(REFEREED RESEARCH)

AN INVESTIGATION ON THE EFFECTS OF PLY AND SINGLE TWISTS ON STRENGTH, HAIRINESS AND ABRASION RESISTANCE PROPERTIES OF TWO-PLY COTTON RING-SPUN YARNS

ÇİFT KAT VE TEK KAT İPLİK BÜKÜMÜNÜN ÇİFT KATLI PAMUK RİNG İPLİKLERİN MUKAVEMET, TÜYLÜLÜK VE AŞINMA DİRENCİ ÖZELLİKLERİNE ETKİLERİ ÜZERİNE BİR ARAŞTIRMA

Sunay ÖMEROĞLU

Uludag University, Department of Textile Engineering, Bursa, Turkey

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ABSTRACT

The effects of ply and single twists on tensile, hairiness and abrasion resistance properties of two-ply yarns with three different yarn counts were investigated. Tensile test results showed that the effect of ply twist on breaking strength properties of ply yarns was similar to the effect of the twist on the breaking strength of single yarns. Increases in single twist caused decreases in the strength of ply yarns. Increases in both single and ply twists caused increases in the breaking elongation of ply yarns. Single and ply twists affected the hairiness properties of ply yarns and hairiness values decreased as twist levels increased. Ply twist was more effective on hairiness properties than single twist. Abrasion resistance increased both in fine and coarse yarns as ply twist increased. Any important effect of single twist was not observed on abrasion resistance in fine ply yarn while abrasion resistance increased in coarse yarns in the case of low single twist level.

Key Words: Ply twist, Single twist, Yarn properties, Cotton, Ring-spun yarn.

ÖZET

Çalışmada; çift kat ve tek kat bükümünün, üç farklı numaraya sahip çift katlı ipliklerin mukavemet, tüylülük ve aşınma direnci üzerindeki etkileri incelenmiştir. Katlı büküm miktarının katlı ipliklerin mukavemeti üzerindeki etkisinin, bükümün tek katlı ipliklerdeki etkisine benzer olduğu, tek kat bükümündeki artışın katlı iplik mukavemetinde düşmeye sebep olduğu görülmüştür. Kopma uzaması değerleriyle ilgili olarak; gerek katlı büküm, gerekse tek kat bükümü artışının, katlı ipliklerin kopma uzaması değerlerinde artışa yol açtığı görülmüştür. Tüylülük sonuçlarıyla ilgili olarak; gerek katlı büküm, gerekse tek kat bükümünün ipliklerin tüylülük değerleri üzerinde etkili olduğu ve büküm artışıyla birlikte tüylülük değerlerinde azalma olduğu görülmüştür. Bununla beraber; katlı büküm miktarının tüylülük değerleri üzerinde daha etkili olduğu görülmüştür. Gerek ince ipliklerde, gerekse kalın ipliklerde, çift katlı büküm miktarı arttıkça aşınma direnci artmaktadır. İnce ipliklerde, tek kat bükümünün aşınma direnci üzerindeki etkisi görülmezken, kalın ipliklerde, tek kat bükümünün düşük olmasının aşınma direncini arttırdığı görülmüştür.

Anahtar Kelimeler: Katlı büküm, Tek kat bükümü, İplik özellikleri, Pamuk, Ring iplik.

Corresponding Author: Sunay Ömeroğlu, sunay@uludag.edu.tr, Tel: +90 224 294 20 53, Fax: +90 224 294 19 03

1. INTRODUCTION

Single staple yarns do not fulfill the requirements necessary for some weaving and knitting processes and the production of certain types of textiles. Some properties which can not be obtained with a single yarn can be fulfilled by a ply yarn of similar linear density with a single yarn. Majority of the ply yarns have the ply twist in the opposite direction to the single twist. Plying two or more single yarns improves the yarn properties such as strength, elongation, evenness, hairiness, abrasion resistance, bulkiness, twist liveness, etc. (1-4).

Yarn is a structure which consists of staple fibres or filaments. Twist is mostly used method in formation of yarn structure. Yarn twist is one of the most important morphological yarn features which influences of yarn properties and also significantly determines its processing (3). When the strength of fibres or filaments which constitute yarns are ignored, the strength of a spun yarn mainly depends on fibre orientation and fibre to fibre cohesion while the strength of a multifilament yarn mainly depends on filament orientation (5-7). Twist is of great importance because it directly effects fibre orientation and fibre to fibre cohesion. With the increase of twist level, fibre to fibre cohesion increases but fibre orientation decreases. The researches on ply yarn properties mainly focused on yarn strength. Lord and Radhakrishnaiah (8) investigated the effect of ply twist and its direction on the strength properties of ring, rotor and friction-spun yarns while Chattopadhyay (9) made a similar research on polyester and polyester-viscose blended air-jet-spun yarns. Nawaz et al. (10) investigated how a balanced ply structure could be achieved by the effect of different twist levels and their directions considering strength properties of polyester-cotton blended yarns. Palaniswamy and Mohamed (5) investigated the effect of single yarn twist and ply to single yarn twist ratio on strength and elongation of combed cotton ring-spun ply yarns.

Barella, being one of the leading researchers in yarn hairiness, stated that yarn hairiness is formed by protruding fibre ends, looped fibres arced out of the yarn core and ‘wild fibres’ which can be explained as loose fibres which are randomly located on yarn surfaces (11). Hairiness is necessary in staple yarn to some extent but it causes problems both in post-spinning processes and in some product properties after a certain limit. Protruding fibres from yarn surface can be classified in two groups which are the ones until 3 mm and the ones longer than 3 mm, the latter is regarded as a problem in post spinning processes (12-15). Yarn hairiness is a complex parameter of yarn quality. The factors that affect yarn hairiness can be summarized in four groups; fibre properties (length, length distribution, fineness, blend ratio, etc.), spinning process parameters (draft ratio, speed, spinning system, etc.), yarn structural properties (count, twist) and post-spinning processes (winding, plying, sizing, singeing, etc.). The effects of these factors on yarn hairiness have been mostly researched for single-ply yarns (16-23). It is stated in researches related to the effect of twist on yarn hairiness that increasing twist causes yarn hairiness to decrease (23, 24). However, in a research about the hairiness of polyester/viscose blended yarns, it was found that yarn hairiness decreased until a certain twist level but then it increased as the twist increased (25). The papers about the effect of twist on hairiness of two-ply yarns are rare. Palaniswamy and Mohamed (26) investigated the effect of single yarn twist and ply to single yarn twist ratio on hairiness of combed cotton ring-spun ply yarns while Punj et al. (27) investigated the effect of ply twist on hairiness of polyester/viscose blended air-jet-spun ply-yarns.

It is well known that twist changes the surface characteristics and also friction properties of yarns. Because of that twist is an important factor which influences abrasion properties of yarns (12). For any yarn, a general consideration can be proposed so that there is an optimum twist level which can ensure the highest abrasion resistance (28). In a general manner, determination of yarn abrasion is important in determination of optimum sizing in single yarns and weavability of two-ply yarns which generally do not need sizing. A variety of abrasion mechanisms has been used, including abrasion around rods, and against three rods, an agate knife-edge, and emery paper, yarn-against-yarn abrasion, and abrasion in model loom simulators (29). The parameters which were considered in the studies about yarn abrasion resistance are raw material, yarn type (ring-spun, rotor-spun, etc.), yarn count, number of ply, twist (single, ply, ply to single), yarn tension, etc.(12, 26, 29-31). The study in which the effect of twist on abrasion of ply yarns were investigated, Brorens et al. (29) studied the effect of single and ply twists on abrasion resistance of worsted yarns which were produced from wool tops of 22 µm**.** Palaniswamy and Mohamed (26) investigated the effect of single yarn twist and ply to single yarn twist ratio on yarn to yarn and yarn to emery abrasion resistances of combed cotton ring-spun ply yarns. Punj et al. (27), in their research which was focused on the determination of the optimum ply twist level, investigated the abrasion properties of polyester/viscose blended air-jet-spun two-ply yarns.

It can be generally stated that single and ply twist directions, single and ply twist levels, number of ply, twisting method and twisting tension are the parameters which affect the production and properties of ply yarns. Among these, single and ply twist level parameters must be very carefully chosen because they effect yarn structure and properties, and also yarn production costs. In this paper, effects of single and ply twists on tensile, hairiness and abrasion resistance properties of two-ply yarns which were produced from single-cotton yarns.

2. MATERIALS AND METHODS

In the experimental part, nine different single-ply ring spun cotton yarns of three nominal counts (Ne 20, Ne 30 and Ne 36) and having three different twist levels ($\alpha_e = 5$, $\alpha_e = 6$ and $\alpha_e = 7$) were used and two-ply yarns that have four different twist levels (120 tpm, 360 tpm, 600 tpm and 840 tpm) were produced by using two-for-one twisting machine. Single ply yarns had “Z” twist direction while ply-yarns had “S” twist direction.

The tensile properties of single- and two-ply yarns were measured using an Uster Tesorapid 3 tensile tester with a gauge length of 500 mm and a testing speed of 5000 mm/min. Fifty tests were carried out for each single- and two-ply yarn type.

The hairiness properties of single- and two-ply yarns were measured using a Zweigle G565 hairiness tester. The yarns were tested at a speed of 50m/min for a period of one minute. Five tests were carried out for each single- and two-ply yarn type.

The abrasion resistance of two-ply yarns were measured using a Zweigle G550 abrasion tester. Twenty tests were performed with each of the produced ply yarns. A constant weight of 20 g was applied to each yarn under test and the number of strokes of the roller which abraded yarn resulting in breakage was recorded. The roller was coated with ultra fine (800 P) emery paper.

Actual counts of single- and ply-yarns were determined by using Zweigle L232 reel and a precision balance, and actual twist values were determined by a universal twist tester.

Prior to the tests, all yarns were conditioned in standard atmospheric conditions (20±2 ºC and 65±2 % relative humidity) for 24 hours. The results of tensile (breaking strength and breaking elongation), hairiness (1mm, 2mm and S3 classses of hair length) and abrasion resistance (breaking cycle) were also statistically tested using two way analysis of variance and the means were compared by Student-Newman-Keuls (SNK) tests at 0.05 significance level; separately for each nominal count of the two-ply yarns (Ne 20/2, Ne 30/2 and Ne 36/2).

The codes and properties of single yarns were presented in Table 1, and the codes and constructional properties (count and twist) of ply yarns were presented in Table 2.

Table 1. Codes and properties of single yarns

Single yarn code	Count (Ne)		Twist coefficient (α_e)		Tensile properties		Hairiness properties		
	Nominal	Actual	Nominal	Actual	B. Strength (cN/tex)	B. Elongation (%)	1 mm class	2 mm class	S3-Class ($\Sigma \geq$ 3mm)
11	20	19.6	5	5.2	18.22	8.37	8833	2149	1841
12	20	19.3	6	6.4	18.10	8.99	8958	2014	1804
13	20	19.4	7	7.5	16.78	9.95	8871	2214	2030
21	30	29.3	5	5.4	17.81	6.54	5808	1619	1549
22	30	29.2	6	6.2	17.24	7.27	5522	1473	1279
23	30	29.0	7	7.3	15.07	7.74	5462	1574	1696
31	36	35.3	5	5.4	16.99	6.61	4982	1505	1522
32	36	35.5	6	6.5	15.75	6.96	4653	1407	1428
33	36	35.1	7	7.4	14.87	7.35	4767	1476	1693

Table 2. Codes and constructional properties of ply yarns

Ply yarn code	Single yarn used	Count (Ne)		Twist (tpm)		Ply yarn code	Single yarn used	Count (Ne)		Twist (tpm)	
		Nominal	Actual	Nominal	Actual			Nominal	Actual	Nominal	Actual
111	11	20/2	9.6	120	111	**223**	22	30/2	14.7	600	597
112	11	20/2	9.8	360	384	**224**	22	30/2	14.7	840	834
113	11	20/2	9.8	600	605	**231**	23	30/2	14.6	120	115
114	11	20/2	9.3	840	843	**232**	23	30/2	14.3	360	376
121	12	20/2	9.7	120	120	**233**	23	30/2	14.3	600	607
122	12	20/2	9.6	360	375	**234**	23	30/2	14.9	840	848
123	12	20/2	9.8	600	612	**311**	31	36/2	18.1	120	115
124	12	20/2	9.7	840	837	**312**	31	36/2	17.6	360	376
131	13	20/2	9.8	120	118	**313**	31	36/2	17.8	600	609
132	13	20/2	9.9	360	384	**314**	31	36/2	18.0	840	845
133	13	20/2	9.8	600	604	**321**	32	36/2	17.8	120	109
134	13	20/2	9.7	840	838	**322**	32	36/2	18.1	360	377
211	21	30/2	14.9	120	114	**323**	32	36/2	17.7	600	601
212	21	30/2	15.0	360	386	**324**	32	36/2	17.7	840	831
213	21	30/2	14.5	600	609	**331**	33	36/2	17.3	120	114
214	21	30/2	14.4	840	823	**332**	33	36/2	17.9	360	380
221	22	30/2	14.5	120	112	**333**	33	36/2	17.9	600	616
222	22	30/2	14.5	360	380	**334**	33	36/2	17.9	840	832

3. RESULTS AND DISCUSSION

3.1. Tensile properties

Tensile properties results of ply yarns including mean values and standard deviation were presented in Table 3. Breaking strength and breaking elongation values of ply yarns were compared in graphical form in Figures 1 and 2 respectively.

According to the breaking strength results of ply yarns, for the set of the chosen ply twist levels (120 tpm, 360tpm, 600tpm and 840tpm) in Ne 20/2 and Ne 30/2 group of yarns, yarn strength first increased until a certain ply twist level and then decreased as the ply twist level increased. However, in Ne 36/2 group of yarns, a certain ply twist level was not obtained in which yarn strength decreased as ply twist increased. When it is considered that the same ply twist levels were used in all group of ply yarns, the results revealed the fact that "the effect of ply twist on tensile strength is similar to the effect of ply twist on tensile strength of single yarns (4, 10)". According to this, generally, it was reached to the maximum strength values in coarser yarns at lower ply twist level than in finer yarns. P results which were given in Table 4 showed that ply twist had a statistically meaningful effect on the strength of ply yarns and SNK results supported the above mentioned assessment. Tensile test results showed that the breaking strength of ply yarns decreased as single yarn twist increased. Statistical results showed that the effect of single yarn twist was significantly meaningful on ply yarn strength. With the increase of single twist, the decrease in ply yarn strength was more evident in Ne 20/2 group of yarns. SNK results given in Table 4 also revealed these findings. However, Palaniswamy and Mohamed (5) found that strength of ply yarns increased as single yarn twist increased for the yarns 14.8 tex (Ne 40), 11.8 tex (Ne 50) and 9.8 tex (Ne 60) which had α_e values between 4.0 – 5.5 approximately. One of the most important differences between these two studies is that the single yarns which were used in the production of ply yarns in this research had much higher twist levels than the ones regularly used in textile processes. When it is considered that the strength of yarns produced from staple fibres mainly depend on fibre-fibre cohesion and fibre orientation, it could be stated in this research that the high twist of single yarns impaired the fibre orientation rather than improving the fibre-fibre cohesion; and as a result the axial load bearing property of ply yarns decreased.

Table 3. Results of tensile properties of ply yarns (mean ± SD)

Group of Ne 20/2			Group of Ne 30/2			Group of Ne 36/2		
Yarn code	B. Strength (cN/tex)	B. Elongation (%)	**Yarn code**	B. Strength (cN/tex)	B. Elongation (%)	**Yarn code**	B. Strength (cN/tex)	B. Elongation (%)
111	20.36 ± 1.14	8.72 ± 0.38	**211**	17.89 ± 1.03	6.74 ± 0.34	**311**	17.09 ± 1.18	6.55 ± 0.35
112	20.81 ± 1.09	8.69 ± 0.29	**212**	18.86 ± 0.86	7.08 ± 0.26	**312**	17.80 ± 1.04	6.86 ± 0.29
113	20.56 ± 0.99	9.33 ± 0.31	**213**	19.97 ± 0.95	7.55 ± 0.27	**313**	17.51 ± 1.05	7.16 ± 0.31
114	19.97 ± 1.04	9.78 ± 0.31	**214**	19.47 ± 0.90	8.36 ± 0.37	**314**	18.10 ± 1.13	7.76 ± 0.36
121	19.51 ± 0.84	8.56 ± 0.50	**221**	18.13 ± 1.54	7.52 ± 0.52	**321**	16.86 ± 1.06	7.06 ± 0.42
122	20.23 ± 0.94	8.63 ± 0.35	**222**	19.49 ± 1.74	8.08 ± 0.58	**322**	17.95 ± 1.59	7.34 ± 0.51
123	20.48 ± 1.05	9.54 ± 0.45	**223**	19.48 ± 1.14	8.47 ± 0.38	**323**	18.11 ± 1.14	7.79 ± 0.33
124	20.26 ± 1.24	9.86 ± 0.38	**224**	19.01 ± 1.58	8.89 ± 0.45	**324**	17.87 ± 1.06	8.17 ± 0.34
131	18.76 ± 1.37	8.54 ± 0.50	**231**	16.21 ± 1.70	7.37 ± 0.71	**331**	15.93 ± 1.73	7.50 ± 0.69
132	19.01 ± 1.39	9.10 ± 0.52	**232**	17.71 ± 2.12	7.93 ± 0.77	**332**	16.41 ± 1.78	7.84 ± 0.64
133	19.51 ± 1.32	9.89 ± 0.49	**233**	17.89 ± 1.42	8.65 ± 0.50	**333**	17.00 ± 1.32	7.97 ± 0.47
134	18.22 ± 1.22	10.33 ± 0.46	**234**	17.63 ± 1.38	9.06 ± 0.50	**334**	17.23 ± 1.24	8.41 ± 0.45

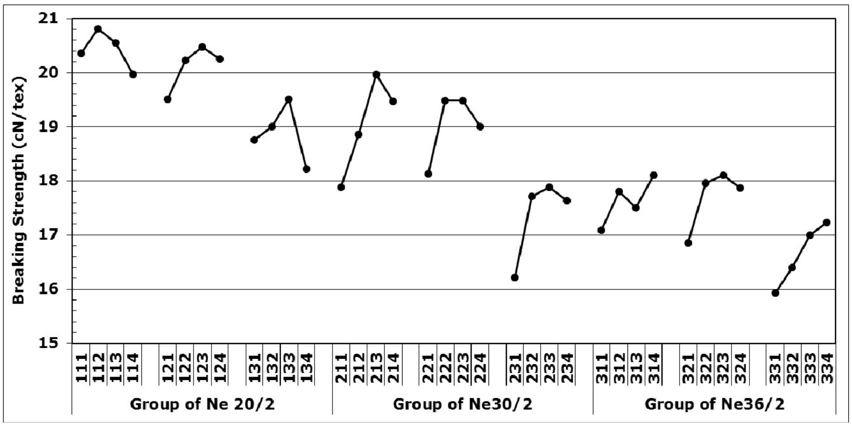

Figure 1. Breaking strength values of ply yarns

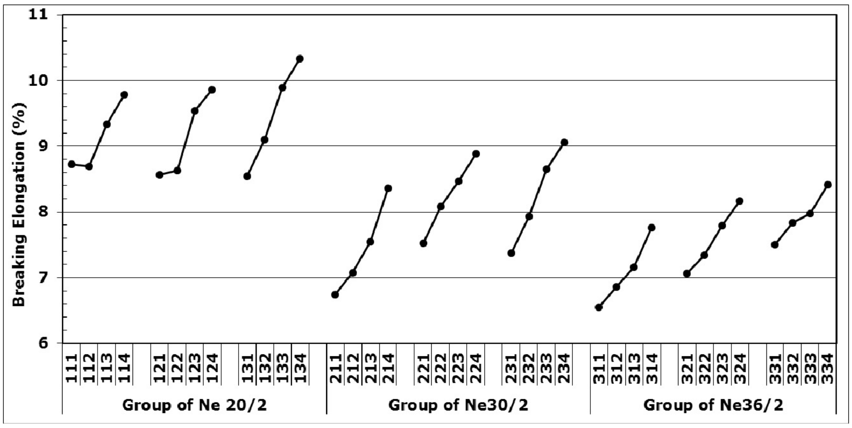

Figure 2. Breaking elongation values of ply yarns

According to test results, breaking elongation of the yarns increased as ply twist increased. This may be due to higher length of wrapping of one strand over another and as a result, higher elongation property of the ply yarns when subjected to tensile. The reason of the increase in breaking elongation values as yarns got coarser (Ne 36/2 to Ne 20/2) could be explained by the same approach. The effect of ply twist on breaking elongation of the ply yarns was found statistically meaningful (Table 4).

The increase in single yarn twist caused breaking elongation of the ply yarns to increase. This was mostly evident in Ne 36/2 group of yarns (Table 4). Unwinding of single yarn twist during the production of the ply yarns (because of ply twist direction was S while single twist direction was Z) could have caused a decrease in the angle between the fibres of single yarn and yarn axis which resulted in higher elongation of the ply yarn under tension. According to statistical evaluation given in Table 4, it could be stated that single twist had a statistically meaningful effect on breaking elongation of the ply yarns.

3.2. Hairiness properties

The hairiness results of ply yarns including mean values and standard deviations were presented in Table 5. Hair numbers of 1 mm, 2 mm and S3 (total number of 3 mm and longer hairs) length classes were presented in Figure 3.

Hairiness values of ply yarns showed that number of hairs in all three length classes (1 mm, 2 mm and S3) decreased for every yarn count and single twist. Ply twist had a statistically meaningful effect on hair numbers of all three length classes (Table 6). Also, SNK results showed that each increase in ply twist level decreased the number of hairs in all three length classes in statistically meaningful terms. When it is considered that ply twist causes the hairs of strands (single yarns) to be trapped between the strands or to wrap them on the surface of yarn, then the increase of the binding points (with the increase of ply twist) along unit yarn length is aspected to cause hairiness to decrease. The decrease in hairiness because of increase of ply twist also offered two additional findings. One of them is that the greatest decrease in hair numbers for every length class was obtained when ply twist increased from 120 tpm to 360 tpm. After 360 tpm level, hair numbers continued to decrease slightly. The second finding is the much greater decrease (63-75%) of the 2 mm length class when ply twist increased from 120 tpm to 800 tpm, while hair numbers of 1 mm and S3 classes decreased almost at the same percentages (37-45%). Lower decrease in 1 mm class hairiness could be expected because these short hairs would become more rigid to the effect of ply twist. When it is considered that S3 class hairs compose 3 mm and longer hairs, the length of emerging hairs out of the yarn surfaces would be expected to decrease because of trapping between strands or wrapping round ply yarn surfaces. But the hairs formerly longer than 3 mm (before ply twist) would be expected to stay still as S3 class. The lower decrease in hair numbers of this class although ply twist increased could be explained by this statement.

Concerning the effect of single twist, it was obvious that all three hair length classes decreased as single twist increased and single twist was statistically meaningful on all three length classes (Table 6). However, the effect of single twist on hairiness was lower when compared with the effect of ply twist and it was less clear according to SNK results. The choice of near twist levels in single yarns could be regarded to have a contribution on this situation.

Table 4. Statistical analysis (analysis of variance and SNK test) results for tensile properties

Yarn Group	Factor	Breaking Strength		Breaking Elongation	
		P / Sign.	SNK ranges (high to low)	P / Sign.	SNK ranges (high to low)
Ne 20/2	Ply Twist (P)	0.000 / *	600 tpm (a) 360 tpm (a) 120 tpm (b) 840 tpm (b)	0.000 / *	840 tpm (a) 600 tpm (b) 360 tpm (c) 120 tpm (d)
	Single Twist (S)	0.000 / *	$\alpha_\varepsilon = 5$ (a) $\alpha_\varepsilon = 6$ (b) $\alpha_\varepsilon = 7$ (c)	0.000 / *	$\alpha_\varepsilon = 7$ (a) $\alpha_\varepsilon = 6$ (b) $\alpha_\varepsilon = 5$ (b)
Ne 30/2	Ply Twist (P)	0.000 / *	600 tpm (a) 840 tpm (b) 360 tpm (b) 120 tpm (c)	0.000 / *	840 tpm (a) 600 tpm (b) 360 tpm (c) 120 tpm (d)
	Single Twist (S)	0.000 / *	$\alpha_\varepsilon = 5$ (a) $\alpha_\varepsilon = 6$ (a) $\alpha_\varepsilon = 7$ (b)	0.000 / *	$\alpha_\varepsilon = 7$ (a) $\alpha_\varepsilon = 6$ (a) $\alpha_\varepsilon = 5$ (b)
Ne 36/2	Ply Twist (P)	0.000 / *	840 tpm (a) 600 tpm (a) 360 tpm (a) 120 tpm (b)	0.000 / *	840 tpm (a) 600 tpm (b) 360 tpm (c) 120 tpm (d)
	Single Twist (S)	0.000 / *	$\alpha_\varepsilon = 6$ (a) $\alpha_\varepsilon = 5$ (a) $\alpha_\varepsilon = 7$ (b)	0.000 / *	$\alpha_\varepsilon = 7$ (a) $\alpha_\varepsilon = 6$ (b) $\alpha_\varepsilon = 5$ (c)

* statistically significance ($P < 0.05$)
(a), (b), (c), (d); statistical difference ranges according to SNK test.

In the study which the hairiness index (H; total length of hairs emerging out of 1 cm of yarn) of two-ply cotton yarns was researched, Palaniswamy and Mohamed (26) found that hairiness reducing effect of single twist was higher than that of ply twist. The difference between two studies could be emanated from the range between the maximum and minimum single twist values. The ratio of maximum to minimum single twist was quite similar (1.4) in both of the studies but the maximum to minimum ply twist ratio was 3.0 in the study of Palaniswamy and Mohamed (26) while it was 7.0 (840/120 = 7) in this study.

Table 5. Results of hairiness properties of ply yarns (mean ± SD)

Group of Ne 20/2				Group of Ne 30/2				Group of Ne 36/2			
Yarn code	1 mm class	2 mm class	S3 class (Σ ≥ 3mm)	**Yarn code**	1 mm class	2 mm class	S3 class (Σ ≥ 3mm)	**Yarn code**	1 mm class	2 mm class	S3 class (Σ ≥ 3mm)
111	17767 ± 559	3848 ± 182	1873 ± 59	**211**	15540 ± 691	3125 ± 176	1341 ± 98	**311**	13842 ± 426	3300 ± 157	1772 ± 125
112	13972 ± 989	2107 ± 198	700 ± 108	**212**	10226 ± 965	1562 ± 169	492 ± 64	**312**	10197 ± 468	1862 ± 87	783 ± 43
113	11438 ± 897	1619 ± 139	488 ± 16	**213**	8701 ± 1226	1249 ± 199	364 ± 69	**313**	8681 ± 580	1413 ± 75	483 ± 38
114	11256 ± 907	1418 ± 108	341 ± 34	**214**	7568 ± 828	921 ± 107	230 ± 54	**314**	7560 ± 581	1168 ± 110	373 ± 51
121	17206 ± 182	3522 ± 152	1584 ± 86	**221**	13624 ± 454	2928 ± 139	1372 ± 65	**321**	12548 ± 496	2750 ± 204	1335 ± 86
122	12723 ± 341	1767 ± 57	569 ± 18	**222**	9836 ± 482	1603 ± 135	595 ± 49	**322**	8229 ± 427	1169 ± 111	379 ± 27
123	10625 ± 947	1387 ± 113	374 ± 29	**223**	8193 ± 692	1133 ± 86	322 ± 42	**323**	6620 ± 558	869 ± 138	236 ± 39
124	10032 ± 850	1258 ± 147	324 ± 29	**224**	7171 ± 621	956 ± 100	276 ± 26	**324**	6055 ± 665	767 ± 93	212 ± 30
131	14698 ± 350	2801 ± 61	1261 ± 72	**231**	12250 ± 541	2695 ± 118	1222 ± 87	**331**	10578 ± 518	2374 ± 153	1260 ± 57
132	11570 ± 399	1674 ± 69	540 ± 53	**232**	9381 ± 608	1531 ± 120	537 ± 36	**332**	8557 ± 531	1446 ± 101	530 ± 35
133	10231 ± 735	1260 ± 90	273 ± 15	**233**	7590 ± 779	1054 ± 122	313 ± 36	**333**	6612 ± 524	942 ± 119	258 ± 22
134	8860 ± 499	1033 ± 67	241 ± 16	**234**	6386 ± 547	878 ± 69	230 ± 23	**334**	5631 ± 399	767 ± 72	209 ± 13

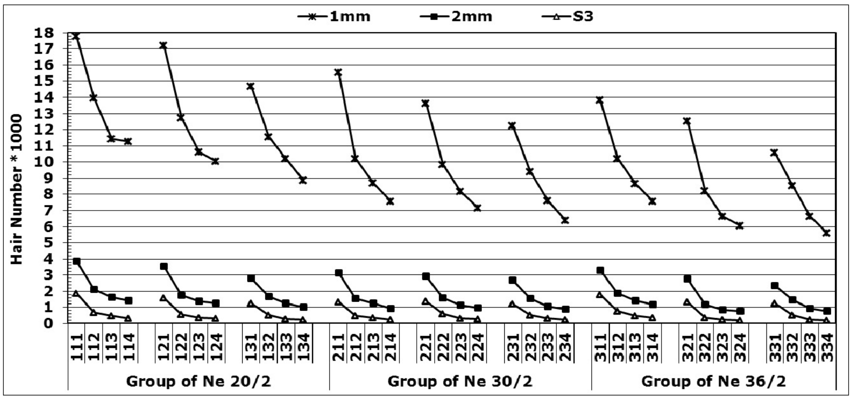

Figure 3. Hairiness values of ply yarns

Table 6. Statistical analysis (analysis of variance and SNK test) results for hairiness properties

Yarn Group	Factor	1 mm class		2 mm class		S3 class	
		P / Sign.	SNK ranges (high to low)	P / Sign.	SNK ranges (high to low)	P / Sign.	SNK ranges (high to low)
Ne 20/2	Ply Twist (P)	0.000 / *	120 tpm (a) 360 tpm (b) 600 tpm (c) 840 tpm (d)	0.000 / *	120 tpm (a) 360 tpm (b) 600 tpm (c) 840 tpm (d)	0.000 / *	120 tpm (a) 360 tpm (b) 600 tpm (c) 840 tpm (d)
	Single Twist (S)	0.000 / *	$\alpha_\varepsilon = 5$ (a) $\alpha_\varepsilon = 6$ (b) $\alpha_\varepsilon = 7$ (c)	0.000 / *	$\alpha_\varepsilon = 5$ (a) $\alpha_\varepsilon = 6$ (b) $\alpha_\varepsilon = 7$ (c)	0.000 / *	$\alpha_\varepsilon = 5$ (a) $\alpha_\varepsilon = 6$ (b) $\alpha_\varepsilon = 7$ (c)
Ne 30/2	Ply Twist (P)	0.000 / *	120 tpm (a) 360 tpm (b) 600 tpm (c) 840 tpm (d)	0.000 / *	120 tpm (a) 360 tpm (b) 600 tpm (c) 840 tpm (d)	0.000 / *	120 tpm (a) 360 tpm (b) 600 tpm (c) 840 tpm (d)
	Single Twist (S)	0.000 / *	$\alpha_\varepsilon = 5$ (a) $\alpha_\varepsilon = 6$ (b) $\alpha_\varepsilon = 7$ (c)	0.000 / *	$\alpha_\varepsilon = 5$ (a) $\alpha_\varepsilon = 6$ (a) $\alpha_\varepsilon = 7$ (b)	0.003 / *	$\alpha_\varepsilon = 6$ (a) $\alpha_\varepsilon = 5$ (ab) $\alpha_\varepsilon = 7$ (b)
Ne 36/2	Ply Twist (P)	0.000 / *	120 tpm (a) 360 tpm (b) 600 tpm (c) 840 tpm (d)	0.000 / *	120 tpm (a) 360 tpm (b) 600 tpm (c) 840 tpm (d)	0.000 / *	120 tpm (a) 360 tpm (b) 600 tpm (c) 840 tpm (d)
	Single Twist (S)	0.000 / *	$\alpha_\varepsilon = 5$ (a) $\alpha_\varepsilon = 6$ (b) $\alpha_\varepsilon = 7$ (c)	0.000 / *	$\alpha_\varepsilon = 5$ (a) $\alpha_\varepsilon = 6$ (b) $\alpha_\varepsilon = 7$ (b)	0.000 / *	$\alpha_\varepsilon = 5$ (a) $\alpha_\varepsilon = 7$ (b) $\alpha_\varepsilon = 6$ (b)

* statistically significance ($P < 0.05$)
(a), (b), (c), (d); statistical difference ranges according to SNK test.

3.3. Abrasion properties

The results of breaking cycle values of ply yarns including mean values and standard deviations were presented in Table 7. Breaking cycle values of ply yarns were compared in graphical form in Figure 4.

When the breaking cycle values of all the yarns were considered, abrasion resistance increased when the yarns got coarser, as it would be expected, because they had greater amount of fibres in yarn cross section and they were subjected to a lower relative tension than finer yarns (20 g of constant load was used for all yarn in the test). Besides, increase in ply twist also increased abrasion resistance of yarns in all yarn groups. Ply twist was found statistically meaningful on abrasion resistance and SNK results given in Table 8 showed that each increase in ply twist level also increased abrasion resistance of the yarns statistically. In Ne 20/2 group of yarns, abrasion resistance increased almost linearly with the increase in ply twist. However, in Ne 30/2 and Ne 36/2 groups of yarns, a slight increase was observed in abrasion resistance when ply twist increased from 120 tpm to 360 tpm. At higher twist levels a much greater increase in abrasion resistance was observed.

The reason of breakage because of abrasion could be the result of slippage of fibres through the body of the yarn (because of low fiber-fiber cohesion), breakage of fibres or both. Counts of Ne 30/2 and Ne 36/2 yarns were closer to each other and they were finer when compared to Ne 20/2 group of yarns. Fibre-fibre cohesion increasing effect of ply twist could be better utilized in Ne 30/2 and Ne 36/2 group of yarns because of their finer and similar counts when compared to Ne 20/2 group of yarns. The results of the effect of ply twist on abrasion resistance were consistent with the former researches (26, 27, 29).

When the effect of single twist on abrasion resistance was considered, it was observed that single twist did not have a statistically meaningful effect on the abrasion resistance of Ne 30/2 and Ne 36/2 groups of yarns. In other words, a significant change was not observed in the abrasion resistance for a certain ply twist level. In Ne 20/2 group of yarns, single twist was found statistically meaningful on abrasion resistance. Ply yarns which were produced from single yarns with lower twist level had greater abrasion resistance according to SNK results given in Table 8.

A general consideration which was observed in the three group of yarns must be outlined. When the abrasion test of ply yarns which had lower ply twist (such as 120 tpm and 360 tpm) was considered, as the experiment advanced, the distance between the binding points of the ply yarns became wider. After a certain time of experiment, strands that constitute the ply yarn became almost separated from each other and later abrasion affected more densely on one strand. Eventually, one strand broke first and sometime later the second strand also broke. Time intervals of breakages of two strands were almost the same at Ne 30/2 and Ne 36/2 groups of yarns while it was longer in Ne 20/2 group of yarns. The reason could be the lower relative tension on Ne 20/2 group of yarns during the abrasion test and the capability of one strand to resist the effect of abrasion for a longer period. Additionally, the higher hairiness (especially because of higher number of S3 class hairs) of the single yarns which had lower twists could have protected the remaining strand from the effect of abrasion for a longer period.

4. CONCLUSIONS

The following conclusions could be drawn on the results of tensile, hairiness and abrasion resistance properties of cotton two-ply yarns with different levels of single- and ply-yarn twist.

The effect of ply twist on the breaking strength of ply yarns was found similar to the effect of the twist on the strength of the single yarns and the effect was statistically meaningful. The maximum breaking strength was generally obtained at lower ply twist levels as the yarns got coarser. It was found that single twist also affected the ply yarn strength, and ply yarn strength decreased as single twist level increased. When breaking elongation values were considered, it was observed that both ply twist and single twist statistically affected breaking elongation and the effect of single twist was more evident in fine yarns.

Table 7. Results of breaking cycle of ply yarns (mean ± SD)

Group of Ne 20/2		Group of Ne 30/2		Group of Ne 36/2	
Yarn code	Breaking cycle	**Yarn code**	Breaking cycle	**Yarn code**	Breaking cycle
111	528 ± 70	**211**	272 ± 27	**311**	209 ± 28
112	1623 ± 227	**212**	404 ± 50	**312**	315 ± 49
113	2508 ± 439	**213**	860 ± 137	**313**	572 ± 107
114	4079 ± 681	**214**	1535 ± 331	**314**	831 ± 156
121	461 ± 67	**221**	258 ± 36	**321**	232 ± 31
122	1627 ± 213	**222**	410 ± 63	**322**	258 ± 43
123	2074 ± 267	**223**	979 ± 179	**323**	564 ± 92
124	3002 ± 492	**224**	1467 ± 258	**324**	820 ± 120
131	494 ± 72	**231**	234 ± 40	**331**	196 ± 26
132	1222 ± 244	**232**	393 ± 64	**332**	282 ± 36
133	1976 ± 508	**233**	781 ± 152	**333**	482 ± 52
134	2531 ± 558	**234**	1521 ± 280	**334**	855 ± 124

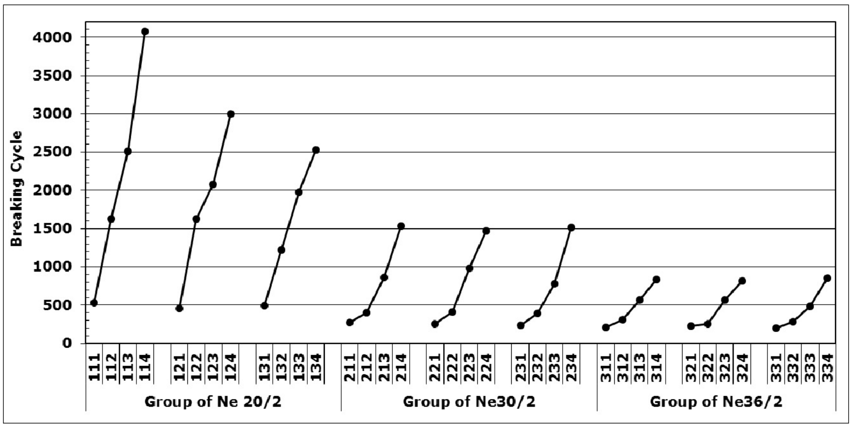

Figure 4. Breaking cycle values of ply yarns

Table 8. Statistical analysis (analysis of variance and SNK test) results for breaking cycle values

Yarn Group	**Factor**	**Breaking cycle**	
		P / Sign.	SNK ranges (high to low)
Ne 20/2	Ply Twist (P)	0.000 / *	840 tpm (a) 600 tpm (b) 360 tpm (c) 120 tpm (d)
	Single Twist (S)	0.000 / *	$\alpha_e = 5$ (a) $\alpha_e = 6$ (b) $\alpha_e = 7$ (c)
Ne 30/2	Ply Twist (P)	0.000 / *	840 tpm (a) 600 tpm (b) 360 tpm (c) 120 tpm (d)
	Single Twist (S)	0.199 / ns	$\alpha_e = 6$ (a) $\alpha_e = 5$ (a) $\alpha_e = 7$ (a)
Ne 36/2	Ply Twist (P)	0.000 / *	840 tpm (a) 600 tpm (b) 360 tpm (c) 120 tpm (d)
	Single Twist (S)	0.111 / ns	$\alpha_e = 5$ (a) $\alpha_e = 6$ (a) $\alpha_e = 7$ (a)

***** statistically significance ($P < 0.05$), **ns** non-significant
(a), (b), (c), (d); statistical difference ranges according to SNK test.

According to hairiness results, both ply twist and single twist affected hairiness of the ply yarns and hairiness values decreased as twist levels increased. Additionally, the effect of ply twist was more evident on hairiness values. Hair numbers in length classes of 1 mm and S3 decreased similarly as ply twist increased but the decrease in 2 mm class hair number was different, and it was greater than the other two hair length classes.

Abrasion resistance increased in both fine and coarse yarns as ply twist increased. Any important effect of single twist on abrasion resistance was not observed in fine yarns. However, abrasion resistance increased because of increasing hairiness in coarse yarns which composed of single yarns that had low twist; the twist, being not under a certain level and supplying a certain fiber- fiber cohesion.

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