(REFEREED RESEARCH)

A COMPARATIVE STUDY BETWEEN THE DYNAMIC FRICTION CHARACTERISTICS OF COMPACT AND SIRO YARNS

KOMPAKT VE SİRO İPLİKLERİNİN DİNAMİK SÜRTÜNME ÖZELLİKLERİNİN KARŞILAŞTIRILMASI ÜZERİNE BİR ARAŞTIRMA

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ABSTRACT

This study was conducted to compare the dynamic frictional properties of less-hairy yarns (compact, compact-siro and sirospun yarns) to conventional ring-spun yarns. Due to different surface characteristics affecting the frictional behavior, yarns spun by various spinning technologies differ from each other. Identical yarns of varying parameters including yarn type, yarn count, and strand spacing (for sirospun yarns) were produced from the same cotton roving to eliminate variability in raw material. Yarn-to-yarn friction (μYY), yarn-to-metal friction (μYM) and yarn abrasion characteristics of these yarns were determined by CTT instrument. The results have revealed that spinning method and yarn linear density have significant effects on the frictional and lint shedding features of the yarns whereas strand spacing has a limited influence on the yarn frictional properties.

Keywords: Yarn-to-yarn friction, yarn-to-metal friction, dynamic tensile testing, compact yarns, lint generation, yarn abrasion.

ÖZET

Bu çalışma, düşük iplik tüylülüğüne sahip (kompakt, siro, kompakt siro) iplikler ile konvansiyonel ring ipliklerinin dinamik sürtünme özelliklerini kıyaslamak amacıyla gerçekleştirilmiştir. Farklı eğirme sistemleriyle üretilen ipliklerin sürtünme özellikleri, farklı yüzey özelliklerine bağlı olarak değişiklik göstermektedir. Hammaddenin etkisini bertaraf etmek için, aynı pamuk fitilleri kullanılarak iplik tipi, iplik numarası ve fitiller arası mesafe (siro iplikler için) gibi çeşitli eğirme parametreleriyle özdeş iplikler üretilmiştir. İplik-iplik sürtünme katsayısı (μYY),, iplik-metal sürtünme katsayısı (μYM) ve ipliklerin aşınma özellikleri CTT cihazı ile test edilmiştir. Sonuçlar incelendiğinde, eğirme yönteminin ve iplik inceliğinin ipliklerin sürtünme özellikleri ve döküntü oluşturma özellikleri üzerinde önemli etkisi olduğu ancak fitiller arası mesafenin iplik özelliklerini sınırlı düzeyde etkilediği tespit edilmiştir.

Anahtar Kelimeler: İplik-iplik sürtünmesi, iplik-metal sürtünmesi, dinamik mukavemet testleri, kompakt iplikler, toz oluşumu, iplik aşınması.

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INTRODUCTION

Over decades, ring spinning became the cornerstone of spinning, and it has been boosted further with the development of compact spinning. Compared to the conventional ring yarns, compact yarns have more uniform and regular structure, therefore, they have relatively larger strength, less hairiness and higher twisting efficiency than ring spun yarns. (1) Compact spinning gives the possibility of attaining yarn strength identical to that in conventional ring spinning, with lower twist. This results with a softer yarn, increased production and reduced energy consumption (2).

In order to avoid quality problems based on spinning triangle, alternatively, sirospun system is started to preferred for short staple spinning due to quality and cost advantages. This system also provides much less yarn hairiness and greater strength with reduced spinning triangle.

Yarns encounter friction in a variety of ways, either between themselves or against a fixed surface during processing. Friction in between fibers is effective in orientation of the fibers as well as bringing them together and resisting against axial forces during the spinning of the yarns that are the constituent of textile products. Frictional properties are also effective in resistance and comfort properties of fabrics. In the course of the friction between fibers whose axes are perpendicular; point contact, however, in friction of fibers which are wrapped onto a cylinder, distributed contact can be taken into consideration. Therefore, textile fibers can give different frictional coefficients in different friction conditions. Static friction is the force that exists between two surfaces, one surface sliding over another, when there is no movement, whereas dynamic friction is the force necessary to stop this slippage. Dynamic friction is lower than static friction, generally. If the difference between dynamic and static friction of the fibers is high, the noise of sliding/holding motion can be heard (like the swish of silk). Static and dynamic (kinetic) friction coefficients of some fibers are given on Table 1 according to studies of Morton and Hearle (3, 4).

Fiber fly generated by friction between yarns or yarn-metal parts causes fiber loss, deterioration in yarn properties, efficiency loss, unwanted appearances on fabrics and affects work environment, negatively (5). In this context, occupational diseases such as byssinosis and pneumoconiosis pose a risk for the textile stuff (6, 7).

Several studies have been carried out on the resistance of yarn to abrasion and the actual abrasion of the yarn on another surface (5, 8, 9). A considerable part of these studies were focused on the effects of the fiber and yarn characteristics and the production parameters on the frictional characteristics of yarns. Čiukas and Svetnickienė analyzed the flax, bamboo, bamboo-flax, soy, cotton-sea cell yarns, Özçelik Kayseri analyzed regenerated cellulosic yarns, Liu et al. , used a twisted strand method and a capstan method to measure the coefficient of yarn-to-yarn friction of PP/glass yarns (10-12). Rengasamy et al., investigated the effects of overfeed, air pressure on dynamic friction of polyester air-jet textured yarns and compared the dynamic pressure of dry/wet texturing and normal/core-and-effect texturing (13). Supuren et al., investigated the friction coefficient changes in the textured yarns with the changes of heater temperatures, draft, delivery speed, D/Y ratio and jet pressure (14). Ramkumar conducted a study to characterize the frictional properties of friction spun yarns (15). Ghosh et al analyzed the frictional characteristics of OE friction, rotor, air-jet and ring spun yarns (16). Kılıç and Sülar investigated the frictional properties of ring spun, compact and vortex yarns (17).

Koo et al., analyzed many potential factors including yarn tension, feeding angle and speed, influencing fluff shedding during knitting. They have resulted that, the amount of the fluff shedded at the circular knitting machines is affected by yarn-to-knitting needle friction. Even though the yarn tension can be decreased partially by waxing the yarn, it is insufficient to resolve the fluff problem in the knitting machine (18). Dönmez and Marmaralı have built models for predicting the coefficient of yarn friction and the knittability of the yarns. They've analyzed the number of machine stops, yarn breaks, and holes. Besides, they've developed a mechanism for determining yarn-to-yarn and yarn-to-needle friction. They have observed that coefficient of friction increases with the increase of yarn count (Ne), twist coefficient, %CV value and speed of the mechanism. Yarn hairiness and breaking force had contrary effects. The coefficients of yarn-yarn friction values were higher than the coefficients of yarn-needle friction values (19).

The influence of the relative speed and input tension on dynamic friction properties of viscose ring, rotor, air-jet and open-end friction yarns were studied and it is confirmed that the surface character of the yarns have a significant effect on dynamic friction (16). Rougher yarn surface caused higher yarn-to-yarn but lower yarn-to-metal friction. In terms of yarn-to-yarn friction, ring spun yarns had the lowest friction and it was higher for air-jet, rotor and open-end friction, respectively. A reverse order was noticed for yarn-to-metal friction. On the other hand, the frictional forces increased but the tension ratio reduced with the increase of the input tension. As the relative speed increased yarn-to-metal friction increased, but yarn-to-yarn friction passed through a minimum with speed.

Kothari et al. compared the tensile properties of polyester/cotton blended yarns under static and dynamic conditions. They've find out that static tensile tests results overestimates the strength and breaking elongation (20). In a similar manner, static and dynamic tensile properties of false twist textured PES yarns were compared (21). The dynamic strength, measured by Lawson-Hemphill CTT was found approximately 10.4% lower than the static strength measured by Zwick Z010 Universal Tensile Testing. In order to analyze the static and dynamic failure mechanism of cotton ring spun yarns, Ishtiaque et al. classified the broken ends of the yarns according to their captured breaking zone images, as sharp, taper and slipped ends. They've observed that the failure mechanism in static conditions is more dominated by the yarn count than twist multiplier but it is contrary in dynamic condition (22).

Table 1. Typical values of μ for some fibres. (Hearle and Morton).

Fibres	Between fibres		Yarns passing over guides			
	Crossed fibres	Parallel fibres	Hard steel	Procelain	Fibre pulley	Ceramic
Nylon	0,14-0,6	0,47	0,32	0,43	0,2	0,19
Silk	0,26	0,52	-	-	-	-
Viscose rayon	0,19	0,43	0,39	0,3	0,36	0,3
Acetate	0,29	0,56	0,30-0,38	0,29-0,38	0,19-0,2	0,20-0,22
Cotton	0,29-0,57	0,22	0,29	0,32	0,23	0,24
Wool, with scales	0,20-0,25	0,11				
Wool, against scales	0,38-0,49	0,14				

Kılıç and Sülar investigated the frictional properties of cotton/tencel blended yarns spun in compact, ring and vortex spinning systems. They have resulted that vortex yarns have the lowest whereas ring yarns have the highest yarn-to-yarn friction coefficient. In terms of yarn-to-metal and yarn-to-ceramic friction; vortex yarns had the highest, compact yarns had the lowest coefficient of friction values. With regards to the effect of twist factor, a regular trend could not be observed (17).

The relationship between the frictional properties and lint generation of the regenerated cellulosic yarns was investigated and yarn-to-yarn friction and yarn-to-metal friction values of the lyocell yarns were found to be the lowest whereas the viscose yarns' were the highest (11). In terms of lint factor, the highest values were obtained from lyocell yarns due to higher yarn hairiness. Yarns in higher diameter had higher lint factor because of hairy structure. Barella et al. investigated yarn attrition by self-abrasion in parallel with yarn hairiness. They've stated that, ring spun yarns are most likely to lose matter during abrasion and as the proportion of cotton in the blend increases, the fibre lose, during abrasion appears to affect mainly the cotton (5).

Altaş and Kadoğlu, observed that, twist coefficient hasn't got a significant effect on friction coefficients, yarn-to-yarn friction coefficient decreases with the increase of yarn evenness and yarn count (Ne), coarser carded yarns and more hairy yarns have higher yarn-to-metal friction coefficient (23). Ring, rotor and friction spun cotton, polyester and viscose yarns' frictional behavior were discussed and friction-spun yarn showed the highest yarn-to-yarn friction and lowest yarn to guide friction followed by rotor and ring-spun yams for cotton and viscose fibres. The highest yarn to ceramic friction values belonged to the friction-spun PES yarn and is followed by rotor and ring-spun yarns. With a decrease in the number of wraps (for measurement of yarn-to-yarn friction), the input-tension level, and fibre fineness and with an increase in speed and twist level, friction decreased (24).

Following the developments in the ring spinning frame, spinners are focused on the properties and process parameters of less hairy yarns notwithstanding the friction properties of compact and sirospun yarns have not attracted sufficient attention. For these reasons, the aim of this study is to investigate the frictional properties of the yarns by considering the effect of yarn count, spinning method (ring, siro, compact, compact-siro) and strand spacing (for sirospun yarns).

Experimental

In this study, identical yarns of varying parameters including yarn type, yarn count, and strand spacing (for only sirospun yarns) were produced with the same twist factor (α_e 4,5) and from the same long staple cotton roving to eliminate variability in raw material. Totally, 24 different types of yarns were produced in ring, compact, siro and compact siro spinning systems, in three different linear densities (Ne 20, Ne 30 and Ne 40) (Table 2). Compact and compact siro yarns produced on Rieter K45 compact spinning machine whereas siro and ring spun yarns produced on Rieter G30 ring spinning machine, with the same spindle speed of 14000 rev./min and at the same production conditions for all yarn types. According to previous researches, the effect of twist coefficient on frictional properties was not significant, so it is not taken as a parameter (23). On the other hand, strand spacing, which can be defined as the distance between two parallel rovings fed to drafting arrangement in siro spinning method, is an important parameter effecting yarn characteristics (25). Therefore three different strand spacing (3mm, 4mm and 7mm) was used for the production of siro and compact-siro yarns.

Table 2. Some structural properties of the cotton yarns used in the experimental study (Twist factor α_e4,5).

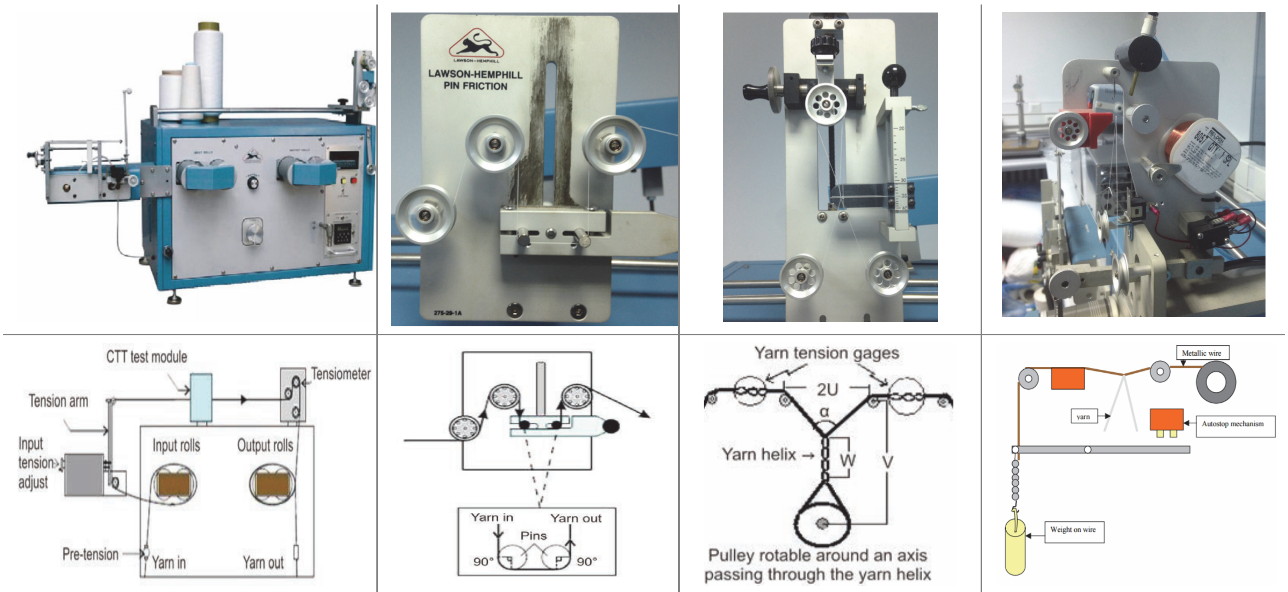
Yarn no.	*Yarn code*	*Yarn count*	*Spinning system*	*Strand spacing*
1	K2	Ne 20	Compact	-
2	K3	Ne 30	Compact	-
3	K4	Ne 40	Compact	-
4	KS2-3	Ne 20 (Ne 40/2)	Compact-siro	3 mm
5	KS2-5	Ne 20 (Ne 40/2)	Compact-siro	5 mm
6	KS2-7	Ne 20 (Ne 40/2)	Compact-siro	7 mm
7	KS3-3	Ne 30 (Ne 60/2)	Compact-siro	3 mm
8	KS3-5	Ne 30 (Ne 60/2)	Compact-siro	5 mm
9	KS3-7	Ne 30 (Ne 60/2)	Compact-siro	7 mm
10	KS4-3	Ne 40 (Ne 80/2)	Compact-siro	3 mm
11	KS4-5	Ne 40 (Ne 80/2)	Compact-siro	5 mm
12	KS4-7	Ne 40 (Ne 80/2)	Compact-siro	7 mm
13	S2-3	Ne 20 (Ne 40/2)	Siro	3 mm
14	S2-5	Ne 20 (Ne 40/2)	Siro	5 mm
15	S2-7	Ne 20 (Ne 40/2)	Siro	7 mm
16	S3-3	Ne 30 (Ne 60/2)	Siro	3 mm
17	S3-5	Ne 30 (Ne 60/2)	Siro	5 mm
18	S3-7	Ne 30 (Ne 60/2)	Siro	7 mm
19	S4-3	Ne 40 (Ne 80/2)	Siro	3 mm
20	S4-5	Ne 40 (Ne 80/2)	Siro	5 mm
21	S4-7	Ne 40 (Ne 80/2)	Siro	7 mm
22	R2	Ne 20	Ring	-
23	R3	Ne 30	Ring	-
24	R4	Ne 40	Ring	-

The basic physical properties of the yarns such as mass coefficient of variation (CV%), number of thin places, number of thick places, number of nep, yarn hairiness (H) and standard deviation of hairiness (sH) values were measured by Uster Tester 3 evenness tester. Besides, yarn tenacity (Rkm) and breaking elongation (%) were measured by Uster Tensojet.

Produced yarns were tested for obtaining friction coefficient, lint generation and abrasiveness on a Lawson-Hemphill CTT (Continuous Tension Transport) tester (Figure 1), at Ege University. CTT instrument provides the closest conditions to the processing steps of the yarns with its dynamic testing principle. Weak spot detection, lint generation, yarn abrasion, dynamic tension-friction and stick-slip tests can be carried out with interchangeable test attachments (26).

During production, the yarn tension is affected by various machine part interaction such as tension bars, yarn guides, needles, loom parts etc. This phenomenon is simulated through applying constant input tension, monitoring the output tension on the yarn and measuring the build-up tension on the yarn. By this way, friction coefficient can be obtained according to ASTM D 3108 and D3412 (Table 2) (27, 28). The software calculates the coefficient of yarn friction using the input and output tension values as well as the number of wraps and apex angle (Fig. 1).

For the measurement of friction coefficient, yarn is moved at 100 m/min speed in contact with itself (3 turns) at a specified wrap angle (35°apex angle) for yarn-to-yarn friction coefficient and in contact with a metal surface using a specified wrap angle (180°) for yarn-to-metal friction coefficient. As a result of these contacts, the output tension on the yarn changes. The software calculates the coefficient of yarn friction using the difference in the tension values as well as the number of wraps and wrap angle according to the formulas given in Table 3.The abrasiveness of the yarn, which causes frequent changes of the contacting machine parts and increases productions costs can be tested by running the yarn over a standard abrasion wire. The length of yarn required to sever the wire is recorded. CTT Lint Generation module enables to determine the amount of the lint, generated during the running of 1 km long yarn that is wrapped around itself, under constant tension at a test speed of 360m/min. In this test, yarn is tested dynamically under the condition of yarn to yarn friction to simulate actual production conditions, particularly during weaving. Generated lint is collected on a filter paper and measured amount is expressed as mg/1km (26).



CTT	Yarn-to-metal friction	Yarn-to-yarn friction [8]	Wire abrasion [24]

Figure 1. CTT (Continuous Tension Transport) tester and test attachments for measuring friction coefficient and abrasion.

Table 3. The principle and standards for obtaining yarn-to-yarn and yarn-to-metal coefficient of friction.

Yarn to yarn friction	Yarn to metal friction
ASTM D 3412-07	ASTM D 3108-07
Twisted strand method	Yarn to solid material friction (Capstan formula)
$$\mu = \frac{\ln(T_2/T_1)}{4\pi(n-0.5)\sin\beta/2}$$	$$\mu = \frac{\ln\left(\frac{T_2}{T_1}\right)}{\theta}$$
β, is 35° (lower apex angle between two yarns)	Θ is the cumulative wrap angle (radian)
μ, is the coefficient of friction	N, is the number of wraps (n=3)
T_1, is the input tension	T_2, is the output tension

The test results were evaluated by SPSS software to examine the effects of yarn production parameters on yarn frictional properties. For this purpose, variance analyses were performed by using 95% confidence intervals. Initially, the effect of spinning method and yarn count on yarn physical, mechanical and frictional properties were evaluated. At the second step, the effect of strand spacing on the properties of sirospun and compact siro spun yarns were analyzed and evaluated.

Results and Discussion

The mean values of yarn evenness, yarn hairiness, yarn tenacity and elongation values for all test yarns are given in Table 4.

Correlation analyses and the effect of yarn count and spinning method on yarn frictional properties

Correlation analyses were conducted in order to analyze the relationship between the physical and frictional properties of the yarns and Pearson correlation coefficients (r) are given in Table 5. Based on correlation analysis, yarn hairiness has a negative significant effect on the friction coefficients and evenness values of the yarns. Besides, it correlates with the spinning method and finer yarns have lower hairiness, as expected. As the roughness of the yarn surface increases, coefficient of friction increases, and this result is compatible with the studies carried out previously (11, 17, 23).

Yarn count has positive and statistically significant correlation with both µYM and µYY values and the power of the relation between µYM is very high (r=0,933). Finer yarns have higher friction coefficients due to the reduction in surface area of the yarn (Fig. 2). This result is parallel with the results of Altaş and Kadoğlu. As the yarn gets thinner, the mass variation of the yarn increases and friction coefficient increases, as well. The Pearson correlation coefficients between yarn evenness-yarn count and yarn evenness-friction coefficients are very high. Only the number of thin places has a negative relation with µYY.

In terms of spinning method, it can be seen from Table 6 that the yarn-to-metal and yarn-to-yarn friction coefficient of the compact yarns have the highest values, while siro spun yarns have the lowest yarn-to-metal friction coefficient value for all yarn counts. Besides, statistical evaluations showed that the differences between the yarn-to-yarn friction coefficients of the yarns produced in different systems and yarn-to-metal coefficients of siro-ring and compact-compact siro yarns are not statistically significant (Table 6).

Table 4. The mean values of the basic yarn properties.

SM	*Yarn count*	*SS (mm)*	*Yarn evenness*				*Yarn hairiness*		*Tenacity*		*Elongation*	
			CV %	*Thin pl. (-50%)*	*Thick pl. (+50%)*	*Neps (+200)*	*H*	*sH*	*(Rkm)*	*CV%*	*(%)*	*CV%*
C	Ne 20	-	9,44	0	1	1	4,60	0,89	31,07	6,54	6,31	5,78
	Ne 30	-	11,08	0	2	1	3,81	0,77	31,33	7,38	6	7,85
	Ne 40	-	12,01	0	6	6	3,35	0,74	29,72	7,95	5,64	8,06
CS	Ne 20	3	9,38	0	0	0	3,79	0,72	29,61	6,33	6,38	7,41
		5	10,06	0	2	1	3,73	0,55	31,55	5,84	6,46	7,26
		7	9,94	0	0	1	4,32	0,79	30,48	6,33	6,38	7,49
	Ne 30	3	9,84	0	2	2	3,35	0,70	30,18	6,8	6,36	8,19
		5	10,58	0	2	2	3,18	0,61	31,46	6,66	6,21	6,79
		7	10,27	0	1	2	3,88	0,78	30,07	5,93	6,21	7,6
	Ne 40	3	10,22	1	1	4	3,06	0,63	31,06	6,74	5,44	7,89
		5	10,72	1	2	4	2,83	0,57	32,62	6,99	5,73	7,85
		7	10,66	0	2	6	3,38	0,68	31,7	6,64	5,68	8,66
S	Ne 20	3	8,58	0	0	0	4,81	0,92	32,87	6,16	6,4	6,72
		5	8,47	8	0	0	4,61	0,90	33,8	5,91	6,39	6,47
		7	8,48	0	0	0	4,76	0,93	33,2	5,34	6,39	6,55
	Ne 30	3	9,78	0	0	3	4,42	0,89	30,01	5,9	5,79	6,39
		5	9,99	0	1	1	4,03	0,87	30,03	6,01	6	7,82
		7	9,93	0	0	1	3,97	0,83	30,47	6,27	6,04	6,89
	Ne 40	3	10,68	1	1	2	3,96	0,93	30,56	6,93	5,53	7,17
		5	10,88	0	2	2	3,85	0,89	30,13	7,36	5,72	7,28
		7	11,10	0	3	4	3,65	0,84	30,04	7,14	5,6	7,53
R	Ne 20	-	9,11	0	1	0	4,91	0,98	29,48	7,24	6,25	7,39
	Ne 30	-	10,82	0	0	1	4,24	0,95	28,06	7,94	5,71	7,83
	Ne 40	-	11,93	1	4	2	3,92	0,94	27,2	8,49	5,44	7,7

SM: Spinning method, C: compact, CS: Compact-siro, S: Siro, R: Ring, SS: Strand spacing.

Table 5. Pearson correlation coefficients between yarn count, spinning method and yarn properties.

	Spin. Meth.	*Ne*	*µ YM*	*µ YY*	*CV%*	*H*	*Rkm*	*% El*
Spin.Meth.	1	0,000	-0,082	-0,077	-0,162	0,450**	-0,504	0,234
Ne	0,000	1	0,933**	0,336*	0,832**	-0,659**	-0,361	0,651*
µ YM	-0,082	0,933**	1	0,076	0,757**	-0,626**	-0,278	0,603*
µ YY	-0,077	0,336*	0,076	1	0,359*	-0,305	-0,487	0,527
CV%	-0,162	0,832**	0,757**	0,359*	1	-0,631**	-0,511	0,712**
H	0,450**	-0,659**	-0,626**	-0,305	-0,631**	1	-0,103	-0,192
Rkm	-0,504	-0,361	-0,278	-0,487	-0,511	-0,103	1	-0,744**
% El	0,234	0,651*	0,603*	0,527	0,712**	-0,192	-0,744**	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

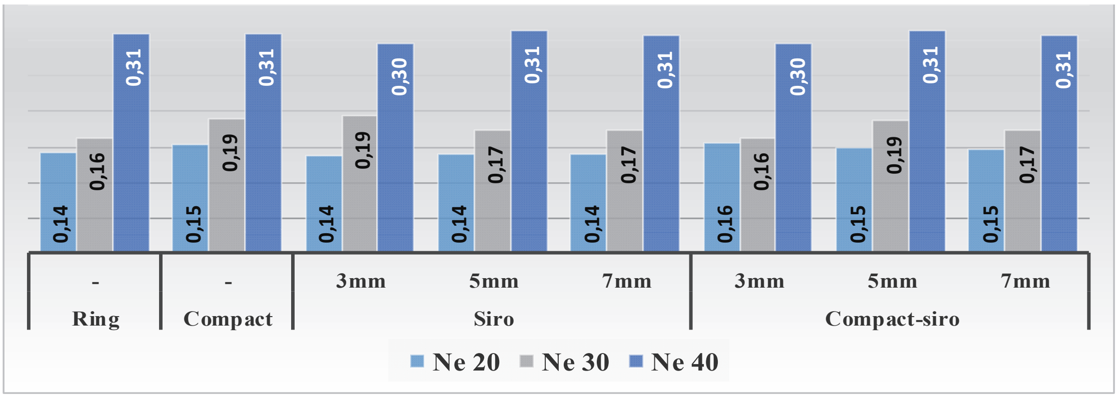


Figure 2. Yarn-to-metal friction coefficients of the yarns spun in different spinning systems with different yarn counts

Table 6. Multivariate Comparison results for spinning method.

SM	µ YM 1	µ YM 2	SM	µ yy 1	SM	H 1	H 2	H 3	H 4	SM	CV% 1	CV% 2	CV% 3
S	0,202		**R**	0,1811	**CS**	3,28				S	9,76		
R	0,2056		**CS**	0,1811	**C**		3,88			CS		10,485	
CS		0,2167	**S**	0,1822	**S**			4,16		R		10,60	
C		0,2178	**C**	0,1833	**R**				4,40	C			10,868
Sign.	**0,831**	**0,992**		**0,751**		**1,000**	**1,000**	**1,000**	**1,000**		**1,000**	**0,726**	**0,096**

SM: Spinning method, C: compact, CS: Compact-siro, S: Siro, R: ring,

It is found that, yarn count has a statistically significant effect on yarn-to-metal friction coefficient, yarn-to-yarn friction coefficient, yarn hairiness and yarn evenness. The lowest yarn-to-metal friction coefficient, yarn-to-yarn friction coefficient, yarn evenness and the highest yarn hairiness values belong to coarser yarns (Ne 20). Finest yarns in the experimental plan have the highest friction coefficients and lowest yarn hairiness values (Table 7).

Effect of strand spacing on siro and compact siro yarns frictional properties

As stated in previous papers, the effect of strand spacing on the yarn evenness and hairiness of sirospun yarns were found statistically significant. In terms of frictional properties, siro and compact siro yarn producing with 5 mm strand spacing have the lowest yarn-to-metal, highest yarn-to-yarn frictional coefficient and it is just the contrary for the yarns produced with 7 mm. However, only the differences between the yarn-to-yarn coefficient of frictions of the sirospun yarns produced with 7 mm and 3 mm were found statistically significant; closer the rovings, higher the friction coefficient. Compact siro yarns produced with 3 mm strand spacing have the lowest yarn-to-metal and yarn-to-yarn friction coefficients but the effect of strand spacing was not significant for compact siro yarns (Fig. 3).

In parallel to the previous results, the difference between the yarn-to-metal friction coefficients of the compact and ring spun yarns is more pronounced at finer yarns whereas for coarser ones the properties of such yarns are comparable approximately, and any one of the spinning systems can replace the other (29).

Lint shedding and abrasion characteristics of the yarns

The lint generation tendency under yarn to yarn friction of the experimental yarns were measured and evaluated. The results have indicated that compact siro yarns generate minimum lint whereas ring spun yarns generate the maximum lint, as expected due to yarn hairiness (Figure 4), alike a previous study (30). Besides, as the yarn gets finer, lint generation decreases in relation to the decrease in yarn diameter, yarn hairiness and friction area. Yarn count's affect and the difference between the lint factors of Ne20 and Ne40 yarns were statistically significant (p=0,022).

Instead of comparing the length of the yarns required to sever the wire, a specific length of the yarn (5000mt) run over the wire at a speed of 360 m/min and it is tried to observe the abrasion through examining under the microscope. Yarns, at a constant tension run over a tensioned 0,2 mm copper wire. By using this method, yarn abrasion test were performed for Ne 20 and Ne 40 compact and ring spun yarns and the abrasion is evaluated optically. Yarn images are given in Fig. 5.

Table 7. Multivariate Comparison results for yarn count.

	µ YM			µ yy			CV%			H		
	1	2	3	1	2	3	1	2	3	1	2	3
Ne20	0,15			0,17			9,25					4,47
Ne30		0,18				0,19		10,63			3,84	
Ne40			0,31		0,18				11,40	3,48		
Sig.	**1,00**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**

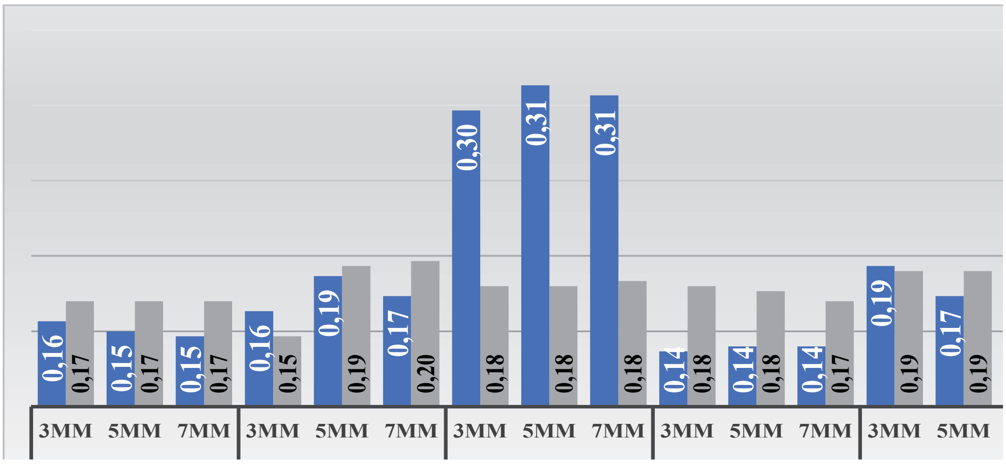


Figure 3. Friction coefficients of the siro and compact siro yarns spun in with different strand spacings.

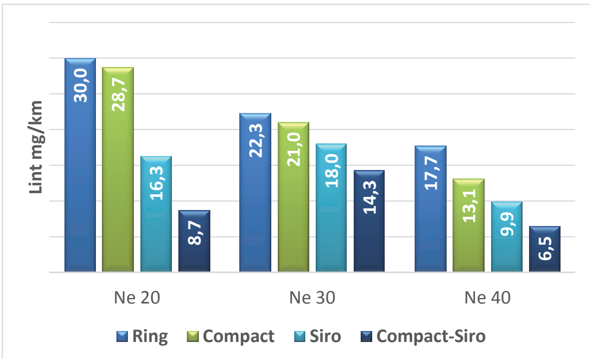


Figure 4. Lint factor values of the yarns spun with different spinning methods.

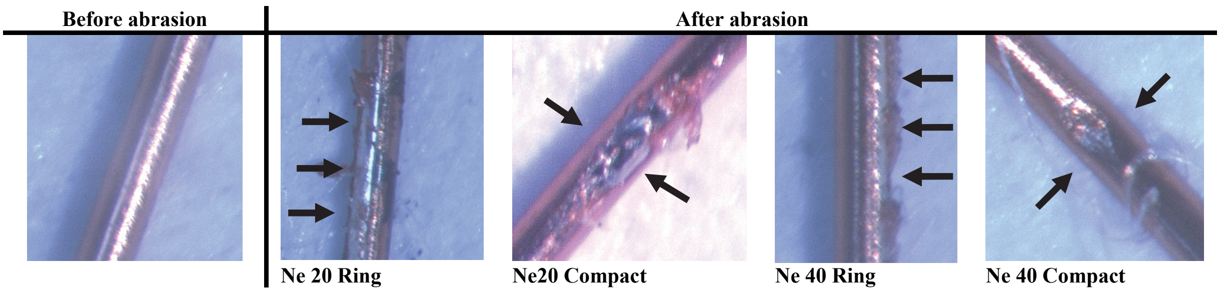


Figure 5. The appearance of the wires after yarn abrasion test.

It is observed that the abrasion of the wire by friction was occurred on a wider area with ring spun yarns. The higher hairiness of the ring spun yarns may cause this. On the other hand, compact yarns left a narrow but a deep abrasion mark on the wire due to fibres holding more tightly together within the yarn.

Conclusion

With the purpose of investigating the frictional properties of the less hairy yarns by considering the effect of yarn count, spinning method (ring, siro, compact, compact-siro) and strand spacing, identical yarns of varying parameters were produced with the same twist factor and the same cotton roving. Results of the can be summarized herein below.

- Yarn count has positive and statistically significant correlation with both µYM and µYY values and the power of the relation between µYM is very high. Furthermore, yarn count has a statistically significant effect on the yarn friction coefficients, yarn hairiness and yarn evenness. The lowest yarn-to-metal friction coefficient, yarn-to-yarn friction coefficient, yarn evenness and the highest yarn hairiness values belong to coarser yarns.

- In terms of spinning method, friction coefficients of the compact yarns have the highest values, while siro spun yarns have the lowest yarn-to-metal friction coefficient value for all yarn counts. However, generally the influence of the spinning method on the frictional properties is statistically insignificant. This result is parallel with Kılıç and Sülar's statement. It is supposed that this is an influence of the yarn structure of the experimental yarns, which are close to each other in terms of fibre orientation, alignment, and arrangement. Yarns are produced in different spinning systems but they are all based on ring spinning theory, indeed.
- As for the effect of strand spacing, yarn evenness and hairiness of sirospun yarns were affected statistically significantly, as in our previous study (25). Still, it is seen that there is no systematical change depending on strand spacing for frictional properties.
- When the effect of spinning technology on the lint generation tendency of the yarns analyzed it is correlated with yarn hairiness evidentially. Finer yarns with lower hairiness cause less lint shedding during yarn-to-yarn friction.

In conclusion, the frictional behavior of the yarns has an important role on their processability. Therefore the results of this study can be used for the optimization of process parameters of hairless yarns. Testing the frictional properties of the yarns after vacuum steaming and winding processes may change the results. Because twist liveness of the yarns are prone to create problems during testing and reduction in weak places of the yarn during winding will influence testing performance positively. To investigate the effects of these parameters will have a considerable contribution for further studies.

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