Relationship between Yarn Properties and Process Parameters in False-Twist Textured Yarn

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ABSTRACT
The properties of false-twist textured yarns in the aspects of crimp characteristic and tensile behavior depend mainly on the draw ratio and the *D*/*Y* ratio. This study comprises investigations of the effect of *D*/*Y* ratio and draw ratio on the crimp and tensile properties and percent crystallinity. While there was no noticeable change on the percent crystallinity by altering these parameters, tenacity increased and crimp contraction decreased with increasing draw ratio, and crimp stability decreased when the *D*/*Y* ratio increased. K/S value also decreased with increasing draw ratio.

INTRODUCTION
One of the main disadvantages of man-made fibers is the flat geometry and smooth surface. The fiber waviness or crimp increases volume, resilience, moisture absorption, etc. Texturing methods have been developed to overcome this problem. False-twist texturing method is the most common process. False-twist texturing process can be investigated based on three main parameters, which are called 3t: tension, twist, and temperature. The properties of the textured yarn can be altered by changing these parameters [1]. Draw ratio, *D*/*Y* ratio, and heater temperatures are the main process parameters to change 3t.

The ratio of the disk surface speed to the yarn speed is usually referred to as *D*/*Y* ratio. *D*/*Y* ratio is calculated as follows:

$$D/Y = \frac{\text{circumferential speed of disks } (m/min)}{\text{throughput speed of yarn } (m/min)} \qquad (1)$$

If *D*/*Y* ratio is low, the yarn tension before twisting unit will be low and the tension after the twisting unit will be high [3-5]. This situation can cause yarn damages. Draw ratio is the ratio of center shaft speed to the input shaft speed as shown in *Figure 1* and is calculated as follows:

$$\text{Draw ratio} = \frac{\text{center shaft speed (m/min)}}{\text{input shaft speed (m/min)}} \qquad (2)$$

The draw ratio influences the final yarn linear density, tenacity, molecular orientation, dye uptake and dyeing uniformity, residual shrinkage, fiber breakages, etc. [1, 4].

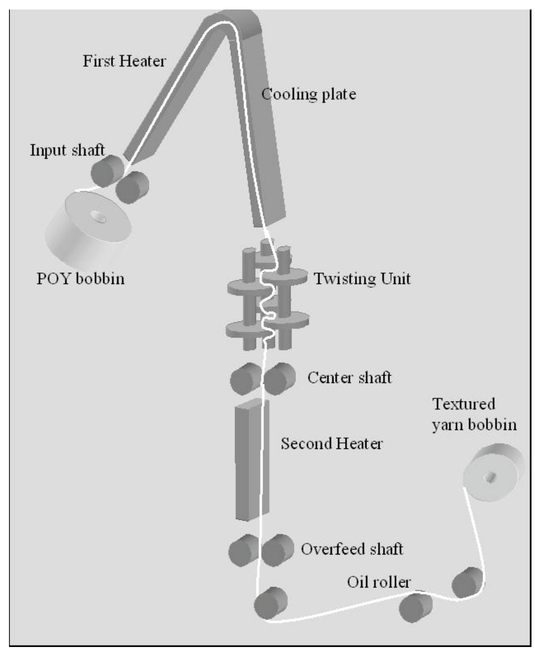

FIGURE 1. Barmag M profile false-twist texturing machine

The effect of draw ratio and *D*/*Y* ratio on the tensile and crimp properties of textured PET [poly(ethylene terephthalate)] yarn has been investigated in this paper. The study has been executed in the commercial range in order to detect effects of small changes on production parameters of textured yarn properties.

EXPERIMENTAL

Materials

150 denier, 96 filaments, semi-dull, PET partially oriented yarn (POY) was draw-textured on the lab-type Barmag AFK-M texturing machine with two heaters. Process speed was 650 m/min. The first heater length and temperature were 2.5 m and 190°C, respectively. Second heater length and temperature were 1.25 m and 165°C, respectively. Disk-type friction texturing unit was used. The disk configuration was 1+6+1. The disk material was ceramic and the disk thickness was 9 mm.

Methods

The simultaneous draw-texturing process was carried out. All the processing parameters except *D*/*Y* ratio and draw ratio were kept constant. *D*/*Y* values were 1.5, 2.0, and 2.5 and the draw ratios were 1.55, 1.60, and 1.65.

One-way ANOVA model was used in the experiments and results were analyzed accordingly.

Measurements

Degree of Crystallinity

The calculation of peak area on melting region according to *Eq. (3)* is very helpful in process development and material characterization. The peak area can also be used to identify the percent crystallinity of material [5]. The crystallinity measurements were performed using a Perkin–Elmer Sapphire differential scanning calorimeter. 140.1 mJ/mg was used for ΔH (fusion) for 100% crystallinity PET.

The samples were heated at a rate of 10°C/min. Two replicas have been made for crystallinity measurements for each temperature.

$$\% \text{ Crystallinity} = [\Delta H_m - \Delta H_c] / \Delta H_m^{\circ} \times 100\% \qquad (3)$$

ΔH_m : The heat of melting (J/g)
ΔH_c : Cold crystallization (J/g)
ΔH_m° : The heat of melting if the polymer were 100% crystalline (J/g) [12].

Tensile and Crimp Properties of the Multifilament Yarn

Breaking elongation and breaking strength of the yarn were tested according to ISO 2062 using SDL universal tensile tester having 2500 N load cell. Fifteen replicas were made for each temperature.

Crimp stability and crimp contraction tests were performed according to DIN 53840 using Textechno Texturmat ME.

Dyeing and Color Measurements

Dyeing was performed in a sample jet dyeing machine (ATAC, Turkiye). Color strength (K/S) values of the dyed samples were measured at maximum wavelength (630 nm) using a Hunter Lab, Lab Scan XE spectrophotometer under D 65 illuminate and 10° standard observer, with specular and UV components included.

RESULTS AND DISCUSSION

Degree of Crystallinity

The percentage crystallinity of the textured filaments decreases with increasing twist amount, which is determined by *D*/*Y* ratio, [4]. However, any noticeable difference could not be observed for draw ratio, *D*/*Y* ratio, and their interaction on crystallinity in this study as well as seen from *Table I*, according to *Figure 2* and ANOVA results for 5% significance level.

TABLE I. ANOVA tests for crystallinity dependent variable

Variance source	Sum of Squares	df	Mean Square	Fs	P
Draw ratio	2.6	2	1.291	0.57	0.58
D/Y	4.2	2	2.093	0.92	0.43
Draw ratio*D/Y	4.8	4	1.188	0.52	0.72
Error	20.4	9	2.265		
Total	35651	18			

R squared =0.361

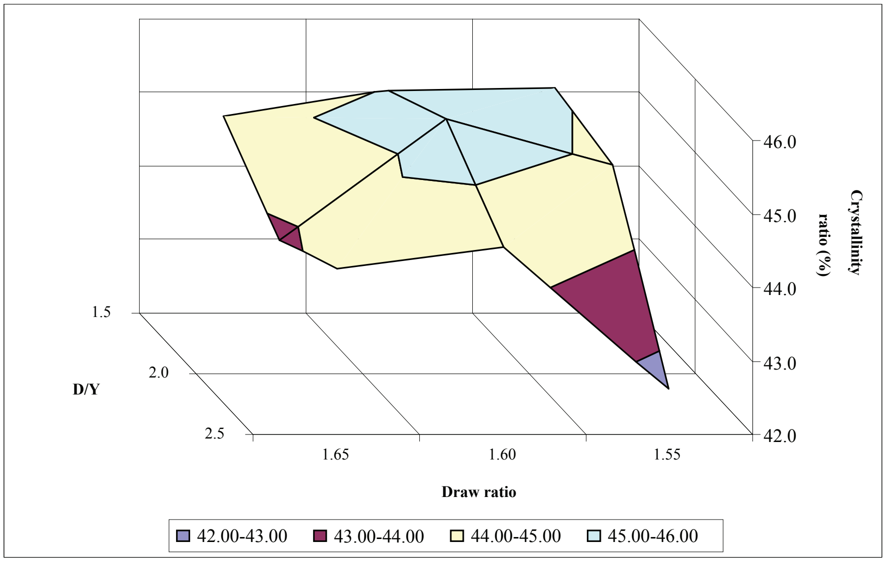

FIGURE 2. The influences of draw ratio and *D/Y* ratio on crystallinity ratio

Tenacity

Ghosh and Wolhar [6] and Pal et al. [4] found that textured yarn tenacity increases when the draw ratio is increased**.** Gupta et al. [1] also observed an increase in tenacity with an increase in tension. In this study, similar results were obtained as shown in *Table II* and *Figure 3*. According to SNK test results, the effects of draw ratios are different from each other for 5% significance level and yarn tenacity increases to 3.09 cN/dtex from 2.96 cN/dtex.

TABLE II. ANOVA tests for tenacity dependent variable

Variance source	Sum of Squares	df	Mean Square	Fs	P
Draw ratio	0.643	2	0.321	23.547	$2x10^{-9}$
D/Y	0.511	2	0.255	18.721	$7x10^{-8}$
Draw ratio*D/Y	0.141	4	0.035	2.580	0.04
Error	1.719	126	0.014		
Total	1246	135			

R squared =0.429

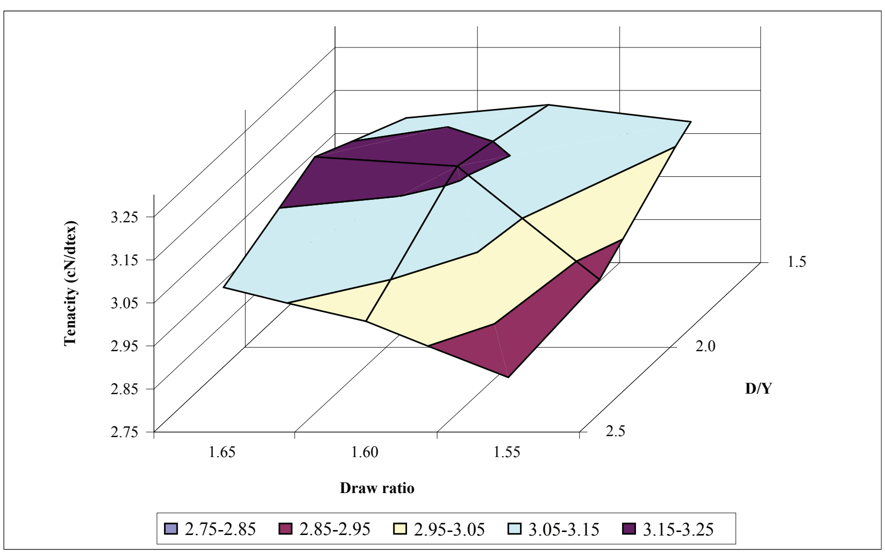

FIGURE 3. The influences of draw ratio and *D/Y* ratio on tenacity

This small rise can be explained with an increase in molecular orientation when draw ratio increases [1, 4]. The feeding material was partially oriented yarn; therefore, drawing in the heater can develop molecular orientation significantly.

Textured yarn tenacity is decreased slightly when the *D*/*Y* ratio is increased according to ANOVA results for 5% significance level as given in *Figure 3* and *Table II*. As mentioned before, *D*/*Y* ratio affects texturing twist. According to Du and Hearle's study [8], yarn texturing twist reaches its maximum at a certain level of *D*/*Y* ratio (around 1.61 for their study) and then levels off. Gupta and Amirthara [9] claimed that higher twisting forces can reduce orientation. The slight decrease in tenacity in this study can be attributed with reduced orientation; however, the effect of filament migration on yarn tenacity has to be taken into account [2, 4].

An effect of *D*/*Y* ratio and draw ratio interaction on tenacity was also detected as observed by Pal et al. [4].

Crimp Properties

According to Pal et al. [4] and Ghosh and Wolhar [6], crimp contraction is decreased with increasing draw ratio. In this study, minimum crimp contraction, which was 11.56%, was obtained at maximum draw ratio, which was 1.65. Although no statistical difference is observed for the draw ratios of 1.55 and 1.60 according to ANOVA test results shown in *Table III*, the obtained crimp contraction values are lower than that of 1.65. This could be explained by some aspects. When the tension in the texturing zone increases, the number of twists per unit length can decrease [10]. Sasaki and co-workers claimed that the decrease in twist was related to yarn elongation. In another aspect, an increase in draw ratio can restrict rapid filament migration required for crimp development [6]. The relationship between twist and linear density is also considered. According to Du and Hearle [8], texturing yarn twist becomes higher with increased draw ratio. The draw ratio affects the yarn twist level through the change in yarn radius. As a result of above studies, it can be concluded that the draw ratio affects twist level and consequently crimp contraction. Similar comments can be made for *D*/*Y* ratios. *D*/*Y* ratio directly affects twist level and yarn tension. In this study, crimp contraction reaches its maximum around 2.0 D/Y ratio, and then starts to decrease, as shown in *Figure 4*.

According to Du and Hearle [8], yarn texturing twist reaches its maximum at a certain level of *D*/*Y* ratio (around 1.6) and then levels off as mentioned.

These results are compatible with this study, twist level directly relates with crimp contraction and crimp contraction increases up to 2.0 and then starts to decrease in this study. Besides, the tension can be suppressed by the torsional and bending stresses,

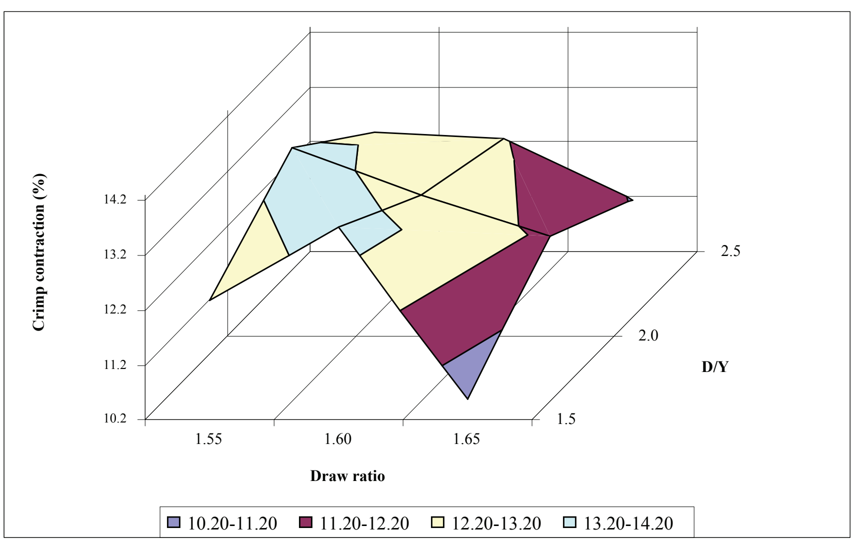

FIGURE 4. The influences of draw ratio and *D*/*Y* ratio on crimp contraction

which would normally cause the yarn to develop crimp [11]. Above 2.0, the tension could reach the level to diminish torsional and bending stress.

TABLE III. ANOVA tests for crimp contraction dependent variable

Variance source	Sum of Squares	df	Mean Square	Fs	P
Draw ratio	25.7	2	12.8	38.673	$1.08x10^{-9}$
D/Y	6.0	2	3.0	9.062	$6.49x10^{-4}$
Draw ratio*D/Y	10.0	4	2.5	7.497	$1.68x10^{-4}$
Error	12.0	36	0.33		
Total	6882	45			

R squared = 0.777

Crimp stability increases slightly when draw ratio increases as shown in *Figure 5*. However, there was no difference between 1.60 and 1.65 statistically for 5% significance level. The ANOVA test results were depicted in *Table IV*. The effect of *D*/*Y* ratio was more evident. Crimp stability decreases when the *D*/*Y* ratio increases. With increasing *D*/*Y* ratio, input tension also increases [1].

The fibers subject to tension over glass transition temperatures and tension inhibits mobility; therefore, large, well-developed crystals cannot grow. Furthermore, increased *D*/*Y* ratio causes a rise in twist level up to 2.0; high twist gives rise to a distortion in crystals [9]. As a result of these, setting performance and consequently crimp stability can decrease.

TABLE IV. ANOVA tests for crimp stability dependent variable

Variance source	Sum of Squares	df	Mean Square	Fs	P
Draw ratio	11.0	2	5.511	13.14	$5x10^{-5}$
D/Y	127.8	2	63.9	152.3	$-3x10^{-18}$
Draw ratio*D/Y	5.4	4	1.4	3.2	0.023
Error	15.1	36	0.42		
Total	295316	45			

R squared = 0.905

Apart from the effect of fine structure changes, the tension effect on crimp development is also considered. An increase in *D*/*Y* ratio also increases input tension. Higher tension levels can inhibit torsional and bending stresses and as a result of this, crimp development decreases.

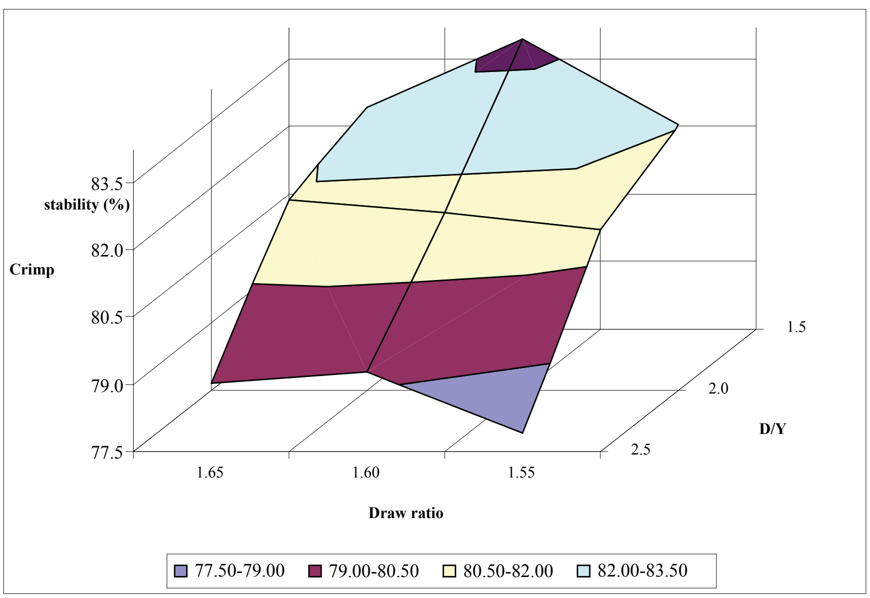

FIGURE 5. The influences of draw ratio and *D*/*Y* ratio on crimp stability

Dyeing Properties

Dye sorption of the yarn can deeply affect end-product quality and can show texturing process parameters variations. A small alteration in orientation and crsytallinity may change dye diffusion. Dye sorption increases with increasing mobility of the amorphous chains, and dye diffusion depends on the orientation of the amorphous chain segments [13]. According to ANOVA results and graphics which are shown in *Table V* and *Figure 6* respectively, dye sorption decreases with increasing draw ratio. The decrease in the color strength can be attributed to the higher amorphous orientation due to increased drawing ratio, since oriented amorphous material inhibits dye molecules diffusion and therefore lowers the dye uptake [13].

TABLE V. ANOVA tests for K/S dependent variable

Variance source	Sum of Squares	df	Mean Square	Fs	P
Draw ratio	58.2	2	29.1	72.540	2.43×10^{-9}
D/Y	3.7	2	1.9	4.640	0.023
Draw ratio*D/Y	8.5	4	2.1	5.298	0.005
Error	7.2	18	0.40		
Total	26095	27			

R squared =0. 907

According to the results, K/S value decreases with increasing D/Y ratio however there is not any significance difference at 5 % level between 2.0 and 2.5 D/Y ratios.

CONCLUSIONS

The effects of draw ratio and *D/Y* ratio on some properties of the false twist textured PET yarn were studied. Draw ratio and D/Y ratio, together with heater temperature, are the main effective process parameters. For dependent variables of crsytallinity and tenacity, independent parameters do not explain fully on the changes on the structure. However changes in the dependent variables of crimp stability, crimp contraction and dyeing properties can be explained significantly by independent parameters which are factors of experimental design.

Although there is no significant change on crystallinity, they have an influence on the crimp properties, tenacity and dyeing properties. While breaking strength increases with increasing draw ratio, it reaches at maximum level between 1.5 and 2.0 *D/Y* ratio. Crimp contraction is decreased with increasing draw ratio as a result of varied twist level; it is increased up to 2.0 *D/Y* ratios, and then starts to decrease. The effect of *D/Y* ratio on crimp stability is significant. The crimp stability decreases when the *D/Y* ratio increases. The changes in orientation and inhibited torsional and bending stresses might give rise to this decrease. K/S values also decreases when draw ratio increases because of inhibited molecular mobility.

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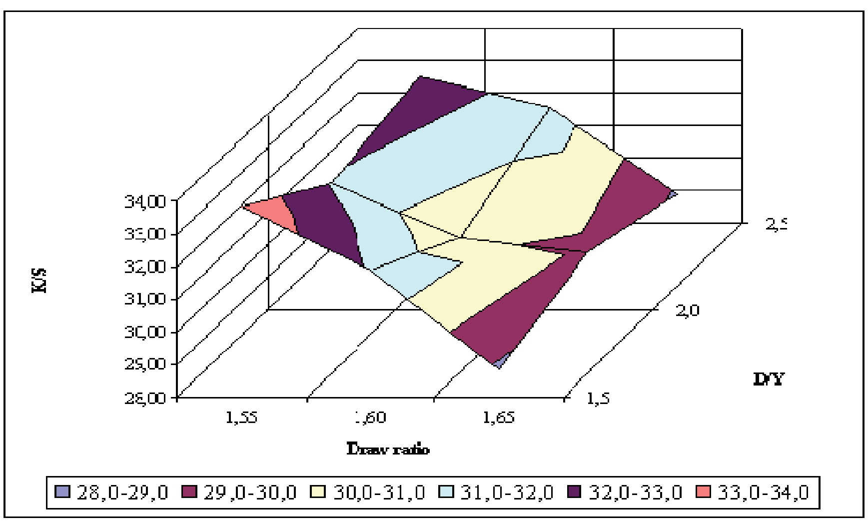

FIGURE 6. The influences of draw ratio and *D/Y* ratio on K/S

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