TEKSTİL VE MÜHENDİS

(Journal of Textiles and Engineer)

http://www.tekstilvemuhendis.org.tr

The Effect of Drawing Ratio and Cross-Sectional Shapes on the Properties of Polypropylene CF and BCF Yarns

Çekim Oranı ve Enine Kesit Şeklinin Polipropilen CF ve BCF İplik Özellikleri Üzerindeki Etkisi

Mustafa KEBABCI[1], Osman BABAARSLAN[2], Selcen ÖZKAN HACIOĞULLARI[2], Abdurrahman TELLİ[2]
[1]KETS Exclusive Home Textiles, İstanbul, Turkey
[2]Cukurova University, Department of Textile Engineering, Adana, Turkey

Online Erişime Açıldığı Tarih (Available online): 30 Aralık 2015 (30 December 2015)

Bu makaleye atıf yapmak için (To cite this article):

Mustafa KEBABCI, Osman BABAARSLAN,Selcen ÖZKAN HACIOĞULLARI, Abdurrahman TELLİ (2015): The Effect of Drawing Ratio and Cross-Sectional Shapes on the Properties of Polypropylene CF and BCF Yarns, Tekstil ve Mühendis, 22: 100, 47-53.

For online version of the article: http://dx.doi.org/10.7216/1300759920152210006

Araştırma Makalesi / Research Article

THE EFFECT OF DRAWING RATIO AND CROSS-SECTIONAL SHAPES ON THE PROPERTIES OF POLYPROPYLENE CF AND BCF YARNS

Mustafa KEBABCI[1]
Osman BABAARSLAN[2]
Selcen ÖZKAN HACIOĞULLARI[2]
Abdurrahman TELLİ[2*]

[1]KETS Exclusive Home Textiles, İstanbul, Turkey
[2]Cukurova University, Department of Textile Engineering, Adana, Turkey

Gönderilme Tarihi / Received: 31.08.2015
Kabul Tarihi / Accepted: 17.11.2015

ABSTRACT: Polypropylene (PP) is a versatile and widely used polyolefin polymer with outstanding properties such as low density, easy processability, lower cost, low melting point, etc. Properties of the polymer, fiber cross-section and process parameters have an important influence on the filament yarn properties. In this study, PP filament yarns as C-shaped and round cross-sectional shapes were produced with five different drawing ratios by using CF and BCF yarn types. We focused on changes of yarn test results (linear density, tenacity-breaking elongation, shrinkage in boiling water and the amount of spin finish lubricants) with the effect of drawing ratios, cross-sectional shapes and yarn types (CF and BCF). The findings from this study make several contributions to the current literature. We found that drawing ratios, cross-sectional shape and yarn types are effective on the testing results separately. Furthermore, these differences are statistically significant when their effects are taken together.

Keywords: Filament yarn, drawing ratio, cross-sectional shape, yarn types, yarn properties

ÇEKİM ORANI VE ENİNE KESİT ŞEKLİNİN POLİPROPİLEN CF VE BCF İPLİK ÖZELLİKLERİ ÜZERİNDEKİ ETKİSİ

ÖZET**:** Polipropilen düşük yoğunluk, kolay işlenebilirlik, düşük maliyet, düşük erime noktası gibi özellikleri öne çıkan bir polyolefin polimeridir. Polimerin özellikleri, lif enine kesit şekli ve işlem parametreleri filament iplik özellikleri üzerinde etkilidir. Bu çalışmada c ve yuvarlak kesit şekillerinde beş farklı çekim oranında CF ve BCF polipropilen filament iplikler üretilmiştir. Çalışmada bu farklı üretim parametreleriyle ipliklerdeki incelik, mukavemet-uzama, yağlayıcı madde miktarı ve kaynama çekmesi değişimlerine odaklanılmıştır. Çalışmanın bulguları mevcut literatüre katkı sağlamaktadır. Çekim oranı, enine kesit şekli ve iplik türünün test sonuçları üzerinde ayrı ayrı etkileri bulunmuştur. Ayrıca bu etkiler birlikte ele alındığında da istatistiksel olarak farklılıklar tespit edilmiştir.

Anahtar Kelimeler**:** Filament iplik, çekim oranı, enine kesit şekli, iplik tipi, iplik özellikleri

**** Sorumlu Yazar/Corresponding Author:*** *atelli@cu.edu.tr*
DOI: *10.7216/1300759920152210006, www.tekstilvemuhendis.org.tr*

1. INTRODUCTION

The production of synthetic fibers has been growing as a necessity. Because, cultivation fields of natural fibers are declining and consumption demands are rising due to rapid population growth. Academic studies on the production and processing of synthetic fibers are also increasing simultaneously with the consumption of synthetic fibers. In recent years, polypropylene (PP) is very important polyolefin polymer and the fastest growing polymer family [1]. Polyolefin began to replace other plastics and materials with lower production and processing costs. PP is a versatile and widely used polyolefin polymer with outstanding properties such as low density, easy process ability, lower cost, good wicking, low melting point, etc. PP fibers are often preferred directly for some textile products as home textiles, upholstery fabrics, carpet backing and sports clothing. Furthermore, PP fibers are used a broad spectrum in the industrial applications (geotextiles, motor vehicles, surgical masks, diapers, hygiene bands, filters, automotive parts, etc.) thanks to their superior properties. Produced filament yarns consist of mono- or multi filaments with no twist to moderate levels of twist. Moreover, the filament yarns can be plied, textured, or crimped to enhance the aesthetic and mechanical characteristics according to requirements of applications [1-3].

Multiple production parameters determine yarn structure and features during production of continuous filament yarns. Besides the structure and properties of the polymer, fiber cross-section and yarn types have an important influence on the filament yarn properties. Fiber cross-section is determined by the shape of spinneret on the spinning machine. Special yarn characteristics can be developed by using different cross-section of the spinneret on filament production machines and these yarns can be used in various fields. Naturally, the changes of yarn properties will affect fabric structure and features. For example, the cloth handle, drape, brightness, air permeability, tenacity, elongation, etc. are affected by mentioned parameters [4-6].

According to literature findings, there are many factors in determining mechanical properties of the filament yarns. Karacan and Benli (2011) investigated the influence of annealing treatment on the molecular structure and the mechanical properties of isotactic PP fibers [7]. Bueno et al. (2004) examined surface properties of knitted fabrics produced from polyester yarns having different fiber cross-sectional shapes [8]. Tascan and Vaugh (2008) reported the effects of cross-section shape and linear density parameters on the acoustic insulation feature of nonwoven surfaces [9]. To determine the effect of fiber fineness and cross-section shape factors on yarn and woven fabric features, Varshney et al. (2011) used circular, trilobal, tetrakelion, scalloped shapes and various fiber fineness for polyester and viscose fibers [10]. Karacan and Benli (2011) performed X-ray diffraction study for isotactic PP fibers produced with take-up speeds of 2500-4250 m/min [11]. However, there is no study about the effects of drawing ratio together with cross-section and yarn types on the properties of PP yarns in previous studies. Then, this paper will focus on the changes of yarn test results (linear density, tenacity-breaking elongation, shrinkage in boiling water and the amount of spin finish lubricants) with the effect of drawing ratios, fiber cross-section and filament yarn types.

2. MATERIAL AND METHOD

In this study, a PP homopolymer was used for trial production. The polymer was used as a granule form. The used polymer is particularly suitable for producing continuous filament (CF), bulk continuous filament (BCF) and staple fiber yarns in carpet pile and upholstery sector. Table 1 shows the PP Homopolymer technical data.

Yarns were manufactured with laboratory type filament yarn production machine as seen in Figure 1 [12]. Yarns were produced according to melt spinning principle. On the machine; 1, 2 and 3 godets have only heater and drawing process were realized with these three godets. Drawing ratio is the rate of velocity differences between 3rd and 1st godet. Yarns are produced by using 1.5, 2, 2.5, 3 and 3.25 drawing ratios. Drawing ratio, cross-section and yarn types were variable. Other parameters were maintained as a constant during production. Yarn spinning parameters are presented in Table 2.

Table 1. PP homopolymer technical data

Properties		Unit	Value	ASTM Test Method
Resin Properties	Melt Flow Rate (230°C & 2.16 kg load)	g/10 min.	24	D 1238
	Density (23°C)	kg/m³	905	D 792
Mechanical Properties	Tensile Strength (at yield)	MPa	32	D 638
	Tensile Elongation (at yield)	%	12	D 638
	Flexural Modulus (1% Secant)	MPa	1550	D 790A
	Notched Izod Impact Strength (23°C)	J/m	30	D 256
	Rockwell Hardness, R-Scale	-	100	D 785
Thermal Properties	Vicat Softening Point	ºC	152	D 1525B
	Heat Deflection Temperature (455 KPa)	ºC	118	D 648

Figure 1. Laboratory type filament yarn spinning machine [12]

Table 2. Machine Parameters for Yarn Spinning

Spinning Section	CF Yarn Production (Speed, rev/min)					BCF Yarn Production (Speed, rev/min)					Temperature (°C)
Drawing Ratios	**1,5**	**2,0**	**2,5**	**3,0**	**3,25**	**1,5**	**2,0**	**2,5**	**3,0**	**3,25**	
Pre-Godet	380	380	380	380	380	380	380	380	380	380	-
Godet 1	380	380	380	380	380	380	380	380	380	380	75°C
Godet 2	500	500	500	500	500	500	500	500	500	500	125°C
Godet 3	570	760	950	1140	1235	570	760	950	1140	1235	135°C
Godet 4	525	700	875	1050	1138	-	-	-	-	-	-
Texturizing Drum	-	-	-	-	-	315	420	525	630	683	145°C
Godet 5	525	700	875	1050	1138	380	507	633	760	823	-
Winder	1050	1400	1750	2100	2275	900	1200	1500	1800	1950	-

On the lab type filament yarn spinning machine, texturizing process is also performed with texturizing jet as shown in Figure 2. In this system, hot and compressed air pass from a funnel and expand throughout jet. After this expansion, yarns crash wall of funnel. Then the filaments in the yarn elaborated and intermingled each other. For these reasons, yarn length becomes shorter and volume of yarn increase. Yarn is cooled to keep dimensional stability as constant as possible. Cooling process is occurred with cooling drum. In this experiment, air pressure of texturing was set at 6 bars and air temperature was performed as 145 ºC during the production [13]. Various tests were applied on the yarns to examine the effects of mentioned parameters and to control of the parameters which need to be kept constant during production. Yarn samples were conditioned for 24 hours at 20±2 °C temperature and 65±2 % relative humidity, which are standard atmospheric conditions.

Figure 2. Texturizing jet used on filament spinning machine

Yarn linear density, tenacity, breaking elongation, shrinkage in boiling water and the amounts of spin finish lubricants were measured so as to investigate yarn characteristics. Moreover, multivariate analysis of variance (MANOVA) was performed on yarn linear density, tenacity and breaking elongation which were taken as basis of the study. Yarn linear density test was done according to BS EN ISO 2060 standard procedure. Tenacity and breaking elongation tests were carried out by using TITAN tensile testing device in conformity with BS EN ISO 2062 standard. Shrinkage in boiling water tests were performed using DIN 53840 standards with Texturmat ME device. Finish material amount tests were carried out with Oxford MQA 7020 Device according to BS 3582 test standard.

3. RESULTS and DISCUSSION

Test results and evaluations that were examined the effect of drawing ratio and cross-section of the fiber/filament in CF and BCF yarns are given in below. The results obtained from CF filament yarns are presented in Table 3 and the results obtained from textured yarns are shown in Table 4. Table 5 also provides multivariate analysis of variance (MANOVA) analysis of the taken together the results of drawing ratio with cross-section and yarn types.

From the data in Table 5, it is apparent that drawing ratios, cross-section and yarn types have an important effect on the yarn properties, respectively. Furthermore, these results are significant at the p=0,000* level when their effects are taken together. As Table 5 shows, MANOVA analysis were also found fit in terms of R Squared and Adjusted R Squared (a, b, c).

Table 3. CF yarns test results

Drawing Ratios	Linear Density (tex)		Tenacity (cN/tex)		Breaking Elongation (%)		Shrinkage in Boiling Water (%)		Spin Finish Lubricants (%)	
	Round	C	Round	C	Round	C	Round	C	Round	C
1.5	209	209	14,91	15,39	46,49	142,04*	7,48	6,73	1,294	1,363
2.0	157	158	22,5	22,61	25,68	31,18	4,92	4,24	1,275	1,322
2.5	125	126	32,3	30,51	23,26	23,83	3,3	3,5	1,288	1,243
3.0	104	105	39,68	38,49	17,91	20,35	2,9	3,16	1,308	1,312
3.25	96	96	44,15	41,37	17,57	18,57	2,49	2,63	1,354	1,305

Table 4. BCF yarns test results

Drawing Ratios	Linear Density (tex)		Tenacity (cN/tex)		Breaking Elongation (%)		Shrinkage in Boiling Water (%)		Spin Finish Lubricants (%)	
	Round	C	Round	C	Round	C	Round	C	Round	C
1.5	224	241	14,25	12,76	146,56*	148,73*	7,33	6,5	1,137	1,197
2.0	168	189	20,77	17,74	32,8	46,14	6,5	6,08	1,206	1,216
2.5	132	136	27,81	28,3	23,99	34,13	5,83	5,67	1,212	1,218
3.0	110	110	36,6	33,42	20,29	24,19	4,5	4,83	1,241	1,244
3.25	100	101	41,78	32,98	21,79	25,32	3,67	4,17	1,288	1,285

*Yarns were extended as far as the distance of jaws of Titan Universal machine for these drawing ratios. Tests were not completed in these drawing ratios when the distance of jaws finished. For that reason these results are not final and are extension has stopped by test device.

Table 5. Multivariate analysis of variance (MANOVA) statistical analysis results

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig. (p)	Partial Eta Squared
Corrected Model	Linear Density (tex)	626746,097(a)	19	32986,637	19908,418	**0,000***	0,999
	Tenacity (cN/tex)	29907,561(b)	19	1574,082	1467,961	**0,000***	0,990
	B. Elongation (%)	562397,538(c)	19	29599,870	2345,101	**0,000***	0,994
Intercept	Linear Density (tex)	6282613,596	1	6282613,596	3791744,446	**0,000***	1,000
	Tenacity (cN/tex)	242243,161	1	242243,161	225911,686	**0,000***	0,999
	B. Elongation (%)	582.599,231	1	582599,231	46157,439	**0,000***	0,994
Drawing	Linear Density (tex)	604574,847	4	151143,712	91219,732	**0,000***	0,999
	Tenacity (cN/tex)	28013,498	4	7003,375	6531,223	**0,000***	0,989
	B. Elongation (%)	423580,525	4	105895,131	8389,726	**0,000***	0,992
Cross-section	Linear Density (tex)	1641,276	1	1641,276	990,559	**0,000***	0,780
	Tenacity (cN/tex)	335,816	1	335,816	313,176	**0,000***	0,528
	B. Elongation (%)	16337,106	1	16337,106	1294,336	**0,000***	0,822
Yarn Types	Linear Density (tex)	11867,972	1	11867,972	7162,675	**0,000***	0,962
	Tenacity (cN/tex)	944,822	1	944,822	881,124	**0,000***	0,759
	B. Elongation (%)	20793,186	1	20793,186	1647,376	**0,000***	0,855
Drawing X Cross-section	Linear Density (tex)	1433,895	4	358,474	216,350	**0,000***	0,756
	Tenacity (cN/tex)	280,376	4	70,094	65,369	**0,000***	0,483
	B. Elongation (%)	28716,694	4	7179,174	568,783	**0,000***	0,890
Drawing X Yarn Types	Linear Density (tex)	4677,070	4	1169,268	705,688	**0,000***	0,910
	Tenacity (cN/tex)	110,749	4	27,687	25,821	**0,000***	0,269
	B. Elongation (%)	32717,709	4	8179,427	648,029	**0,000***	0,903
Cross-section X Yarn Types	Linear Density (tex)	1157,582	1	1157,582	698,635	**0,000***	0,714
	Tenacity (cN/tex)	88,436	1	88,436	82,474	**0,000***	0,228
	B. Elongation (%)	4972,645	1	4972,645	393,966	**0,000***	0,585
Drawing X Cross-section X Yarn Types	Linear Density (tex)	1393,455	4	348,364	210,248	**0,000***	0,750
	Tenacity (cN/tex)	133,864	4	33,466	31,210	**0,000***	0,308
	B. Elongation (%)	35279,672	4	8819,918	698,773	**0,000***	0,909
Error	Linear Density (tex)	463,937	280	1,657			
	Tenacity (cN/tex)	300,242	280	1,072			
	B. Elongation (%)	3534,160	280	12,622			
Total	Linear Density (tex)	6909823,630	300				
	Tenacity (cN/tex)	272450,963	300				
	B. Elongation (%)	1148530,929	300				
Corrected Total	Linear Density (tex)	627210,034	299				
	Tenacity (cN/tex)	30207,803	299				
	B. Elongation (%)	565931,698	299				

(a) (R^2 = 0,999) (Adjusted R^2 = 0,999), (b) (R^2 = 0,990) (Adjusted R^2 = 0,989), (c) (R^2 = 0,994) (Adjusted R^2 = 0,993)

3.1. Graphical Analysis of the Test Results

3.1.1. Linear Density

To know yarn linear density value is important for starting to the other tests. The changes of yarn linear density with drawing ratio are compared in Figure 3. The increase of drawing ratios cause decrease in yarn linear density as “tex” in terms of “C” and “round” fiber cross-section. Indeed, the increase of drawing ratios has a significant effect on each filament and this condition is affecting all filaments. Yarns were produced approximately same linear density for CF yarns with same drawing ratio and different cross-section, because feeder and winder velocity were not changed. However, this situation was not possible in 1.5 and 2 drawing ratio for BCF yarns. Although winder velocity set up same value, yarns winded different velocity owing to winder tension. Thus, yarn linear density have only same counts in 2.5, 3 and 3.25 drawing ratios for BCF yarns because of similar winder tensions.

When the combined effect of drawing ratios and yarn types on yarn linear density is analyzed, it is apparent from Figure 3 that BCF yarns have higher linear density than CF yarns both round and C shapes. Despite the fact that the extruder feeds are similar, winding speed of yarns coming from texturizing drum changes in winding tension. Therefore, winding velocity in BCF yarns was different from CF yarns because of winding tension.

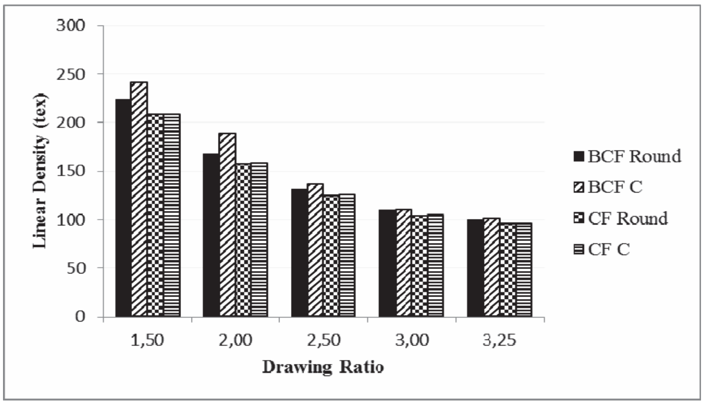

Figure 3. The relationship between drawing ratio and yarn linear density

3.1.2. Tenacity and Breaking Elongation

Tenacity and breaking elongation tests, which give an idea about yarn structure, are the most important tests for yarn production. As seen in Figure 4, there was a strong relationship between the drawing ratios and tenacity of the yarns. The increase of tenacity values were obtained with the increase in drawing ratios. The increase of drawing applied to each filament cause decrease in distance between filaments. As a consequence, filaments range in parallel through yarn length. The contribution of each filament to yarn tenacity by the virtue of parallel filaments shows rise with the increase in drawing ratio.

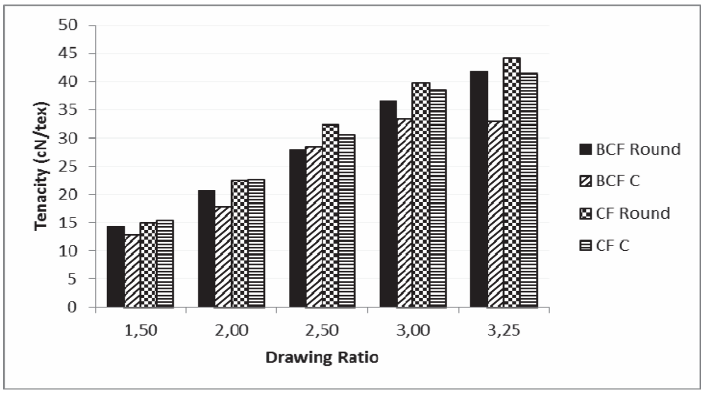

Figure 4. Drawing ratio effect on yarn tenacity

There are no significant differences between different cross-section in the same drawing ratios and yarn types as seen also in Figure 4. But, yarns which have round cross-section have higher tenacity than "C" type cross-section of yarn in 3.25 drawing ratios for both yarn types. This result can be explained that filaments in 3.25 drawing ratios have the highest crystallinity area in the structure among all the other yarn drawing ratios. Thereby, individual broken filaments in C-shaped have begun before the round-shaped because of the increase in tenacity. This situation was observed more clearly in BCF yarns because round-shaped yarns are more resistant than C-shaped yarns against texturizing process. From tenacity results in Figure 4, we can see that CF yarns have higher tenacity than BCF yarns in both cross-sections for the same drawing ratios. Because BCF yarns have an extra processes compared to CF yarns. BCF yarns pass from texturizing jet within the 145 ºC. This temperature is higher than softening temperature of PP. Moreover, filaments crash into texturizing drum under 6 bar pressure. The contribution to total yarn tenacity are reduced with damaged parallel structure of filaments because of these production conditions.

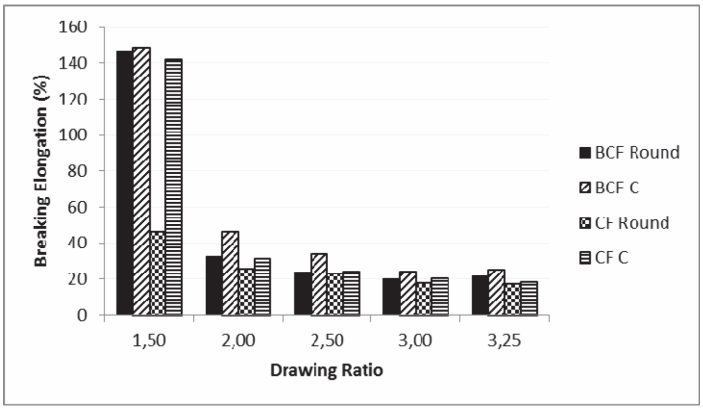

Figure 5. Drawing ratio effect on yarn breaking elongation

The effects of drawing ratios on breaking elongation can be compared in Figure 5. The decrease in breaking elongation of round and C-shaped were obtained with the increase in drawing ratios. Breaking elongation of C-shaped filaments has higher values in both yarn types. This result shows that C-shaped yarns are more stretchable than round-shaped yarns. The breaking elongations obtained from BCF yarns in both cross-sections have higher values according to yarns produced as CF yarns (Figure 5). As can be seen from Table 3 and 4, yarns with C-shaped filaments of CF and BCF types have higher breaking elongation in 1.5 drawing ratio according to others. Because breaking elongation was not completed, yarns were only extended as far as the distance of jaws of strength tester (Titan universal test device) for this drawing ratio. For that reason these results are not final. These yarns are more stretchable than the measured values as elongation.

Tenacity and breaking elongation results of this study confirm the earlier findings on the literature. Vitrauskas et al. (2005) indicated the decrease of breaking elongation with the rise of drawing ratios and they also find out increase in tenacity [14]. It was also emphasized that yarns with round cross-sectional shapes yielded higher tenacity and breaking elongation comparing to the other lobed and channeled shapes [15,16]. This study has argued extra important information with texturizing yarn results besides these findings.

3.1.3. Shrinkage in Boiling Water

Shrinkage in boiling water tests are important to know how yarns react to heat of oncoming processes depending on usage areas. Test results are given in Figure 6. As shown in Figure, shrinkage values clearly decrease with the increase in drawing ratios. And, the porous structure of the filaments gain a more rigid structure owing to the fact that filaments become parallel through yarn length. As a result of decreasing in porous structure, shrinkage results decrease with both cross-section and yarn types [13].

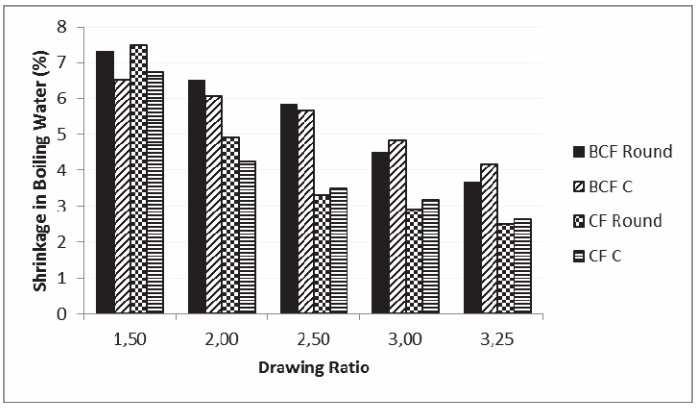

Figure 6: Drawing ratio effect on yarn shrinkage

There is a negative correlation in both cross-sections between drawing ratio and shrinkage results. There are more fluctuations on the result of round-shaped yarns according to C-shaped yarns (Table 3 and 4). Round-shaped yarns seem to be more resistant than C-shaped yarns with the increase of drawing ratios (Figure 6). Because individual filament breaks in the yarn has begun after 3.0 drawing ratio. In literature, there was also some information available relative to the hollow shaped yarns had greater shrinkage values in boiling water than the yarns with round cross-section [6].

3.1.4. Spin Finish Lubricants

Spin Finish lubricants can be applied during filament yarn production so as to make more resistant yarns against friction. The increase of cohesion between filaments in yarn structure provides and gives a great facility for subsequent process [15]. The amount of lubricant changes according to end-usage area, next processes and customer requests.

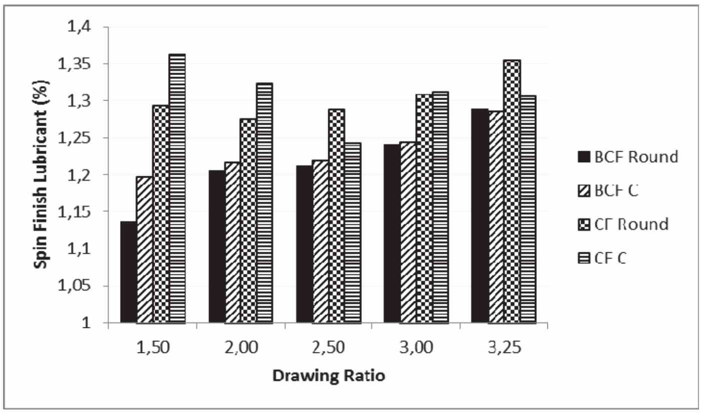

Figure 7. Variances in spin finish lubricants against yarn drawing ratio

It is apparent from Figure 7 that no significant differences were found between lubricant proportion and drawing ratios. Yarns produced as CF type have more lubricant than yarns obtained as BCF type. The changes in the amount of lubricants on CF and BCF yarns are not associated with drawing ratios. BCF yarns have lost some lubricant during texturizing process by the reason of heat and pressure [13]. Furthermore, we can see that the adsorbed amounts on C-shaped yarns have higher comparing to the round cross-section. These results show that spin finish lubricants can be penetrated easily into the yarn by the way of C-shaped structure.

4. CONCLUSION

This study focused on yarns produced with different drawing ratios and test results were analyzed for the yarns which have two cross-sectional shapes and yarn types (CF and BCF). The findings from this study make several contributions to the current literature. We found that drawing ratio, cross-section and yarn types are effective on the testing results separately. Furthermore, these differences are statistically significant when their effects are taken together. The drawing ratio, cross-section and yarn types have an important effect on yarn linear density, tenacity and breaking elongation. Besides, this study has found that CF yarns have higher tenacity than BCF yarns in both cross-sections for same drawing ratios. The decrease in breaking elongation of round and C-shaped were obtained with the increase in drawing ratios. The increases of drawing ratios cause clearly decrease in shrinkage values. There was a negative correlation in both cross-sections between drawing ratio and shrinkage results. No significant differences were found between lubricant proportion and drawing ratios. The changes in the amount of lubricants on CF and BCF yarns are not associated with drawing ratios. Moreover, the adsorbed amounts on C-shaped yarns have higher comparing to the round yarns.

Acknowledgement

This work was financial supported by the "Ministry of Science, Industry and Technology" within research program SAN-TEZ, project number: 00428.STZ.2009-2.

REFERENCES

1. Ugbloue, S.C.O., (2009), *Polyolefin Fibres- Industrial and Medical Applications*, Woodhead Publishing in Textiles, ISBN 978-1-84569-207-0, 406p.
2. Fourne, F., (1998), *Synthetic Fibers-Machines and Equipment, Manufacture, Properties- Handbook for Plant Engineering, Machine Design, and Operation,* Hanser/ Gardner Publications, ISBN 3-446-16072-8, 930p.
3. McIntyre, J. E., (2005), *Synthetic fibres: Nylon, polyester, acrylic, polyolefin*, Woodhead Publishing Ltd and CRC Press LLC, ISBN 0-8493-2592-7, 300p.
4. Özkan S., (2008), *Effect of filament cross-section shape, number of filaments and filament linear density on the properties of POY and textured yarn*, MSc Thesis, Cukurova University, 275p.
5. Babaarslan, O. and Hacıoğulları S.O., (2013), *Effect of fibre cross-sectional shape on the properties of POY continuous filaments yarns*, Fibers and Polymers; 14(1):146-151.
6. Karaca, E. and Özçelik F., (2007), *Influence of the cross-sectional shape on the structure and properties of polyester fibers*, Journal of Applied Polymer Science, 10: 2615-2621.
7. Karacan İ. and Benli H., (2011), *The Influence Of Annealing Treatment On The Molecular Structure And The Mechanical Properties Of Isotactic Polypropylene Fibers*, Journal of Applied Polymer Science, 122: 3322-3338.
8. Bueno M, Aneja AP and Renner, M., (2004), *Influence of the shape of fiber cross-section on fabric surface characteristics*, Journal of Materials Science, 39: 557-564.
9. Tascan M and Vaughn E, (2008), *Effects of fiber denier, fiber cross-sectional shape and fabric density on acoustical behavior of vertically lapped nonwoven fabrics*, Journal of Engineered Fibers and Fabrics, 3: 32-38.
10. Varshney RK, Kothari VK and Dhamija S, (2011), *Influence of polyester fibre fineness and cross-sectional shape on low-stress characteristics of fabrics*, The Journal of the Textile Institute, 102(1): 31-40.
11. Karacan İ. and Benli H., (2011), *"An X-Ray Diffraction Study for Isotactic Polypropylene Fibres Produced With Take-Up Speeds Of 2500-4250 M/Min*", Tekstil ve Konfeksiyon, 21: 201-209.
12. Özkan Haciogullari, S., (2014), *Design and Manufacture of Laboratory Type Filament Yarn Machine and Development of Original Product*, PHd Thesis, Cukurova University, 298p.
13. Kebabci, M., (2014), *Polypropylene Yarn Production with New Developed Laboratory Type Filament Yarn Production Method and Assessment of Yarn Specification,* MSc Thesis, Cukurova University, 95p.
14. Vitrauskas, A., Migliniate, R., Vesa, P., Puolakka, A., (2005), *Mechanical Properties of Polypropylene Multifilament Yarns in Dependence of Their Drawing Ratio*, Materials Science, 11 (4): 407-410.
15. Demir, A. and Behery, H., (1997), *Synthetic Filament Yarn-Texturing Technology,* (pp. 25-32), Prentice- Hall Inc., New Jersey.