A Study on Physical Properties of Microfilament Composite Yarns

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ABSTRACT

In the textile industry, composite yarns with multifilament cores are used to impart strength. There are various spinning systems to produce composite core-spun yarns. In this study, to determine the effects of filament fineness on yarn characteristics of composite yarns, polyester filaments with medium, fine and micro fiber linear densities were used as the core portion and cotton fiber was used as the sheath material. Yarn samples were manufactured using a modified ring spinning system with four different yarn counts and constant twist factor (α_e). The effect of filament linear density on yarn tensile properties, unevenness and imperfections was determined. Yarn evenness and tensile properties were compared with 100% cotton ring spun yarn and to each other. When relative amount of core increases, it was observed that composite yarns had improved tenacity and elongation compared to 100% cotton ring spun yarn. Although filament fineness was found to have a significant effect on the CVm % properties, there was no statistical effect on imperfections other than yarn count parameter.

Keywords: microfilament, composite yarn, modified ring spinning, yarn properties

INTRODUCTION

Composite yarns are produced from yarns with differing advantageous properties. Composite yarns produced by covering sheath fibers around a filament or staple fiber core with a certain twist are known as core-spun yarns [1, 2]. If an elastic filament is used as the core, this yarn is called as "*elastic core-yarn*" If filament or staple fibers are used as the core, it is called "*hard (rigid) core-yarn*". The core part contributes strength and functional properties. The sheath fiber is responsible for traditional appearance, handle and comfort properties.

Elastic core-spun yarns have the same feel as the shield fibers, and possess good moisture absorption because of the natural fibers wrapped around it. The elasticity of the yarn can be modified to fit different end-products [3-11]. Spandex elastomeric fiber is often used as the core component. Polyamide, polyester and derivatives of polyester filaments are also used as core components Wrapping them with cotton, polyester, viscose, acrylic or blends of these staple fibers improves the durability of the end product. Production of core-spun yarn has developed through modification of different spinning machines (friction spinning, air-jet spinning and modified ring spinning systems etc.), beginning in the mid-1960s [12]. There are various studies available about these spinning systems and new attempts at core-spun yarn production [13-29]. The modified ring spinning system is the most widely used method for producing core-spun yarn.

There are various studies regarding the mechanical, physical and structural properties of both elastic and hard core-spun yarns and fabrics. To obtain the optimum yarn properties, choosing the exact twist and draft is essential [10]. When the twist factor increases, it positively affects the tensile properties of elastic cotton core-spun yarn [4,6]. Elastane ratio is an important parameter that influences the tenacity and elongation at break of wrapped elastane core-spun yarns with the same twist factor. The tenacity and elongation of core-spun yarn is affected negatively with increasing the elastane percentage [6, 10, 30].

In addition to elastomeric fibers, drawn, crimped and textured multi or mono filaments are also used to produce core-spun yarn named as hard or rigid core yarn. Filaments contribute the strength, durability, aesthetic and functional properties of the fabrics [14]. Çelik et al. determined the influence of both twist factor and filament blend ratio on strength of yarn consisting of polyester filament covered with cotton fiber [31]. Twist factor and roving positions have highly significant influences on the strength of core-spun yarns [32]. Rameshkumar et al. analyzed the effect of core positioning on sheath coverage, core sheath ratios as well as plying effects on yarn and knitted fabric properties using polyester filament and waste silk [33]. Pramanik et al. compared cotton covered with crimped and drawn polyester filament hard-core yarns and 100 % cotton ring yarn [28]. Jeddi et al. also compared nylon monofilament core to 100 % cotton yarns with different twist factors and filament pretensions [34]. Mahmood et al. observed better yarn count at minimum twist factor. Optimum yarn strength of nylon monofilament core cotton ring spun yarn was obtained at the lowest spindle speed used [2].

Conductive core-spun yarn containing metal wire i.e. copper or stainless steel was fabricated by using an added guide mechanism on the roller-weighting arm of a ring spinning system and different feed angles and twist levels were used to evaluate properties of the resulting yarns [35-40].

A microfiber is a fiber or a filament of linear density approximately 1 dtex (0.9 denier) or less [41-46]. The relationship between fiber classification and fiber linear density is illustrated in *Table I*. Micro denier fibers have excellent flexibility, improved regularity, higher elongation, better softness, drape, dimensional stability and wicking, thus ensuring better mechanical and comfort properties [42,43]. They are also relatively strong and durable in relation to other fabrics of similar weight, and they are more breathable and more comfortable to wear [46].

TABLE I. Relationships between fiber linear density and classification [46].

Fiber linear density, dtex/f	Fiber classification
>7	Coarse
7.0-2.4	medium
2.4-1.0	fine
1.0-0.3	micro
<0.3	Super-microfibers including nanofibers when their cross-sectional dimensions are within a range of nm, that is of <0.1dtex or <1μm

This study considers false twist textured polyester filament yarns with different filament fineness at the same linear density. There is little research reported on the effect of filament fineness (especially microfilaments) on composite yarn characteristics. Polyester filaments were used as the core part of the hard core-spun yarn. The effect of linear density of polyester filament on tensile properties, unevenness and imperfections of hard core-spun yarns with different counts were analyzed and compared with each other and 100 % cotton ring-spun yarns.

MATERIALS AND METHODS

For this study, 110 dtex false twist textured polyester filament yarns with different filament fineness were used as core components and covered with combed cotton fiber to manufacture hard core-spun yarn samples at different yarn counts. Polyester filament yarns were obtained from Korteks Company located in Bursa, Turkey. All false twist textured polyester filament yarns selected are commonly used products. The properties of these polyester filament yarns are shown in *Table II.*

TABLE II. Physical properties of polyester filament yarns.

Fiber Classification	Decitex/ Filament	Fiber Count, dtex/f	Tenacity, cN/dtex	Elongation, %
Medium	110/36	3.05	4.11	20.97
Fine	110/96	1.15	3.77	21.04
Micro	110/144	0.76	3.69	18.85
	110/192	0.57	3.77	17.16
	110/333	0.33	4.17	19.44

Cotton fiber with 30 mm length, 4.5 micronaire and 34 g/tex strength was used as the sheath fiber. To compare with hard core-spun yarn samples, 100 % ring-spun cotton yarns were also produced at the same yarn counts (Ne 16/1, Ne 20/1, Ne 24/1, and Ne 28/1) using the same production parameters Different yarn counts were produced in order to evaluate the contribution of core part at different core/sheath ratios.

The hard core-spun yarn samples were produced on a modified ring spinning system as illustrated in *Figure 1*. The filament yarn was positioned on an additional feed roller at creel of the machine and passed through a V-grooved roller at an angle to the front top roller. Finally, it was fed in with cotton fibers behind the front roller at the drafting unit, resulting in hard core-spun yarns.

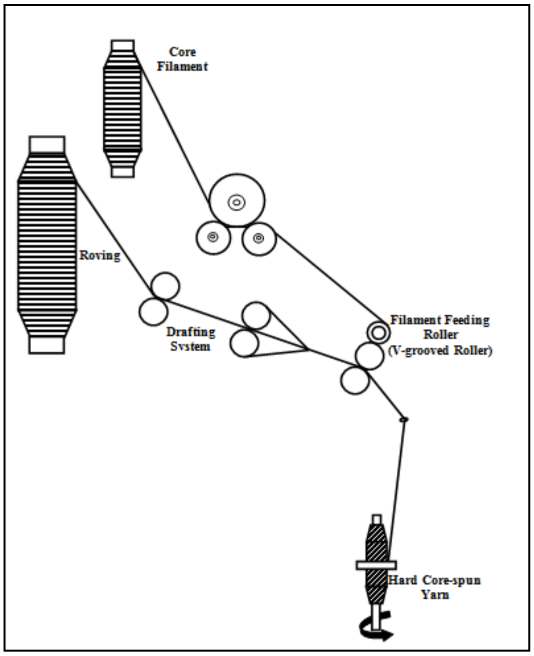

FIGURE 1. Modified ring spinning system [12].

Twist factor (α_e=3.9), spindle speed (8000 rpm) and combed cotton sliver count (Ne 0.6) were constant for all yarn samples produced. The production order of hard core-spun yarn samples is shown in *Table III*.

TABLE III. Production order of hard core-spun yarn samples.

Machine Order	Manufacturer
Blowroom	Trützschler (2006)
Carding Machine	Trützschler (2006)
Drawframe (1)	Rieter RSB 35(2005)
Unilap (Combing Preparation)	Rieter 600 (2003)
Combing	Rieter E62 (2003)
Drawframe (2)	Rieter RSB 40(2005)
Roving Frame	Zinser 668 (2003) 120 flyers
Ring Frame	Zinser 351 (2003) 240 spindles
Bobbin Machine	Shlafhorst 338 Autocore (2005)

Production parameters for hard core-spun yarn and 100 % combed cotton yarn are shown in *Table IV*. As seen in *Table IV*, twist values are increased from Ne 16/1 to Ne 28/1 for hard core-spun yarn samples as a result of applying constant twist factor. A total of twenty hard core-spun yarn samples and four 100 % cotton yarn samples were produced.

All yarn tests were carried out after conditioning the specimens in a standard atmosphere at 20 ± 2°C temperature and 65 ± 2% relative humidity for 24 hours according to the standard of BS EN ISO 139:2005+A1:2011.

TABLE IV. Production parameters of hard core-spun yarn samples.

Yarn Count (Ne)	16/1	20/1	24/1	28/1
Core/Sheath Ratio (%)	30/70	37/63	45/55	52/48
Draft Ratio	27	33	40	47
Twist (t.p.m)	614	687	752	812

Breaking strength and elongation measurements of all yarn samples were carried out on Uster® Tensorapid-3 in accordance with BS EN ISO 2062:2009. Determination of single-end breaking force and elongation at break was carried out using a constant rate of extension (CRE) tester. Thirty tests were performed on each yarn sample; reported values represent the average of those test results. Coefficient of variation of mass (CVm %), total imperfections (thin places, thick places and neps) and hairiness were measured using Uster® Tester-4 at a speed of 400 m/min for 5 minutes according to ISO 16549:2004. Twenty tests were performed on each yarn sample; reported values represent the average of those test results.

To perform the statistical evaluation, the regression analysis and Analysis of Variance (ANOVA) of the test results were done using Design Expert 6.0.1. statistical software package at 95% confidence interval. A general factorial design was performed to determine the various degrees of relationships between the independent and dependent parameters. For this purpose, as an experimental of design, filament fineness and yarn count were chosen as independent parameters and breaking strength, elongation, unevenness, yarn imperfections and hairiness were evaluated as dependent parameters *(Table V)*.

TABLE V. Experimental design.

Independent Parameter	Level
Filament Fineness (dtex)	0*- 0.33- 0.57- 0.76- 1.15- 3.05
Yarn Count (Ne)	16- 20- 24- 28

*100% Cotton yarn

Regression models that explain the relationship between the independent parameters and yarn properties were established and models offered by the software for all dependent variables were evaluated.

The statistical analysis performed the best fit models for all dependent variables. Finally, regression equations were determined. The lack of the filament in the cross-section of the yarn filament fineness was taken as "0" value for cotton ring-spun yarn samples.

The percent contribution of the independent parameters and their interactions on the dependent parameters were calculated. To decide whether the parameters were significant or not, *p* values were examined. If "*p*" value of a parameter is greater than 0.05 ($p > 0.05$), the parameter is not important and should be ignored and removed from the model [47]. This process is known as hierarchical backward elimination for multiple regression analysis. In addition, the hierarchy of the model parameters is taken into consideration. After elimination of non-significant parameters, the statistical analysis is repeated.

RESULTS AND DISCUSSIONS

Breaking Strength and Elongation

Figure 2 and Figure 3 show the results of breaking strength and elongation for composite yarns at five different filament finenesses of each yarn count. Histograms with error bar graphs were drawn. The results show that highest breaking strength is obtained from Ne 28/1 hard core-spun yarn for all filament finenesses. This situation is due to the presence of more polyester filaments in the cross section and a higher core ratio, which contributes to the breaking strength of the yarn samples. When compared with 100 % cotton yarn, it is seen that core part affects the breaking strength positively. Twist factor was kept constant for all yarn counts, so twist value increased from Ne 16/1 to Ne 28/1. This affects the breaking strength of samples with polyester filament yarns used as core part with different finenesses. As seen in *Figure 3*, elongation values of hard core-spun yarns are much higher than those of 100 % cotton yarns. This indicates that the filament core part greatly affects the hard core-spun yarn elongation.

ANOVA analysis and regression equations of yarn samples are illustrated in *Table VI*. Filament fineness and yarn count have a significant effect on breaking strength at $\alpha = 0.05$ confidence interval. The coefficient of variation (R^2) is a measurement of "*goodness of fit*" and ranges from "0" to "1". Analysis explains about 91.4 % of the variability in yarn breaking strength for all yarn samples. The adjusted R-Square for the model ($R^2_{adj.} = 88.4$ %) is close to the ordinary R^2. This situation indicates a true goodness of fit. $R^2_{adj.}$ is found as 93.4 % for elongation statistical analysis and it is evaluated as statistically significant. It is seen that the effect of filament fineness is statistically significant on both yarn breaking strength (p=0.0014) and elongation ($p < 0.0001$) of yarn samples. The effect of yarn count is statistically significant on both yarn breaking strength ($p < 0.0001$) and elongation ($p < 0.0001$) of yarn samples. The presence of the filament in the yarn cross-section makes the yarn more elastic with respect to 100 % cotton yarns. When the core ratio is increased from Ne 16/1 to Ne 28/1, it is seen in *Figure 3* that elongation of all hard core-spun yarn samples also increases due to the presence of the false twist textured yarns in the core. Elongation increases are obtained for the Ne 24/1 and Ne 28/1 hard core-spun yarns compared to 100% cotton yarn. Regression equations of breaking strength and elongation are also given in *Table VI* as Eq. (1) and Eq. (2), respectively.

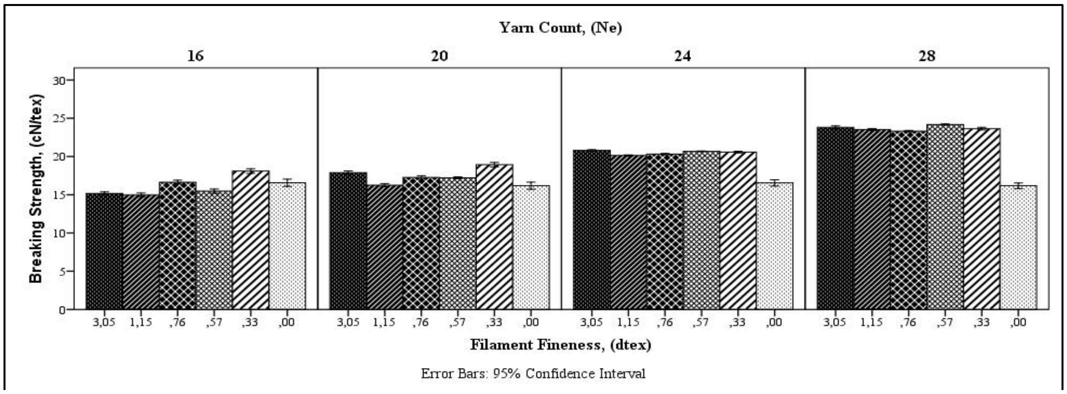

FIGURE 2. Effect of filament fineness on the breaking strength of each yarn count.

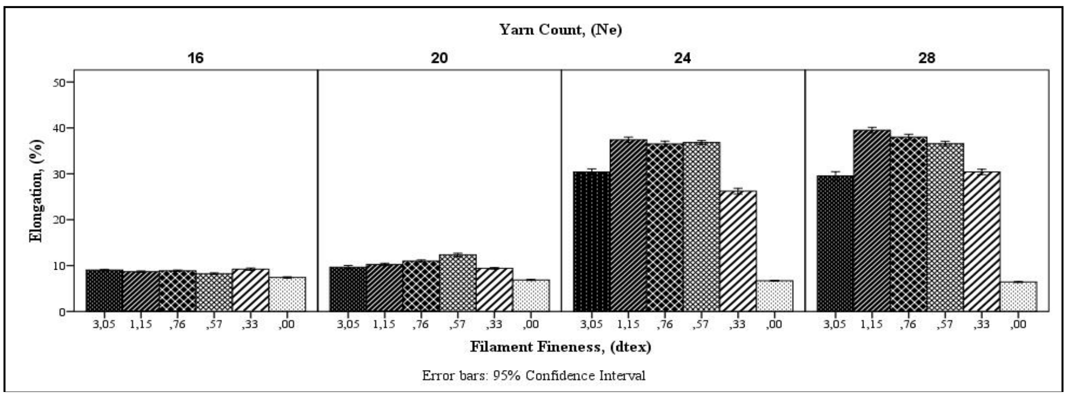

FIGURE 3. Effect of filament fineness on the elongation of each yarn count

TABLE VI. ANOVA analysis and regression equations.

Physical Properties	Sum of Squares	DF	Mean Square	F Value	Prob > *p*	R-Squared	Adjusted R-Squared
Breaking Strength, cN/tex	196.14	6	32.69	30.07	<0.0001	0.9139	0.8835
Breaking Strength =	14,57607-8,50610Filament fineness+ 0,095310Yarn count-6,81608Filament fineness2+0,91543Filament fineness xYarn count+2,76985Filament fineness3-0,23413Filament fineness2xYarn count						(1)
Elongation, %	3781.21	8	472.65	41.59	< 0.0001	0.9569	0.9339
Elongation =	922.17761-42.21829 Filament fineness-131.76747 Yarn count -10.58853Filament fineness2+6.15026Yarn count2+ 4.01042Filament finenessxYarn count+7.19567Filament fineness3-0.093251Yarn count3-1.14009Filament fineness2x Yarn count						(2)
CVm, %	15.68	4	3.92	67.46	<0.0001	0.9342	0.9204
CVm =	7.09372-2.34663 Filament fineness+0.17307 Yarn count+2.27638Filament fineness2-0.51171Filament fineness3						(3)
Thin Places, -40 % /km	1147.14	3	382.38	23.48	<0.0001	0.7789	0.7457
Thin Places =	69.09781- 0.56188Filament fineness- 7.42553Yarn count+ 0.19979Filament fineness2						(4)
Thick Places, +50 % /km	2617.85	3	872.62	19.3	<0.0001	0.7433	0.7048
Thick Places =	64.61872+ 0.95730Filament fineness- 7.09015Yarn count+ 0.21113Yarn count2						(5)
Neps, + 200 % /km	4088.25	5	817.65	23.45	<0.0001	0.8699	0.8299
Neps =	-6.12033 -75.24842Filament fineness+0.99351Yarn count+21.39855Filament fineness2+3.96261Filament fineness xYarn count-1.12599Filament fineness2xYarn count						(6)
Hairiness, Uster® H	6.3	3	2.1	33.01	< 0.0001	0.832	0.8068
Hairiness =	7.88843 +1.65131Filament fineness-0.072058Yarn count-0.48261Filament fineness2						(7)

Yarn Unevenness (CVm %)

Yarn unevenness values of hard core-spun and 100 % cotton yarns are shown *Figure 4*. Unevenness values of 100 % cotton yarns are the highest among all yarn samples for all yarn counts.

Textured filament yarns with different fineness used as core improves the unevenness. The findings contributed with the information already present in the literature [34,48].

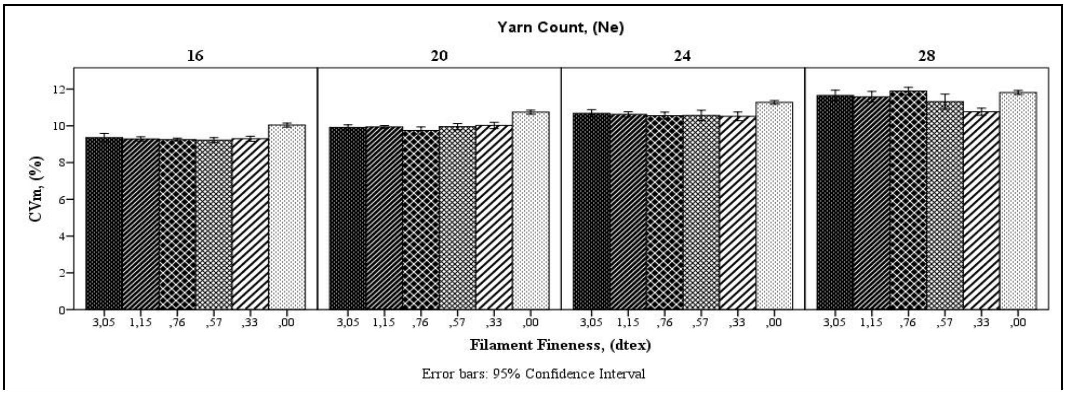

FIGURE 4. Effect of filament fineness on CVm % value of each yarn count.

As a result of the increasing core ratio in the hard core-spun yarn structure, CVm% increases and the maximum unevenness values are obtained for Ne 28/1 yarn samples.

As seen in *Figure 4*, unevenness values of the yarn samples with different filament fineness are similar for all yarn counts except Ne 28/1. Upon the examination of microfilament polyester yarns, unevenness values are seen to decrease. This is probably due to the increasing number of filaments in the yarn structure.

In addition, the effect of filament fineness and yarn count on CVm% is statistically significant and adjusted R- Square is 93.42%. It was also observed that false twist textured filament yarns at the core part improve the yarn uniformity. The regression equation of CVm% is illustrated as Eq. (3) in *Table VI*.

Imperfections

Statistical analysis of thin places (-40%/km), thick places (+50% /km) and neps (+200% /km) of hard-core spun and 100 % cotton yarns are given in *Table VI*. When the ANOVA comparison of filament fineness is taken into consideration, it is seen that thin place values of hard core-spun yarns are not statistically significant with 0.5061 p value. Although the contribution of filament fineness is least ($p>0.05$), it is the main parameter so it was isolated in the model.

On the other hand, yarn count has a significant effect on thin places (p = <0.0001). Furthermore, adjusted R-Square with 74.57 % for both yarn count and filament fineness are statistically significant.

The effect of filament fineness on thick places is not important (p = 0.4966). It was isolated in the model again because it is main parameter. The model explains that the relationship between filament fineness and yarn count on thick places is 74.33 %.

When the effect of both filament fineness and yarn count on imperfections is examined, the neps values are seen as statistically significant (R^2 = 86.99 %). However, the significance is 0.2054 and <0.0001 for filament fineness and yarn count, respectively. The regression equations for thin places, thick places and neps are shown as Eq. (4), Eq. (5), and Eq. (6) in *Table VI*, respectively.

Hairiness

Hairiness (Uster® H) values of both hard core-spun and 100 % cotton yarns with different filament fineness and yarn counts are given in *Figure 5*. In general, hairiness values are found to be higher with respect to 100 % cotton yarn. It is seen that the effect of both filament fineness (p = 0.0031) and yarn count (p < 0.0001) are statistically significant with respect to hairiness. Increasing amount of core negatively affects the hairiness value of hard core-spun yarn. The regression equation (Eq. (7)) for the hairiness value yields 83.20 % adjusted R-Square as seen in *Table VI*.

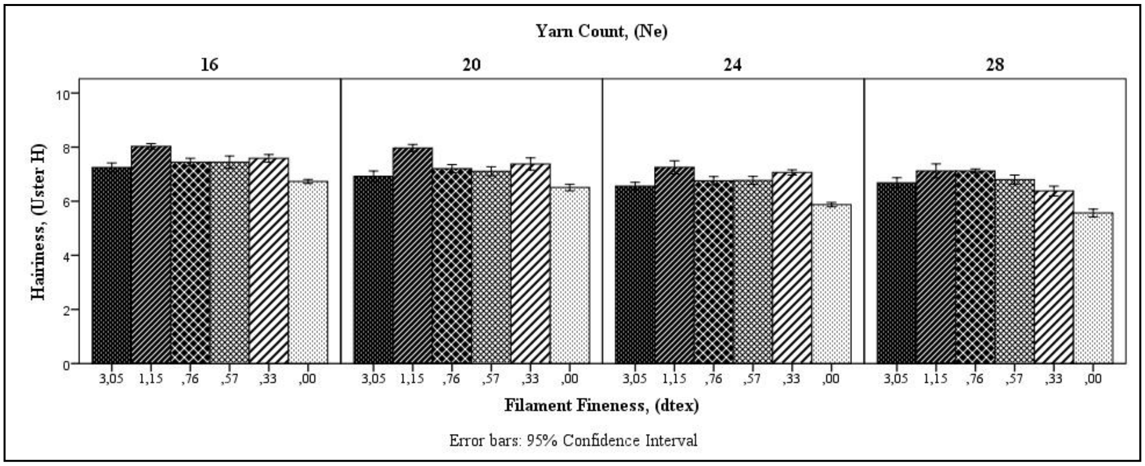

FIGURE 5. Effect of filament fineness on hairiness of each yarn count.

CONCLUSION

Statistical analysis showed that the filament fineness and yarn count significantly affected breaking strength and elongation properties of hard core spun yarns with false twist polyester cores. Although core filament fineness has a significant effect on the unevenness properties, it was determined that there is no statistical effect on imperfections other than yarn count. On the other hand, higher hairiness values are obtained for hard core-spun yarns than for 100 percent cotton yarns.

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