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Effect of major false-twist texturing parameters on tensile properties and crystallinity of polyester microfilament yarn and optimized by RSM

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The effect of major texturing parameter in the aspect of tensile behavior and percent of Crystallinity for Microfilament polyester yarn were studied.D/Y ratio, draw ratio, First heater temperature and speed of texturing machine are the major process parameters that used and other texturing parameters were constant. PET (poly ethylene terephthalate) POY with 136 dtex 144 filament was used. The response surface methodology (RSM) was also useful for the experimental plane with four variables on the result. The yarn was textured by experimental plane and 4 major parameters were changed and 25 samples were produced. Than examined by measuring their strength, tenacity, elongation and degree of crystallinity.After wards, conclusions were drawn using the test value. The result was that, as the first Heater temperature increase, the value of tenacity, strength and elongation change slightly and when draw ratio increase, strength and tenacity increase, than the statistical analysis confirms the optimum conditions obtained by the experimental result.

Keywords: false-twist texturing machine, microfilament PET, tensile properties, percent of crystallinity, response surface methodology (RSM).

1.INTRODUCTION

Numerous studies have been conducted in recent years on the false-twist texturing method as well as polyester yarns texturized through this method. The most significant properties of man-made fibers are their flat surface, proper bulk, and good physical properties and suitable dye absorption [1]. During high speed spinning, the physical properties and microstructure of filaments such as tenacity, elongation, density and crystallinity are improved by the effect of orientation [2]. In this respect, the false-twist texturing method is considered as the main method [2]. Microfilament yarns are kind of textiles material with improved physical and microstructural properties (breaking strength; elongation, density; and crystallinity) at high spinning speeds due to their increased crystallinity [3-4]. Polyethylene terephthalate (PET) is one of the principal man-made fibers with widespread applications and the highest level of consumption. Among the polyethylene terephthalates, microfilament polyester has, in recent years, been widely used by consumers due to its diverse applicability and suitable properties. Microfilaments are filament with a linear density between 0.3 dtex to 1 dtex [6]. Fabrics woven with these filaments are lighter, more wrinkle-resistant, provide a better cover effect, and have a highly attractive appearance [5]. The favorable properties of these fibers include good strength (tenacity), and existence of regions which can improve dye absorption properties (due to their larger specific surface area or SSA). A reduction in the linear density of the filaments is accompanied by an increase in the contact surface of each filament section. In fact, an increase in specific surface area is tangibly associated with reduced linear density of the filaments [6-8]. For this reason, proper texturing of microfilament polyester yarn can greatly affect the mentioned properties. In most cases, three parameters (called "3t") are examined in the texturing process: tension, twist, and temperature [2].

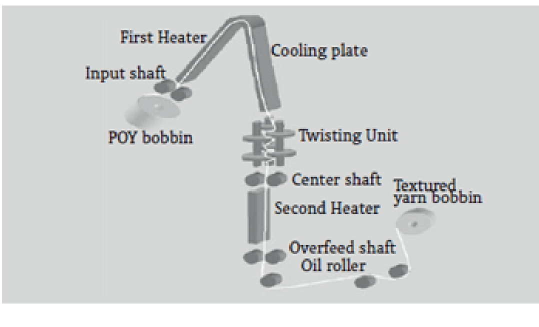

Figure 1. False-twist texturing machine.

Draw ratio, D/Y ratio, and first heater temperature are among the parameters involved in this process. The ratio of disc surface speed to yarn speed (D/Y ratio) is calculated from the following

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formula:

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

A low D/Y indicates that yarn tension decreases before and increases after the twisting area [9-11]. Draw ratio is the ratio of the central shaft speed to the input shaft speed (Fig. 1), calculated from the following formula:

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

Draw ratio affects the following properties: ultimate yarn density, strength (tenacity), orientation, absorption and leveling at dyeing process, filament rupture, etc. [2,10]. Increasing texturing speed would improve physical and microstructural properties of the fiber including tensile strength (breaking strength), elongation, density, and crystallinity due to the greater order introduced in the crystal structure of the fiber [11-13]. Examining the simultaneous effects of the four main parameters on microfilament polyester yarn properties is highly important and can greatly help producers of this type of yarn.

Draw ratio and D/Y ratio together with heater temperature are the main effective process parameters. For dependent variables of crystallinity and tenacity, independent parameters do not explain fully on the changes on the structures [13]. Generally, it is observed that the tenacity increase with an increase in the first heater temperature. Because of the rise in temperature, crystallinity increase within the yarn, which become more orientated. On the other hand elongation decrease when the temperature increase [14].

In this study the polyester Microfilament POY yarn (136 dtex / 144 f) was used to conduct the tests. This yarn is classified as a microfilament yarn with a filament count of 0.85 denier (denier per filament) which is further reduced upon texturing. Machine speed is the primary parameter in false-twist texturing as regards the four main parameters in false-twist texturing. Due to its being equal to the speed of the second shaft in the device, texturing machine speed can have a considerable effect on the physical and mechanical properties of the yarn. The other important parameter is the ratio of disc surface speed to yarn linear velocity (D/Y ratio). This parameter mostly affects yarn twist and crimp, and has a slight effect on the mechanical properties of the yarn. Draw ratio is among the most important texturizing factors and directly affects both orientation and dye ability of the yarn. The ANOVA was used to conduct the experiments.

Twenty five tests were designed in the experimental process. Each test combined the four studied parameters at different levels. The response surface methodology (RSM) was used and the tests were carried out via a RSM data generation scheme called D-Optimal. The second order design model was used. Tensile property tests were conducted on all the samples. Due to the great number of tests involved, percent crystallinity was determined only for 8 samples, and the variations in the crystallinity of these samples were used for examining the results.

2.EXPERIMENTAL

2.1.Materials

To conduct the tests, the polyester filament yarn, POY 136 dtex 144 f (produced by Yas Nakh Alborz Company, Iran) was used. To adapt test conditions to the production conditions, we used a double-sided RPR false-twist texturing machine (Model 3SDXP, made in Italy) with 120 positions on either side as shown in Figure 2. Polyurethane (PU) disks (configuration 1-6-1) were used for false twisting. The maximum speed of this texturing machine was 600 m/min. The yarn moved along a straight line, and the machine had a primary heater about 2m long.

2.2.Microfilament polyester textured yarn

The first step before sampling was to design the problem. The RSM was used for designing the tests. Twenty five tests were designed for this experiment. Each test was examined at four different levels. For each sampling of microfilament polyester yarn, used one position in machine. For all sampling, humidity is 65% and environmental temperature is 24°C and used 0.3% texturing oil for better opening yarn from the bobbin. Four main parameters were studied: texturing speed, draw ratio, D/Y ratio, and first heater temperature. The other parameters were kept constant during sampling.

2.3. Measurements

Yarn count. Upon completing the tests, the yarn number was determined for all the samples. To this end, we separated 9000 meters from each yarn sample via a winding machine (WR-100, Iran) and then measured the weight of this length to obtain the yarn number in Deniers.

Tensile properties. The yarn strength, tenacity, and elongation were measured for the 25 samples in accordance with ASTM D3822 using a Tensolab 2 machine (made in Italy) and a constant rate of elongation (CRE). The jaw speed for all the samples was constant and equal to 500 m/min. Such as test conditions were used for all the samples.

Table 1.Experimental for tenacity, strength and elongation

Run number	A:Temperature(°c)	B:Texturing Speed(m/min)	C:Draw Ratio(%)	D:D/Y Ratio	Strength (g)	Tenacity (g/den)	Elongation (%)
1	155.00	505.00	1.62	2.05	335.620	4.206	26.015
2	215.70	505.00	1.60	2.05	348.885	4.400	23.731
3	230.00	505.00	1.60	1.55	325.385	4.067	19.300
4	200.73	398.27	1.60	1.74	357.449	4.474	25.044
5	155.00	505.00	1.72	2.05	328.505	4.344	18.700
6	215.70	505.00	1.60	2.05	352.445	4.422	21.531
7	193.90	330.00	1.72	2.05	338.320	4.511	18.121
8	155.00	330.00	1.68	1.81	338.220	4.375	20.437
9	225.31	330.00	1.66	1.81	336.025	4.353	18.758
10	230.00	330.00	1.60	2.05	303.350	3.821	18.892
11	230.00	505.00	1.72	1.79	374.915	4.700	13.548
12	191.22	505.00	1.68	1.55	325.915	4.266	17.486
13	155.00	413.68	1.72	1.55	313.940	4.180	15.411
14	155.00	330.00	1.60	1.55	329.450	4.032	21.619
15	230.00	330.00	1.72	1.55	293435	3.923	13.576
16	183.13	439.38	1.68	1.86	349.420	4.580	20.576
17	155.00	362.04	1.60	2.05	337.160	4.152	25.324
18	230.00	505.00	1.60	1.55	345.379	4.328	20.667
19	230.00	330.00	1.61	1.55	329.545	4.140	18.652
20	193.90	330.00	1.72	2.05	333.080	4.423	17.295
21	155.00	505.00	1.60	1.64	336.305	4.183	26.101
22	230.00	420.90	1.68	2.05	234.170	4.085	13.540
23	230.00	420.90	1.68	2.05	265.795	4.511	14.436
24	190.79	351.88	1.66	1.55	337.885	4.377	19.704
25	155.00	413.68	1.72	1.55	315.010	4.195	15.654

Differential scanning calorimetric (DSC). To measure percent crystallinity, 8 of the 25 samples were selected and the tests conducted on these samples. The areas around the peaks can help in identifying percent crystallinity of the samples. The calculation of peak area on melting region according to Eq. (3) is very helpful in process development. Polyester microfilament yarns were tested in a DSC-Maia-200 F3 unit (Netzsch, Germany) with micro punched aluminum pans of 40μl. The testing conditions were sample mass: 13.43 mg; initial temperature: 20°c; final temperature: 600°c, heating rate: 10°c min-1; purging gas: nitrogen 50mL min-1. 140.1 mJ/mg was used for ΔH_m^o (fusion) for 100% crystallinity PET.

$$\%Crystallinity = [\Delta H_m - \Delta H_c] / \Delta H_m^o \times 100\% \quad (3)$$

ΔH_m: $The\ heat\ of\ melting (J/g)$

ΔH_c: $Cold\ crystallization (J/g)$

ΔH_m^o: $The\ heat\ of\ melting\ if\ the\ polymer\ were\ 100\% Crystalline (J/g)$.

Table 2. Range of different variable

Variable	Lower limit	Upper limit
Texturing Speed (m/min)	330	505
Draw Ratio (%)	1.6	1.72
D/Y Ratio	1.55	2.05
First Heater Temperature (°c)	155	230

2.4.Experimental design

The yarns were used for experimental plan along with obtained response is shown in Table 1. Four variables including first heater temperature, texturing speed, draw ratio and D/Y ratio were studied. Range of different variable was shown in Table 2.

Also the influence of the variable on the results strength, tenacity and elongation are fitted in the following second order polynomial function (Eq.4):

$$Response = b_{o+} \sum b_i X_i + \sum b_{ij} X_i X_j + \sum C_i X_i^2 \qquad i \geq j \quad i = 1,2,3,4 \qquad (4)$$

In this equation, b_0 is an independent term according to the mean value of the experimental plan, b_(i)are regression coefficients that explain the influence of the variables in their linear form, b_ij are regression coefficients of the interaction terms between variables and C_i are the coefficient of quadratic form of variables [18]. The estimation equation regression coefficients b_0 , b_ij, C_i along with determination coefficient R for strength, tenacity and elongation are presented in Table 3, 4 and 5.

Table3. Regression coefficient and determination coefficient of tenacity.

Tenacity coefficient	Tenacity
b_0	-38.21528
b_1	0.20252
b_2	0.035193
b_3	16.71213
b_4	19.65857
b_{13}	-0.090206
c_1	-1.47892E-004
c_2	4.13842E-005
c_4	-5.47912

Table 4. Regression coefficient and determination coefficient of strength

Strength coefficient	Strength
b_0	-2452.51750
b_1	14.77598
b_2	-2.83234
b_3	1041.97855
b_4	1489.68916
b_{13}	-6.63216
c_1	-0.010763
c_2	3.3222723E-003
c_4	-415.43308

Table 5. Regression coefficient and determination coefficient of elongation

Elongation coefficient	Elongation
b_0	-157.68034
b_1	0.42356
b_2	0.30459
b_3	-38.58599
b_4	179.09705
b_{12}	-2.31895E-004
b_{13}	-1.16336E-003
b_{14}	-0.080321
b_{23}	-0.18034
b_{24}	2.64383E-003
b_{34}	-4.05347
c_1	-6.23757E-004
c_2	4.13646E-005
c_3	18.05989
c_4	-43.05953

3.RESULTS AND DISCUSSION

3.1.Yarns denier

The yarns denier are given in Table 6. Increasing draw ratio led to decreased yarn denier and greatly influenced the yarn denier. In addition, increasing texturing speed had a significant effect on yarn denier. Upon increasing polymer chain stretch, the yarn would be arranged together (aligned) in an orderly fashion and this order would result in reduced yarn diameter. At greater yarn temperatures, the chains had greater freedom of movement. Increased draw ratio combined with increased temperature contributed to reducing yarn denier.

Table 6. Denier of samples

Run	1	2	3	4	5	6	7	8	9	10	11	12	
Count	79.78	79.3	80.02	79.9	75.1	79.74	75.02	77.29	77.19	79.38	74.3	76.33	
Run	13	14	15	16	17	18	19	20	21	22	23	24	25
Count	75.13	81.7	74.86	76.25	81.14	79.83	79.58	75.27	80.33	78.88	75.68	77.21	75.06

3.2. Strength and Tenacity

Ghosh and Wolhar [12] and Pal et al. [10] found that textured yarn tenacity increase when the draw ratio is increase. Gupta et al. [15] also observed an increase in tenacity with an increase in tension. Overall, studies show that increasing draw ratio would increase the microfilament polyester fiber strength. In addition, increasing draw ratio also increased the draw tenacity of the fibers. The primary heater temperature also played a significant role in this regard, i.e., greater temperatures led to increased fiber strength and tenacity. In this study similar result were obtained and the analysis of variance (ANOVA) for tenacity and strength is given in Tables 7 and 8.

Table 7. ANOVA for response surface quadratic model (Tenacity)

source	sum of squares	DF	Mean square	F Value	P-Value prob>F
Model	1.62	8	0.20	2.77	0.0396
A-Temp	0.42	1	0.42	5.78	0.0287
B-speed	0.053	1	0.053	0.72	0.4084
C-Ratio	0.025	1	0.025	0.34	0.5689
D-D/Y	5.203E-003	1	5.203E-003	0.071	0.7930
Ac	0.49	1	0.49	6.70	0.0198
A^2	0.33	1	0.33	4.50	0.0498
B^2	0.40	1	0.40	5.52	0.0320
D^2	0.41	1	0.41	5.67	0.0301
Residual	1.17	16	0.073		
Lack of fit	1.04	11	0.095	3.66	0.0814
Raw Error	0.13	5	0.026		
cor.total	2.79	24			

Table 8.ANOVA for response surface quadratic model (Strength)

source	sum of squares	DF	Mean square	F Value	P-Value prob>F
Model	13370.30	8	1671.29	3.79	0.0112
A-Temp	3465.59	1	3465.59	7.86	0.0127
B-speed	379.53	1	379.53	0.86	0.3673
C-Ratio	3198.26	1	3198.26	7.25	0.0160
D-D/Y	40.84	1	40.84	0.093	0.7648
Ac	2647.24	1	2647.24	6.00	0.0262
A^2	1743.14	1	1743.14	3.95	0.0642
B^2	2605.31	1	2605.31	5.91	0.0272
D^2	2380.73	1	2380.73	5.40	0.0336
Residual	7054.18	16	440.89		
Lack of fit	6333.60	11	575.78	4.00	0.0690
Raw Error	720.59	5	144.12		
cor.total	20424.49	24			

It can be concluded that all terms in this model are significant. According to the ANOVA result, the fitted model for tenacity is Eq. 5:

$$\boldsymbol{Tenacity} = +(-38.21528) + (0.20252 \times A) + (0.035193 \times B) + (16.71213 \times C) + (19.65857 \times D) + (-0.090206 \times A \times C) + (-1.47892E-004 \times A^2) + (4.13842E-005 \times B^2) + (-5.47912 \times D^2) \quad (5)$$

And the fitted model for strength is Eq. 6:

$$\boldsymbol{Strength} = +(-2452.51750) + (14.77598 \times A) + (-2.83234 \times B) + (1041.97855 \times C) + (1489.68916 \times D) + (-6.63216 \times A \times C) + (-0.010763 \times A^2) + (3.32723E-003 \times B^2) + (-415.43308 \times D^2) \quad (6)$$

In this equation A, B, C and D are temperature (°c), texturing speed (m\min), draw ratio (%) and D/Y ratio, respectively. The response surface of the model for tenacity shows in Figure 2. by using design expert package software the optimum design point with total desirability of 100% is: 203.53 °c temperature, 343.54 m/min texturing speed, 1.63% draw ratio and 1.88 for D/Y.

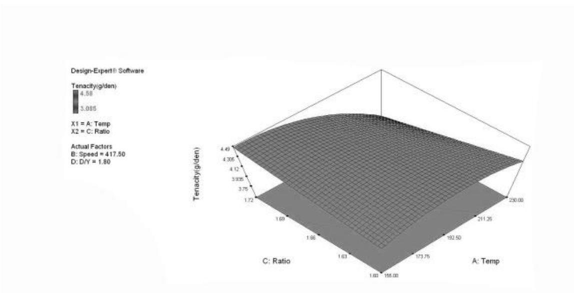

Figure 2. 3D plot of A and C with their continue plot (tenacity).

The response surface of the model for strength shows in Figure 3. by using design expert package software the optimum design point with total desirability of 100% is: 193.79 °c temperature, 497.15 m/min texturing speed, 1.60% draw ratio and 1.73 for D/Y.

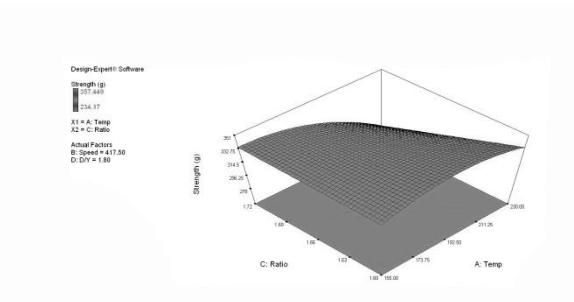

Figure 3. 3D plot of A and C with their continue plot (strength)

The temperature of microfilament polyester must be above the glass transition temperature (Tg) so that the polymer chains can move freely and can be arranged into a more orderly arrangement from their amorphous state.

At increased draw ratio, the coils are straightened from their spiral shape more quickly.

Simultaneously with temperature increase, the chains assume a more ordered arrangement and lateral bonds are formed between the ordered chains. Since the POY yarn is raw, simultaneous tension and heat have a greater effect on the tensile properties of the yarn as compared to the other two parameters. The other important point is greater twist which can reduce the artificial orientation. In other words, if D/Y exceeds the normal limit, then it can very slightly reduce artificial orientation.

3.3 Elongation

Elongation decreases with increasing strength. The experimental results clearly show that the first heater temperature has an insignificant influence on the yarn count, tenacity and elongation. In this study similar result were obtained and the analysis of variance (ANOVA) for tenacity and strength is given in Table 9.

It can be concluded that all terms in this model are significant. According to the ANOVA result, the fitted model for tenacity is Eq. 7:

$$\boldsymbol{Elongation} = +(-\mathbf{157.68034}) + (\mathbf{0.42356} \times \boldsymbol{A}) + (\mathbf{0.30459} \times \boldsymbol{B}) + (-\mathbf{38.58599} \times \boldsymbol{C}) + (\mathbf{179.09705} \times \boldsymbol{D}) + (-\mathbf{2.31895E-004} \times \boldsymbol{A} \times \boldsymbol{B}) + (-\mathbf{1.16336E-003} \times \boldsymbol{A} \times \boldsymbol{C}) + (-\mathbf{0.080321} \times \boldsymbol{A} \times \boldsymbol{D}) + (-\mathbf{0.18034} \times \boldsymbol{B} \times \boldsymbol{C}) + (\mathbf{2.64383E-003} \times \boldsymbol{B} \times \boldsymbol{D}) + (-\mathbf{4.05347} \times \boldsymbol{C} \times \boldsymbol{D}) + (-\mathbf{6.23757E-004} \times \boldsymbol{A}^{\mathbf{2}}) + (\mathbf{4.13646E-005} \times \boldsymbol{B}^{\mathbf{2}}) + (\mathbf{18.05989} \times \boldsymbol{C}^{\mathbf{2}})(-\mathbf{43.05953} \times \boldsymbol{D}^{\mathbf{2}}) \quad (\mathbf{7})$$

Table 9. ANOVA for response surface quadratic model (Elongation)

source	sum of squares	DF	Mean square	F Value	P-Value prob>F
Model	340.51	14	24.32	15.20	<0.0001
A-Temp	82.56	1	82.56	51.61	<0.0001
B-speed	1.367E-003	1	1.367E-003	8.545E-004	0.9773
C-Ratio	210.95	1	210.95	131.86	<0.0001
D-D/Y	10.14	1	10.14	6.34	0.0305
AB	6.68	1	6.68	4.18	0.0682
AC	7.927E-005	1	7.927E-005	4.955E-005	0.9945
AD	6.37	1	6.37	3.98	0.0739
BC	10.26	1	10.26	6.41	0.0297
BD	0.042	1	0.042	0.026	0.8749
CD	0.046	1	0.046	0.029	0.8681
A^2	5.02	1	5.02	3.14	0.1070
B^2	0.31	1	0.31	0.19	0.6697
C^2	0.014	1	0.014	8.809E-003	0.9271
D^2	23.49	1	23.49	14.68	0.0033
Residual	16.00	10	1.60		
Lack of fit	11.87	5	2.37	2.88	0.1355
Raw Error	4.13	5	0.83		
cor.total	356.51	24			

In this equation A, B, C and D are temperature (°C), texturing speed (m\min), draw ratio (%) and D/Y ratio, respectively. The response surface of the model for elongation shows in Figure 4. By using Design Expert Package software the optimum design point with total desirability of 100% is: 176.37 °c temperature, 419.71 m/min texturing speed, 1.60% draw ratio and 1.91 for D/Y. In all the observations and results, it has been found that when polymer chain orientation increases, the free movement of the chains is more restricted, and the elongation to rupture naturally decreases as a result. In addition, the lateral bonds between the oriented chains greatly restrict the free movement of the chains. At greater speeds, i.e., when the yarn has less time to be affected by increased temperature, there is a greater probability of decreased freedom of movement in the chains. The machine speed must be selected such that the yarn can be allowed to move the chain. In addition, the yarn must have enough time during cooling to reach Tg before the spindle does. For this reason, a slight increase of texturing speed alone would lead to increased elongation as well as reduced strength. The number of twists per unit length can decrease by increase the tension in the texturing zone [17].

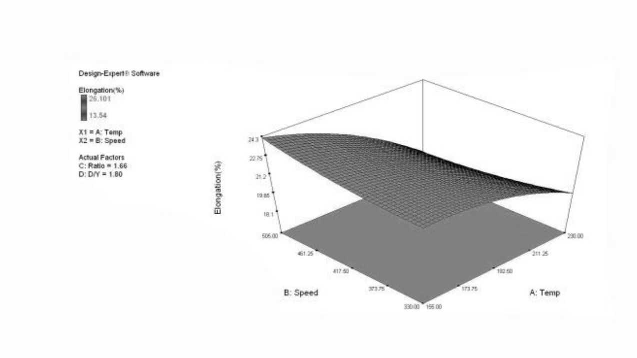

Figure 4. 3D plot of A and C with their continue plot (elongation)

Sassaki et al. claimed that the decrease in twist was related to yarn elongation. According to Du and Hearle [14], texturing yarn twist becomes higher with increase draw ratio and yarn texturing twist reaches its maximum at a certain level of D/Y ratio (around 1.6). The draw ratio affects the yarn twist level through the change in yarn radius. Besides, the tension can be suppressed by the torsional and bending stresses and increase molecular orientation when draw ratio increase [17].

3.3.Degree of crystallinity

To measure percent crystallinity and discuss this parameter, 8 samples were selected and the variations of the main false-twist texturing parameters on these 8 samples were studied. The percentage crystallinity of the textured filament yarns decrease with increasing twist amount, which is determined by D/Y ratio [10]. However, any noticeable difference could not be observed for draw ratio, D/Y ratio and they interaction on crystallinity [1]. The thermal behaviors of 8 samples obtained by DSC curves are shown in Figure 5-12.

Then degree of crystallinity calculated from this curves. The results can be obtained from DSC curves as listed in Table 10This Table shows the maximum amount of crystallinity between 8 samples at the run 11 that the first heater temperature and draw ratio were high and the minimum amount of crystallinity between 8 samples at the run 10 that draw ratio was minimum amount. Increasing the first heater temperature and draw had the greatest effect on the polyester yarn percent crystallinity. Percent crystallinity increased with increase tenacity. Due to the ordered molecular chains and the fact that they were aligned and had lateral bonds, their percent crystallinity increased. In addition, increasing temperature also allowed greater freedom of movement in the chains and increased their crystallinity. Increasing D/Y which increases twist can break the chains in the crystals, leading to increased disorderliness. If texturing speed exceeds the optimum limit, the yarn heating time is reduced and this can slightly reduce crystal formation.

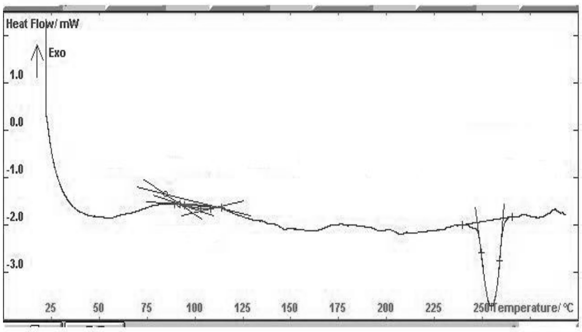

Figure 5. DSC curve for run 19

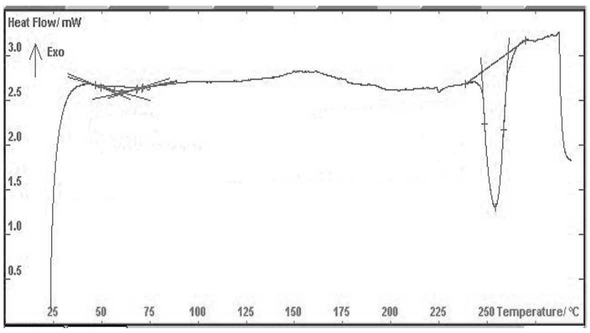

Figure 6. DSC curve for run 5

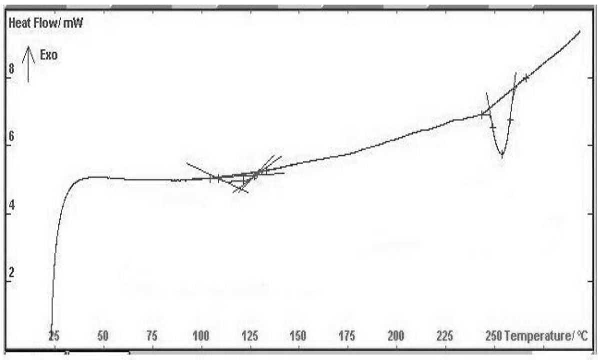

Figure 7. DSC curve for run 10

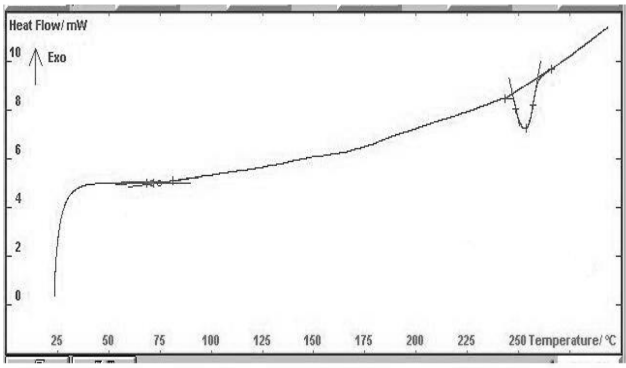

Figure 8. DSC curve for run 3

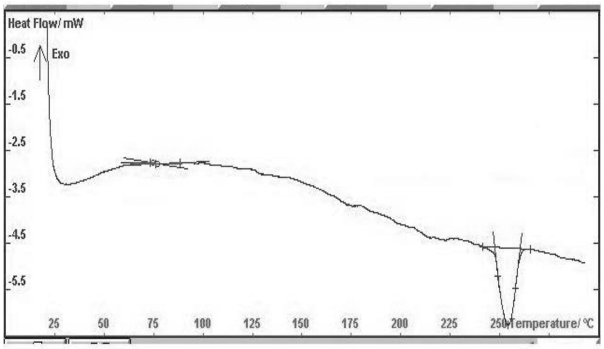

Figure 9. DSC curve for run 1

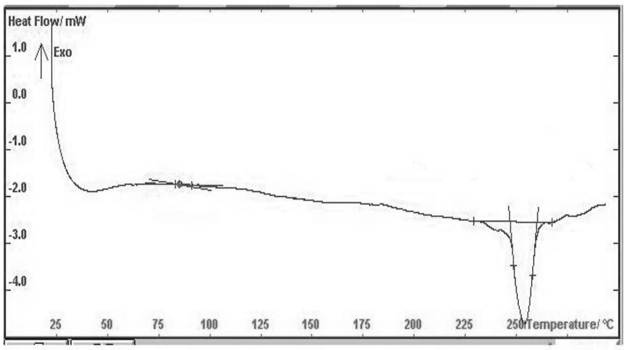

Figure 10. DSC curve for run 11

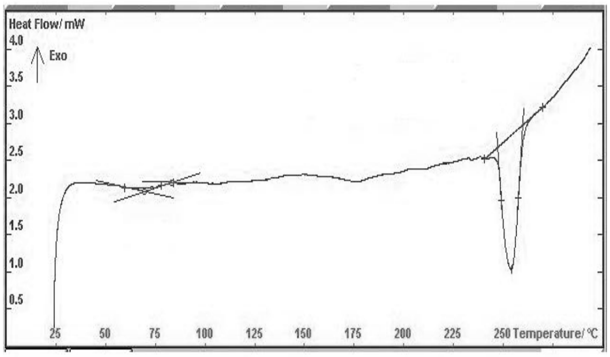

Figure 11. DSC curve for run 24

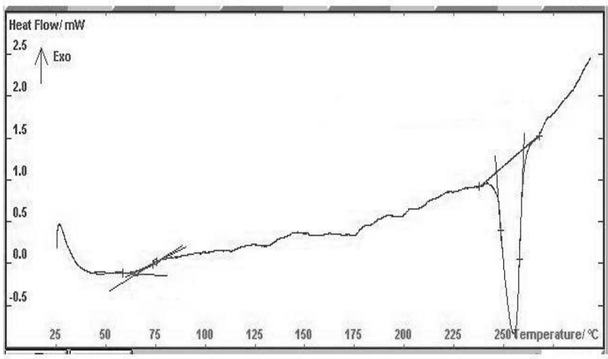

Figure 12. DSC curve for run 23.

Table 10. Degree of crystallinity for selected samples.

Run	1	3	5	10	11	19	23	24
Xc (%)	22.27	23.48	26.37	22.22	33.09	24.5	29.46	25.46

4. CONCLUSION

The effect of 4 important parameters on tensile properties and degree of crystallinity of the false-twist textured microfilament polyester yarn were studied. We produced 25 samples yarn with RSM experimental plane. Statistical analysis showed that the selected components were highly logical and suitable for evaluation, and that they greatly influenced the determined parameters. The greatest effect was due to the primary heater temperature and draw ratio which highly influenced the tensile properties as well as crystallinity. Simultaneous increase of heater temperature and POY yarn tension led to greater orientation of the molecular chains, and consequently, increased crystallinity. Increased orientation in turn led to increased strength and decreased elongation to rupture. Optimum level of 4 texturing parameters for best tenacity obtained at 203.53°C temperature, 343.54 m/min texturing speed, 1.63% draw ratio and 1.88 for D/Y and at this level the tenacity is 4.58187 g/den. Optimum level of 4 texturing parameters for best strength obtained at 193.79 °c temperature, 497.15 m/min texturing speed, 1.60% draw ratio and 1.73 for D/Y and at this level the strength is 365.038 g and finally optimum level for best elongation obtained at 176.37 °c temperature, 419.71 m/min texturing speed, 1.60% draw ratio and 1.91 for D/Y and at this level the elongation is 26.2205%.

Increasing texturing speed led to decreased exposure of the yarn to heat in the heater, thus reducing the possibility of heating the chains and increasing orientation. Increase D/Y ratio to the optimum limit somewhat reduced filament rupture. In addition, orientation reduced perceptibly as D/Y increased. This was due to the bending and torsional stresses applied to the yarn. Degree of crystallinity increase with increase draw ratio and first heater temperature to optimum and after optimum amount maybe decrease slowly. Overall, through test design and statistical analysis, we can examine the exact effects of these factors; and their effect is fully perceptible.

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