
SUMMARY OF STEPWISE SELECTION FOR Y_3

Step	Variable entered	Partial r-square	Model r-square
1	X_7	0.76	0.76
2	X_6	0.04	0.80

B. Statistical Analysis

An optimal model was selected for yarn tenacity with four variables (X_2, X_4, X_7, and X_8) by the stepwise method and desirable R^2. The ANOVA table indicates that the F statistic is significant (F=630.68, P<0.0001), and the R-square (R^2=0.88) accounts for 88% of the variation in yarn strength. Table VIII displays the parameter estimates and other values for the fitted model. This model is as follows:

$$Y_1 = 15.93 + 0.165X_2 - 0.103X_4 - 0.021X_7 - 0.015X_8 \quad (2)$$

According to Table VIII, all effects (variables) are significant. Variance inflation factors (VIFis) are nearly one. These diagnostics indicate that the independent variables are about orthogonal.

We also used an extra sum of squares to obtain the importance and contribution of each independent variable. Therefore, the relative importance and contribution of parameters for yarn strength (Y_1) are approximately X_7-76%, X_8-8%, X_2-2%, and X_4-1%, respectively.

Fig. 6 shows the scatter plot of predicted values versus the experimental values and the regression lines.

The optimal model for yarn elongation was selected with four variables by desirable MSE, R^2, and R^2_{adj} (R^2=0.61, F=134.22, P<0.0001). The final model was obtained as follows:

$$Y_2 = 48.74 - 0.80X_2 + 0.5X_4 + 0.03X_7 + 0.04X_8 \quad (3)$$

According to Table VIII, all variables are significant and nearly independent. Therefore, the extra sum of squares for this model is as Table IX.

Thus, the relative importance and contribution of parameters for yarn elongation (Y_2) are nearly X_7-28%, X_8-21%, X_4-3%, and X_2-7%, respectively. Fig. 6b displays the diagram of predicted values against the experimental values.

Table X shows the parameter estimates for Y_3 and other values.

Therefore, the final model for yarn shrinkage is as follows:

$$Y_3 = 37.77 + 21.98X_6 - 0.11X_7 \quad (4)$$

Based on the data given in Table X, all variables are significant (P<0.0001) and close to independence (VIF≅1).

TABLE XII
IMPORTANCE OF VARIOUS CHARACTERISTICS ON YARN PROPERTIES

Filament properties	Yarn properties		
	Tenacity (Y_1)	Elongation (Y_2)	Shrinkage (Y_3)
Component strength with less shrinkage (X_2)	+5%	-7%	-
Component elongation with less shrinkage (X_4)	-6%	+3%	-
Component shrinkage with less shrinkage (X_6)	-	-	+4%
Twist factor (X_7)	-76%	+28%	-76%
Component share of filaments with higher shrinkage (X_8)	-8%	+21%	-

Table XI shows the extra sum of squares by using the stepwise method. Thus, the relative importance and contribution of parameters for yarn shrinkage are nearly X_7-76% and X_6-4%, respectively. Fig. 6d shows the scatter plot of predicted values (Y_3) versus the experimental values.

The obtained equations show that the yarn properties such as strength, elongation, and shrinkage are influenced by components properties with low shrinkage and the number of twists per meter of yarns.

Table XII shows the relative importance, contribution, and direction of the effect of various characteristics on different properties of yarns.

Regard to Table XIII, as expected, yarn strength is highly influenced by twist factor. In order of importance, contribution, and direction of significant properties are twist factor (-76%), the share of filaments (-8%) of the component with higher shrinkage, and elongation (-6%) and strength (+5%) of component with low shrinkage. Yarn elongation is influenced by the twist factor (+28%), share of filaments (21%) of component with higher shrinkage, and component strength (-7%) and elongation (+3%) with low shrinkage, respectively.

Among the various properties, twist factor (-76%) has the most significant effect on yarn shrinkage. Another factor that influences yarn shrinkage is shrinkage of the component with low shrinkage (+4%).

IV. CONCLUSION

This study was conducted in the two-stage method of producing BSY and investigation of the appearance and physical properties of these yarns and their fabrics. The results of tensile properties (strength and elongation-at-rupture) and shrinkage showed that the number of filaments as BSY components is the most important factor affecting the properties of these yarns. The results further showed that the increase of twisting increases the impact of this factor. Also, the increased twist factor harms the strength and shrinkage of BSYs. The increasing of the twist factor had an unsuitable effect on the BSYs bulkiness. The best appearance bulkiness obtained with a BSY yarn contained similar filaments number. Accordingly, the raw materials should be selected due to the contribution of filaments depending on the expected properties of a BSY.

Statistical analysis well fitted the experimental results. Accordingly, assuming the twist factor constant; the most important parameter is the contribution of the number of yarn filaments on the properties of BSY. Among the various properties, twist factor, and component share of filaments with higher shrinkage have the most significant effect on different properties of yarn (BSY). In this study, we investigated some statistical approaches for modeling and prediction of the effetive properties of BSYs.

Experimental evaluation of results showed that the produced BSYs are very similar to the textured filament yarns. The most important factor affecting the properties of BSYs is the impact of the number of filament components in the BSYs. Also, the best mechanical and appearance properties and shrinkage were observed in the samples with two components contained the same filament number. It can be concluded that producing the BSY using this method not only has no effect on the decrease of the fabrics' tensile properties, but also with the right selection of BSY component, the better breaking load at final fabric can be attainable.

APPENDIX

Some of the concepts of the statistical methods are described as follows:

- Multiple regressions

A regression model is more convenient to deal with multiple regression models if they are expressed in matrix notation as follows:

$$y = X\beta + \varepsilon \tag{5}$$

Typically, y is an n×1 vector of the observation, X is an n×p matrix of the levels of the regressor variables, β is a p×1 vector of regression coefficients, and ε is an n×1 vector of random errors. It is usually assumed that the error term ε has $E(\varepsilon)=0$, $Var(\varepsilon)=\delta^2$, and that the errors are uncorrelated ($Cov(\varepsilon_j, \varepsilon_k)=0$, $j\neq k$). Also, the least-squares estimator of β is as follows provided that the inverse matrix $(X'X)^{-1}$ exists:

$$\hat{\beta} = (X'X)^{-1}X'Y \tag{6}$$

The matrix $(X'X)^{-1}$ exists if the regressors are linearly independent; that is, if no column of the X is a linear combination of the other columns.

Plots of residuals are potent methods for detecting the violation of these underlying regression assumptions. This form of model adequacy checking must conduct for every regression model that is under serious consideration for use in practice.

- Collinearity diagnostic

The main diagonal elements of the inverse of the matrix X′X in correlation form are often called variance inflation factors (VIFs), and they are an important multicollinearity diagnostic factor. In general, the variance inflation factor for the j^{th} regression coefficient uses as follows:

$$VIF_j = \frac{1}{1-R_j^2} \tag{7}$$

Where, R_j^2 is the coefficient of multiple determinations obtained from regressing X_j on other regressor variables. VIF larger than 10 implies serious problems with multicollinearity, and $VIF_1=VIF_2=1$ implies that the two regressors x_1 and x_2 are orthogonal.

- The extra sum of squares

In general, we can partition the regression sum of squares into marginal single-degree-of-freedom components. For example, consider the model:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \varepsilon \quad (8)$$

With the corresponding analysis-of-variance identity:

$$SS_T = SS_R(\beta_1, \beta_2, \beta_3 | \beta_0) + SS_{Res} \quad (9)$$

We may decompose the three-degree-of-freedom regression sum of squares as follows:

$$SS_R(\beta_1, \beta_2, \beta_3 | \beta_0) = SS_R(\beta_1 | \beta_0) + SS_R(\beta_2 | \beta_1, \beta_0) + SS_R(\beta_3 | \beta_1, \beta_2, \beta_0) \quad (10)$$

Where, each sum of squares on the right-hand side has one degree of freedom. In the particular case, if the columns in x_1 are orthogonal to the columns in x_1, we can determine a sum of squares due to β_2 that is free of any dependence on the regressors in x_1. Therefore:

$$SS_R(\beta) = SS_R(\beta_1) + SS_R(\beta_2) \quad (11)$$

Consequently, SSR (β_1) and SSR (β_2), respectively, measure the contribution of the regressors x_1 and x_2 to the model unconditionally. The effect of each regressor when the regressors are orthogonal can unambiguously determine. For more details, see the reference [7].

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