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Statistical Investigation of the Effect of Major Parameters of False Twist Texturing on the Dyeing Characteristic and Color Properties of Microfilament Polyester Yarn

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Abstract

Microfilament polyester yarns are one of the most important and widely used yarns in the textile industry and the fabrics produced from these yarns have a large consumption. One of the most important issues regarding fabrics made from Microfilament yarns is the issue of dyeing and dyeing properties of these fabrics. Among the concerns of DTY polyester yarn manufacturers are the conditions for producing and texturizing these fibers. Choosing the right range for each of the effective parameters in the false twist texturing machines will play a major role in the physical properties, dyeing Characteristic and color properties of the yarn produced. In this paper, we attempt to study the effect of the most important texturing parameters by false twist method: first heater temperature, draw ratio, D/Y rate and texturing speed on some of the most important color properties of microfilament polyester yarn that dyeing with dispersant dyestuff. These properties include color reflectance (% R), color strength (K/S), amount of dye absorbed (q_e) and absorbance number (A). Experiments are designed using ANOVA and Response Surface Methodology (RSM) method. The effect of changes in the main texturing parameters on the color coordinates of the microfilament polyester yarn is studied. The POY yarn used in this study is polyester yarn with a count of 135 dtex and 144 filaments. According to the studies, the interaction between the first heater temperature and the D / Y rate as well as the interaction between the draw ratio and the D / Y rate will have the greatest effect on the color strength and color properties of the microfilament polyester yarn.

Keywords: False Twist Texturing, Microfilament Polyester Yarn, Color Reflection (% R), Color Strength (K / S), Amount of dyestuff absorbed (q_e), Absorption Number (A), RSM.

1. Introduction

The increasing demand for fiber to improve the properties achieved so far, and the development of applications for textile materials, has led to the rapid increase in micro fibers and microfilaments production technology and its potential in the textile industry [1]. Micro filaments have a diameter equal to half the diameter of fine silk fibers, one-third the diameter of cotton, and one-fourth the diameter of fine wool, and one hundred times thinner than human hair. These fibers are of relatively good strength and durability compared to fibers of similar weight and they have good coating comfort [2]. Micro fibers (including staple fibers and filaments) are kind of fibers with a linear density of about 1dtex or less and greater than 0.3detx. Although fine fibers are produced with a fineness of 0.3dtex and less, these fibers belong to the super ultrafine fibers [3]. These are fibers with a fineness of 0.3dtex or less, and are particularly within the range of 0.1dtex. Various methods can be used to produce these fibers, including splitting and separating long fibers from their smaller types [4,5]. The technology in question is to spinning micro filament and fibers at a higher level and at a higher cost than conventional denier fibers. Micro fibers are very thin yarns that require a great deal of care during textile processes [7]. All three conventional spinning methods, namely, melt spinning, wet and dry spinning, can be used to produce micro fibers. [8]. Fabrics which produced with micro fibers are generally light weight and resistant to wrinkles. They also have a beautiful shape and cover and maintain the appearance of the fabric. The strength and durability of these fibers are desirable and have a comfortable wearing and coating. Generally, the yarns that made of texturized microfilament during production have high stress variations, high rupture filaments and undesirable bobbin opening. These fibers give the soft and desirable touching, good bulk, special surface properties, silk-like appearance and good coating properties to fabrics [9]. Applications of fabrics made from micro fibers include types of clothing, sportswear, waterproof clothing and synthetic leather and suede [6]. Other uses of these fibers include cleaning fabrics, medical applications, construction applications and a variety of filters [2,10]. In addition to the effect on the color coordinates of the yarn, the microfilament polyester yarn production conditions have a profound effect on the physical properties and crystallinity of the microfilament polyester yarn and can overshadow the elongation, strength, force to tear, and the crystallinity of these fibers [11]. The strength of any filament of POY microfilaments is higher than that of POY ordinary filaments. The elongation of each filament of POY microfilament is less than that of any normal POY filament. The amount of tensile force for each filament of the microfilament yarn is greater than that of any ordinary filament [8]. From the industrial point of view, the production of microfilament yarn, texturing, dyeing and dyeing uniforms is very important. There have always been challenges in the industry in the texturing condition and dye ability and dyestuff absorption of microfilament yarns. Polyester microfilament yarn is the most widely used micro yarns in the world [12]. One of the most important issues affecting the dye absorption and dye ability of microfilament polyester yarns is how to texturing these yarns. False twist texturing is generally used for these yarns, with texturing conditions being very influential on the physical and chemical properties of the yarns [13]. In terms of physical properties and crystallinity, the greatest effect is due to the change in the temperature of the first heater and the change in the draw ratio of texturing machine when producing microfilament polyester yarn on these filaments. That is, as the temperature of the first heater and the elongation of the POY yarn to be DTY yarn increases simultaneously, the arrangement of the molecular chains increases, thereby increasing the percent of crystallinity the strength and decreasing the elongation of yarn [11]. As the texturing temperature changes, the detectable changes in the overall arrangement and the size of the crystals is determined that In this regard, the speed of yarn staying in the heater, which is a variable of the speed of texturing is very effective [14,15]. When working with friction disc texturing machine, the work is based on surface friction between the yarn and the disc, which may result in damage to the filaments. Filament rupture is one of the main problems in textured yarn. Also the yarn stress may change which is effective in absorbing the dye. To control these factors, use the appropriate D/Y rate, which is the surface velocity of the disk at a linear yarn speed. The decrease in D/Y rate increases the tension of the yarn the after passing the yarn through the friction discs and increases the filament rupture. At low D/Y rates, the disk speed to the yarn speed decreases and the yarn is drawing between the false twisting devices and the output rollers. Therefore, T2 increases (the output stress of the discs). Increasing the D/Y value reduces the value of T2/T1 [16]. Dyeing of microfilament

polyester yarns will always present challenges for dyer in obtaining the appropriate color depth and desired color shade plus optimum color fastness. In order to obtain the proper color depth and optimum fastness, always more dyestuff is needed than ordinary polyester yarn, and the color matching will be very difficult. Whatever the filament's count become fine, the greater amount of dyestuff needed. This is proved by Fothergill's equation in 1944 (Equation 1) [17].

$$\frac{C_1}{C_2} = \sqrt{\frac{w_2}{w_1}} \qquad (1)$$

$C_1 \& C_2$: Amount of dyestuff use (%)

$w_1 \& w_2$: Denier per filament (DPF)

It is difficult to obtain deep dyeing shades in the microfilament polyester yarn. It is also more difficult to obtain color uniformity in microfilament yarns because of the higher dye removal rate and absorption at the wide contact surface of micro fibers and filaments [18]. Microfiber yarns generally have lower rubbing and washing fastness. In view of these cases, dyeing of microfiber polyester yarns has always been practically problematic and has always been of interest in industry [19].

For similar dyestuffs, the rate of exhaustion and heat of dye bath reaches a deeper color depth for the micro fibers, thus requiring a higher amount of dye for the finer fibers [21]. Dyeing of fabrics made from micro fibers has a faster dyeing type when the count of fibers in yarn is reduced. However, in the dyeing equilibrium phase, a large amount of dye remains in the bath. The difference in dyeing rates in deep shades is most pronounced when the role of increasing surface contact is quite significant [22]. Microfilaments have a faster dyeing rate, which is mainly due to the increased contact surface area, which results in a high shade depth percentage [19].

To determine the amount of dye exhaust, determine the amount of dye remaining in the solution at the specified temperature and time. Then the residual dye in solution is obtained by evaporating the solution at a low temperature of 60 ° C and after that drying the residual material. Then this material placed in acetone and the wavelength of the absorbed dye is measured [20].

To determine the color strength, the K/S (Kubelka Munk function) values are determined by measuring the reflectance (%R) of the dye sample at the reflected wavelengths according to the formula in Equation 2: [23]:

$$K/S = \frac{(1-R)^2}{2R} \qquad (2)$$

S: Light scattering

K: Light absorption

R: Measure the reflection of light at minimum reflective wavelength

In order to study the dye adsorption, the effluent of samples dyed was analyzed by transmission spectrophotometer at maximum wavelength and equation 3 was used to determine the dye absorption in the samples [24].

$$q_e = \frac{(c_0 - c_e)v}{w} \qquad (3)$$

Where q is the amount of dye absorbed by the product at equilibrium moment ($mg\,g^{-1}$), c_0 and c_e respectively, the initial dye concentration and the dye concentration at equilibrium moment in the bath ($mg\,l^{-1}$), v bath volume (L) and w are the weight of the fabric (g).

In this study the polyester Microfilament POY yarn (121 den / 144 f) was used to conduct the tests. This yarn is classified as a microfilament yarn with a filament count of 0.85 denier (dpf) 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 chemical and dyeing 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 t on the color coordinates and dye adsorption 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. The obtained samples are analyzed by reflective spectrophotometer and transitional spectrophotometer. Color reflectance, color strength and amount of dye absorbed by the samples are studied and statistically analyzed.

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. 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. Sampling is performed according to the design of the experiment and 25 samples are washed and dyed. The wash is done with 1gr/lit soda and 1gr/lit nonionic detergent and then it is neutralized with acetic acid.

The dyeing of the samples is then carried out by dispersant dye with the help of dispersing agent, acetic acid and sequestering agent in L: R equivalent to 1:30. The acid and auxiliaries are first added at 40 ° C and dyestuff added 15 minutes later. Dyeing is carried out at 130 ° C for 60 minutes and finally the dyeing bath is evacuated and the reduction clearing is performed.

The color used is Disperse Red 73 whose formula is shown in Fig. 1 Molecular Structure is Single azo class. Each sample is first washed and then dyed

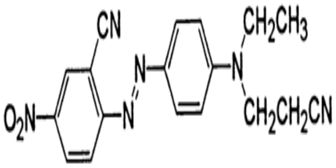

Figure 1: Characteristics of the dye used

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 and design of experiment shown in table 1.

2,3. Measurements

- Reflectance of colored samples(%R)

In order to investigate the effect of the main parameters of false twist texturing on the disperse dyestuff absorption and color coordinates of dyed microfilament polyester yarns, dye samples were examined in Xrite and Model A 7000 reflectance spectrophotometer and color reflectance values were studied.

- Color Strength (K/S).

After determination of the color reflectance values (% R) in the dyed superfine polyester samples, their color strength values were obtained using color reflectance values according to Kubelk-Munk equation (2).

- Dye absorption

In order to determine the amount of dye absorbed, the maximum wavelength of the dispersant dye is first measured by a transmission spectrophotometer, which is used to measure the dye absorption. Initially, a medium concentration of dye (0.04 gr/lit) is placed into the transmission spectrophotometer and λ_{max} is obtained by this device, which is:

$\lambda_{max} = 606{,}0\ nm$

Table 1 Design of experiments table

Run number	A:Temperature(°c)	B:Texturing Speed(m/min)	C:Draw Ratio(%)	D:D/Y Ratio
1	155.00	505.00	1.62	2.05
2	215.70	505.00	1.60	2.05
3	230.00	505.00	1.60	1.55
4	200.73	398.27	1.60	1.74
5	155.00	505.00	1.72	2.05
6	215.70	505.00	1.60	2.05
7	193.90	330.00	1.72	2.05
8	155.00	330.00	1.68	1.81
9	225.31	330.00	1.66	1.81
10	230.00	330.00	1.60	2.05
11	230.00	505.00	1.72	1.79
12	191.22	505.00	1.68	1.55
13	155.00	413.68	1.72	1.55
14	155.00	330.00	1.60	1.55
15	230.00	330.00	1.72	1.55
16	183.13	439.38	1.68	1.86
17	155.00	362.04	1.60	2.05
18	230.00	505.00	1.60	1.55
19	230.00	330.00	1.61	1.55
20	193.90	330.00	1.72	2.05
21	155.00	505.00	1.60	1.64
22	230.00	420.90	1.68	2.05
23	230.00	420.90	1.68	2.05
24	190.79	351.88	1.66	1.55
25	155.00	413.68	1.72	1.55

Then different concentrations of dye are obtained and its absorption is measured at maximum wavelength. In this study dye concentration is studied from 0.01 to 0.06 g / L and repeated test for each specific concentration 3 times. Then, using the results, a table of concentrations and adsorption (Table 2) is prepared and the diagram is plotted as shown in Figure 2 and its line equation is 4. This equation is used to determine the residual dye concentration in the dye effluent in grams per liter.

Table 2: Average amounts of dye adsorption at different concentrations

adsorption	Concentration of dye	No.
0.1675	0.01	1
0.3471	0.02	2
0.5597	0.03	3
0.6533	0.04	4
0.8382	0.05	5
0.9555	0.06	6

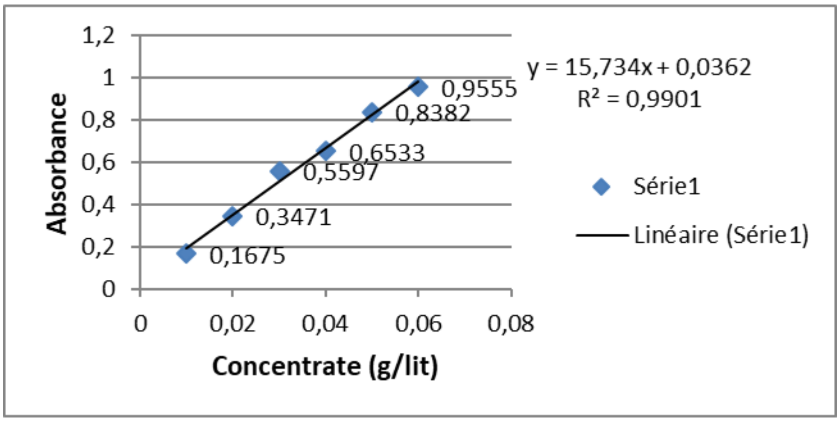

Figure 2: Dispersive dye absorption diagram of disperse red 73 at different concentrations

$$Y = 15{,}734\ X + 0{,}0362 \qquad (4)$$

Then, using Equation 3, the amount of dye absorption in the samples is determined

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 3.

Table 3 Range of different variable

Variable	Lower limited	Upper limited
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

Also the influence of the variable on the results strength, tenacity and elongation are fitted in the following second order polynomial function (Eq.5):

$$Response = b_{o+} \sum b_i X_i + \sum b_{ij} X_i X_j + \sum C_i X_i^2 \qquad i \geq j \quad i = 1,2,3,4 \qquad (5)$$

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 %R, K/S and $q_e$are presented in Table 4, 5 and 6.

Table 4

Regression coefficient and determination coefficient of %R

R coefficient	R
456.28214	b_0
-0.37922	b_1
-216.54229	b_3
237.11751-	b_4
0.21490	b_{14}
119.20415	b_{34}

Table 5 Regression coefficient and determination coefficient of K/S

K/S coefficient	K/S
73.24184	b_0
-0.032034	b_1
0.012608	b_2
-39.63152	b_3
42.01343-	b_4
-7.04140E-005	b_{12}
0.036775	b_{14}
21.17540	b_{34}

Table 6 Regression coefficient and determination coefficient of q_e

q_e coefficient	q_e
10.39506	b_0
2.23939E-004	b_1
-0.51625	b_3
0.020047	b_4
-2.44926E-004	b_{13}
2.51768E-005	b_{14}
-0.17540	b_{34}
2.77436E-007	c_1
0.16458	c_3

3. Results and discussion

1,3. Color Reflection (% R) and Color Strength (K/S)

Samples of microfilament polyester yarns are dyed after production. The dyed samples are then examined for reflectance by a reflectance spectrophotometer. First, the reflectance value (% R) for the samples is obtained at different wavelengths, and then the color strength (K/S) is calculated using the 2 equation. The graph of% R is then plotted in wavelength and is shown in Figure 3.

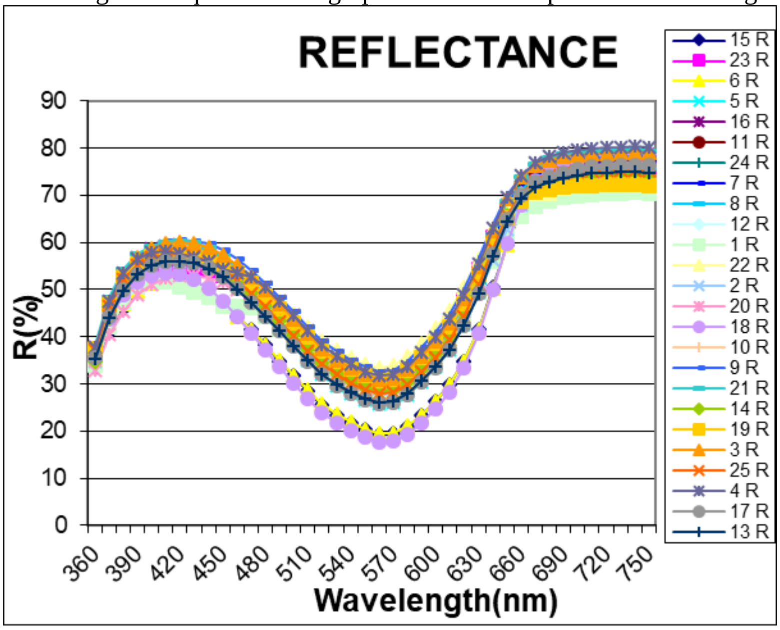

Figure 3: Reflection chart in wavelength

The graph of K / S values is also plotted in different wavelengths in Figure 4.

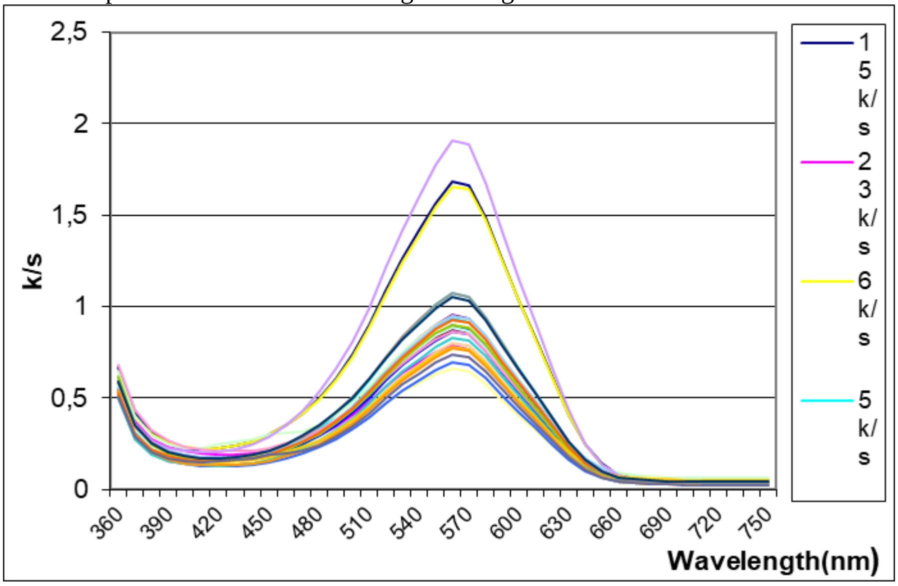

Figure 4: K/S in Wavelength chart

To analyze the data obtained from reflectance spectrophotometry for microfilament polyester yarn samples, the wavelength that has the minimum reflectance value is obtained and analyzed at the same wavelength. The wavelength studied in this study for the samples is 560nm, which has the minimum values at% R, which is also the maximum point in the diagram in Figure 0-4, corresponding to the K/S value.

According to the diagrams, it is clear that the highest amount of color strength at the mentioned wavelength is related to sample number 18. This means that the sample with lower draw ratio, higher heater temperature and high speed of texturing has good color strength. The D/Y rate is also minimal in this sample. That is, it indicates that higher color strength is observed in samples with less draw ratio. Tables 7 and 8, show the reflectance (% R) and color strength (K/S) values for all microfilament polyester samples at 560nm wavelength.

Table 7 % R values for samples at optimum wavelength

نمونه	1	2	3	4	5	6	7	8	9
%R	27.676	27.65	30.939	31.661	25.7	19.54	29.103	27.81	32.642
نمونه	10	11	12	13	14	15	16	17	
%R	30.358	28.855	28.701	26.023	28.408	19.338	27.532	25.701	
نمونه	18	19	20	21	22	23	24	25	
%R	17.72	30.706	29.036	29.752	33.458	30.58	28.507	27.96	

Table 8 K / S values for samples at optimum wavelength

نمونه	1	2	3	4	5	6	7	8	9
K/S	0.945	0.947	0.771	0.738	1.074	1.657	0.864	0.937	0.695
نمونه	10	11	12	13	14	15	16	17	
K/S	0.799	0.877	0.886	1.051	0.902	1.682	0.954	1.074	
نمونه	18	19	20	21	22	23	24	25	
K/S	1.911	0.782	0.867	0.829	0.662	0.788	0.896	0.928	

It can be seen from the tables above that the best color strength (K/S) is for samples with the highest or lowest draw ratio. That is, for samples with maximum draw ratio and low heat the first heater has high color strength, or for samples with minimal draw ratio, it can be concluded that if the temperature of the first heater is low and minimum draw ratio is also observed, K/S value is increased. So the draw ratio and temperature of the first heater will have the greatest impact on the color strength.

1,1,3. Reflective Statistical Analysis (% R)

After obtained above values, the ANOVA program is used to analyze the data more accurately and first the data on reflectance (% R) is analyzed by this program. To analyze the data, the data are normalized first. After performing the data normalization operation, to further investigate the effects of false twist texturing optimization parameters on the reflectance values of the microfilament colored polyester samples, the response procedure is plotted when the texturing speed and draw ratio is constant is shown in Fig. 5. Here X1 is the first heater temperature and X2 is the D/Y rate.

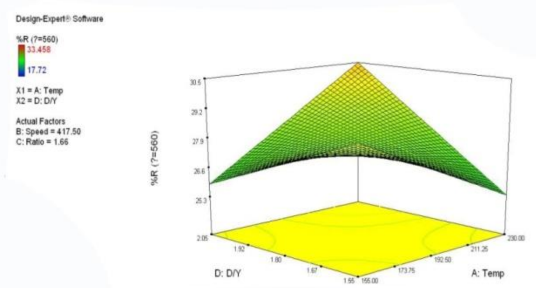

Figure 5: 3-D view of the effect of the first heater temperature and D/Y rate on the % R

As shown in Fig. 5, as the temperature of the first heater decreases, the %R decreases and as the D/Y rate increases, the %R decreases. The optimum % R value is between the values of the first heater temperature and the D/Y rate. It seems that due to the

lower temperature, the molecular chains have a high permeability to move, and because of the disorientation in the molecular chains and the low arrangement, the reflectance value much higher and because of the the disorientation in the chains due to the lower temperature the %R value is increased. Older bonds in POY yarn also break down due to lower first heater temperatures, allowing older bonds to break down in the amorphous areas, allowing less fiber to be broken, resulting in higher reflectivity. A few bonds in the POY yarn are also broken down due to the low initial temperature of the heater, allowing a few bonds to break down in the fiber`s amorphous areas and this resulting in higher reflectivity. The response procedure for% R when the temperature of the first heater and the texturing speed are constant is plotted in Fig. 6. In this graph X1 is the draw ratio and X2 is the D/Y rate.

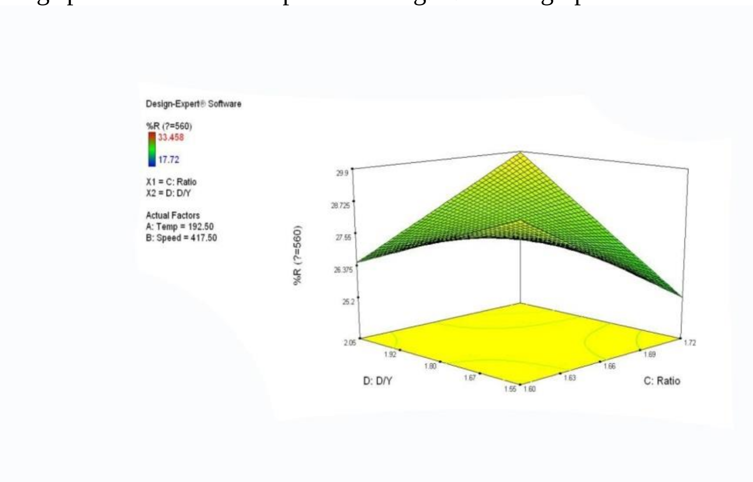

Figure 6: 3-D view of the influence of the draw ratio and the D/Y rate on the % R of the specimens

As shown in Figure 6, as draw ratio rate increases, the reflectance rate decreases, because with increasing draw ratio, molecular chains tend to be orientation, and increasing orientation will reduce reflection in the specimens. As the draw ratio increases, the polymer chains that are amorphous are stretched and aligned along the fiber axis. Increasing the orientation of the chains creates their cross link, followed by an increased orientation and the crystallinity percentage can also be increased. Now, if the temperature of the first heater rises, it helps. Otherwise, if the temperature of the first heater is low, the chains will be less permitted to create orientation and crystally area. So we can say that the reflection percentage is inversely correlated with the elongation rate, and with the decrease in elasticity we see an increase in the reflection percentage. After considering the above, the desirability values for the first heater temperature factors and the texturing speed of the equations are investigated and are shown in Figure 7. For this review, the draw ratio and D/Y rate are kept constant.

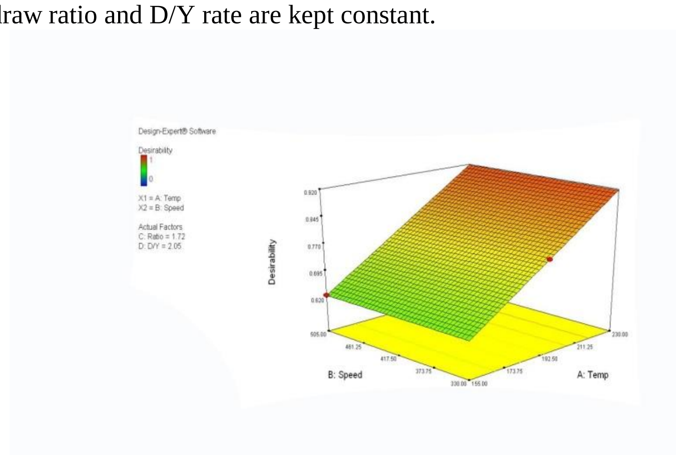

Figure 7: First Heater Temperature desirability and Pitch Rate for Reflection Percentage% R

As shown in Figure 7, the texturing speed does not have a specific effect on the desirability of the factor under investigation and is almost ineffective and constant and does not have an acceptable value. But as the temperature of the first heater increases, the

desirability increases. This means that higher the temperature of the first heater, the better reflectance percentage for this factor, the more appropriate reflection percentage, and the more acceptable analysis. After the above investigations, the results of reflection percentage due to changes in texture parameters on the microfilament polyester yarn are analyzed by ANOVA program and its variance analysis is shown in Table 9.

Table 9 ANOVA for Response Surface Model for % R

source	sum of squares	DF	Mean square	F Value	P-Value prob>F
Model	88.80	5	17.76	1.22	0.3396
A-Temp	1.53	1	1.53	0.11	0.7494
C-Ratio	0.24	1	0.24	0.017	0.8989
D-D/Y	5.40	1	5.40	0.37	0.5505
AD	53.51	1	53.51	3.66	0.0708
CD	44.88	1	44.88	3.07	0.0957
Residual	277.48	19	14.60		
Lack of fit	151.20	14	10.80	0.43	0.9034
Raw Error	126.28	5	25.26		
cor.total	366.28	24			

As the analysis and experiment of Table 4-0 show, the above model is not significant for the% R study and the model is not acceptable, although the interaction of some factors such as heater temperature and D/Y rate as well as the interaction between draw ratio and D/Y rate is meaningful and acceptable. That is, most of the effects in the above model will have the interactions of the factors mentioned, and none of the factors alone are significant and their interactions are significant. Also, the texturing speed, which is completely ineffective on the %R, is also without effect. Therefore, for the above model, it can only be noted that the interaction of the above mentioned parameters is effective and the overall model is not significant. Also, the lack of fitting is not significant as this is acceptable and indicates the appropriate fit of the above model. Since the non-fitting is not significant, the above model can be accepted and used. Then the appropriate mathematical model is obtained from the above table, which shows the influence of the parameters on the reflectance percentage of the microfilament polyester yarn and is shown in Equation 6.

$$\%\boldsymbol{R} = +(456.28214) + (-0.37922 \times \boldsymbol{A}) + (-216.54229 \times \boldsymbol{C}) + (-237.11751 \times \boldsymbol{D}) + (0.21490 \times \boldsymbol{A} \times \boldsymbol{D}) + (119.20415 \times \boldsymbol{C} \times \boldsymbol{D}) \qquad (6)$$

According to Table 3-3, A, C, D are the first heater temperature (C °), draw ratio (%) and D/Y rate respectively, and the texturing speed that ineffective is eliminated. According to the table above, it will have the greatest impact on the reflection percentages of A and D interactions, and then C and D interactions will have the highest impact on the above model. Although the values of A, C and D are also influential, the percentages of their influence alone are very low and their interactions will have a much higher impact on the above model. That is, the interactions of AD and CD are almost significant and acceptable, but the effects of factors A, C, and D alone are not significant and are only marginally acceptable. Figure 8 shows the % R desirability according to the parameters selected for false twist texturing on microfilament polyester yarn.

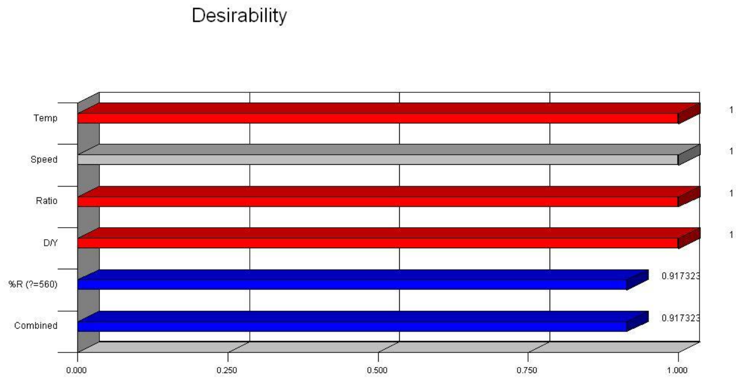

Figure 8: Influence of the main texturing factors on the R% of samples and their desirability

As shown in Fig. 8, the desirability of all texturing parameters is high and their effect on% R is approximately acceptable and is close to 1 and their interaction effect is also acceptable. Also the above factors will have a significant impact on the reflectance percentage of the microfilament polyester samples. Finally, after examining the above for the reflectance percentage (% R) of the samples produced, the best and most optimal settings for having a high and acceptable %R are as follows:

The first heater temperature is 230 ° C, the texturing speed is 350.78 m / min, the draw ratio is 1.72 percent and the D/Y rate is 9.05 percent. If the setting is above, the %R is 32.1568 percent, which is a high percentage and in this value, the desirability would be 0.917. That is, to obtain a high and optimal reflection percentage, we need to use these values for the texture parameters.

2,1,3. Color strength Statistical Analysis (K/S)

The ANOVA program is used to examine more precisely the color strength (K/S) and the relationship between changes in the texturing machine and the color strength of the dyed samples. First, all the K/S results obtained by modifying the original texture parameters are normalized.

Since the data is not normal, a negative exponent must be added to the data to normalize the results to be examined, using the -246 exponent to normalize the results. Then the response procedure for K/S with an exponent of -2.46 when the draw ratio and D/Y rate are constant is plotted by varying the temperature of the first heater and the texturing speed and is shown in Fig. 9. The X1 axis is the temperature of the first heater and the X2 is the texturing speed.

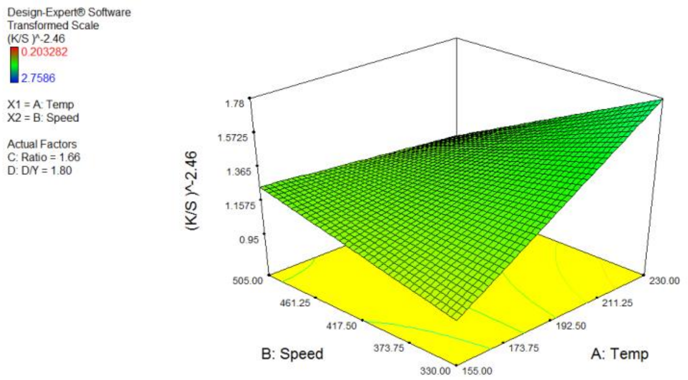

Figure 9: 3-D view of the effect of first heater temperature and the texturing speed on the K/S

As shown in the figure above, as the temperature of the first heater increases, the value of K/S increases, but the change in texturing speed will have less effect on K/S. That is, simultaneously if the temperature is increased at low speed, the K/S value will increase, but at high speed if the temperature is increased the K/S value will decrease or will not change. This is due to the breakdown of molecular chains at higher temperatures, with the cross links being broken at higher temperatures, and as the cross

links break, the chains become more free to move. Then the simultaneous changes of the first heater temperature and the D/Y rate on the K/S are investigated when the texturing speed and the draw ratio are constant and are shown in Fig. 10. The X1 axis is the first heater temperature and the X2 axis is the D/Y rate.

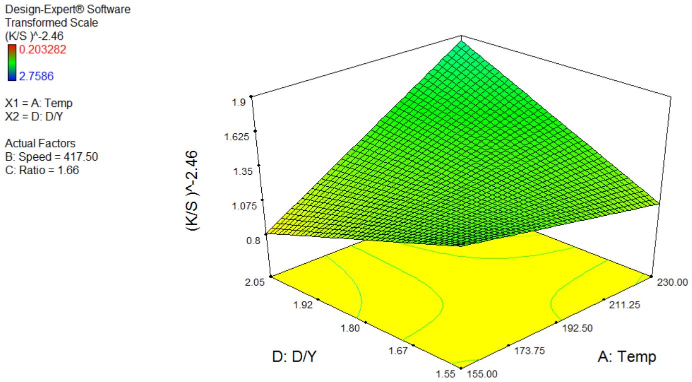

Figure 10: 3-D view of the effect of first heater temperature and D/Y rate on the K/S

As shown in the Figure 10 at the constant D/Y rate, the K/S value increases if the temperature rises. The D/Y rate alone will not have a significant impact on K/S, but its interaction is noticeable. That is, if the temperature is high and the D/Y value is low, the K/S value also decreases, and if the temperature increases and the D/Y value increases, it can increase the K/S value. To further investigate the K/S response procedure, when the first heater temperature and the texturing speed are constant, the draw ratio and the D/Y rate change simultaneously are also plotted in Fig. 11. The X1 axis in the figure is the draw ratio and the X2 axis is the D/Y rate. As shown in Figure 11, if the draw ratio is constant, the value of K/S increases with increasing D/Y. Also at a constant D/Y rate, if the draw ratio is increased, the K/S will decrease. Increased draw ratio is significantly relation with lower K/S rates. That is, the increase in draw ratio due to the orientation of the molecular chains and the increase orientation in the fiber structure greatly contributes to the change in K/S and is one of the important parameters of the change in K/S. To examine more precisely the relationship between K/S and the main parameters of texturing for microfilament polyester yarn using ANOVA and analysis of variance, a statistical model is defined and the relationship between the initial and response variables is attempted and the results are presented in Table 10 is mentioned.

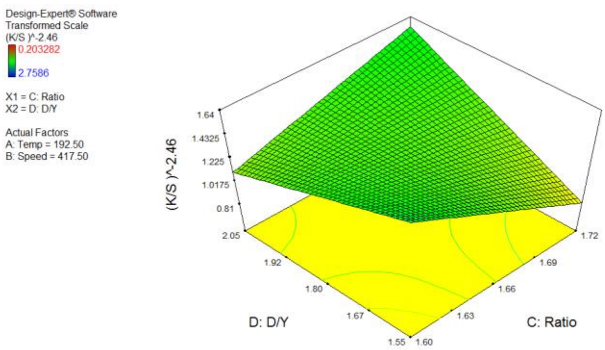

Figure 11: 3-D view of the effect of draw ratio and D/Y rate changes on K/S

Table 10

ANOVA for Response Surface Quadratic Model for K/S

source	sum of squares	DF	Mean square	F Value	P-Value prob>F

Model	4.17	7	0.60	2	0.1147
A-Temp	0.59	1	0.59	2	0.1756
B-speed	0.11	1	0.11	0.38	0.5461
C-Ratio	0.14	1	0.14	0.46	0.5062
D-D/Y	0.055	1	0.055	0.19	0.6719
AB	0.72	1	0.72	2.41	0.1392
AD	1.51	1	1.51	5.06	0.0380
CD	1.39	1	1.39	4.68	0.0450
Residual	5.06	17	0.30		
Lack of fit	2.75	12	0.23	0.50	0.8517
Pure Error	2.31	5	0.46		
cor.total	9.23	24			

Also, the mathematical equation proportional to the change in texturing parameters and the obtained K/S value was obtained and it is mentioned in the relation 7.

$$\frac{K}{S} = +(580.64372) + (-0.27263 \times A) + (-0.44111 \times B) + (-279.09851 \times C) + (-181.26129 \times D) + (0.15434 \times A \times D) + (0.26271 \times B \times C) + (92.37401 \times C \times D) \quad (7)$$

As shown in Table 4-3, A, B, C and D are the first heater temperature (C °), the texturing speed (m/min), the draw ratio (%) and the D/Y rate, respectively. According to the figures, it can be seen that the model is not significant. Also because its P-value is not too high, it is not very acceptable model. According to the table above, the main parameters alone do not have a significant effect on k/s, but the interaction of some of these parameters will have an acceptable effect. The greatest impact is due to the interaction between AD and CD. That is, the interaction between the first heater temperature and the D/Y rate as well as the interaction between the draw ratio and the D/Y rate will have a significant impact.

Among the parameters alone, the effect of the first heater temperature and the draw ratio is higher than the effect of the other parameters on the K/S. The substantial point is the lack of fit of this model which is not significant and this means that the model is approved. Finally, the graph of the K/S desirability according to the selected parameters for the false-twist texturing is shown in figure 12.

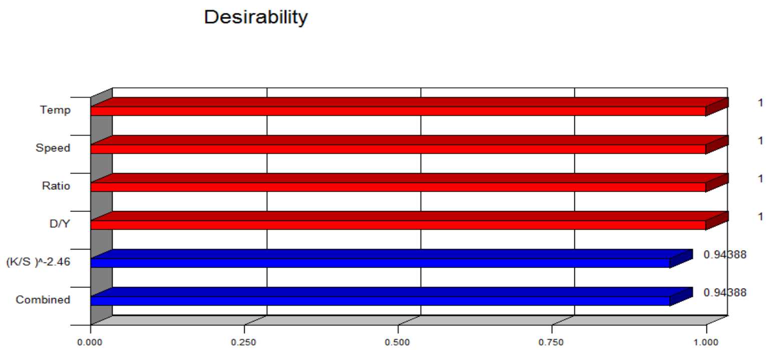

Figure 12: Influence of the main factors of false-twist texturing on K/S and their desirability

Table 11

Adsorption values and adsorption numbers of the samples of microfilament polyester

Samples number	C_e	q_e	A
1	0.304	9.9696	4.8193

2	0.292	9.9708	4.6305
3	0.309	9.9691	4.8980
4	0.294	9.9706	4.6620
5	0.328	9.9672	5.1970
6	0.296	9.9704	4.6935
7	0.357	9.9643	5.6532
8	0.321	9.9679	5.0868
9	0.335	9.9665	5.3071
10	0.299	9.9701	4.7407
11	0.362	9.9638	5.7319
12	0.339	9.9661	5.3700
13	0.331	9.9669	5.2442
14	0.287	9.9713	5.5519
15	0.365	9.9635	5.7791
16	0.340	9.9660	5.3858
17	0.289	9.9711	4.5833
18	0.305	9.9695	4.8351
19	0.315	9.9685	4.9924
20	0.355	9.9645	5.6218
21	0.291	9.9709	4.6148
22	0.349	9.9651	5.5274
23	0.348	9.9652	5.5116
24	0.324	9.9676	5.1340
25	0.325	9.9675	5.1498

As shown in the figure above, the selection factors have a significant influence on the K/S and the desirability of the samples is high and it is significant, indicating the correct selection of the primary variables. 3,1,3. Color absorption and absorption number After dyeing the specimens, the sewage obtained from each dye sample is analyzed by a transmission spectrophotometer and the $C_e$values (dye concentration) are obtained at equilibrium in the bath. Using the C_e values obtained, and by incorporating in equation 3-1, the amount of dye absorbed by the yarns is obtained in the equilibrium bath (q_e). After obtaining q_e value, absorbance number (A) is obtained by using the equation (4) and all the cases are shown in Table 11.

4.4.1 Statistical analysis of the amount of dye absorbed by the samples (q_e)

In order to find the exact statistical relationship between changes in false-twist texturing parameters for microfilament polyester yarn and the amount of dye absorption and the effect of changes on dye dispersion dyeing, the dye absorption values (q_e) of the dyed samples is studied. First, all the data related to q_e are normalized. After normalization, the effect of changes on dye absorption is investigated with respect to normalized data. First, the effect of first heater temperature variations and draw ratio on dye absorption is investigated, when the texturing speed and D/Y rate are constant and its response is plotted in Fig. 13. The X_1 axis of the first heater temperature and X_2 is the draw ratio.

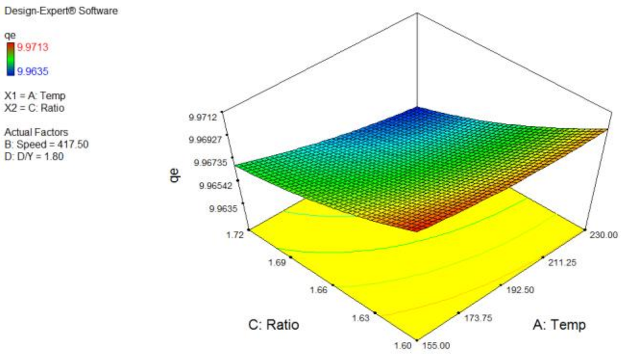

Figure 13: 3-D view of the first heater temperature change and the draw ratio change on the q_e

As shown in Figure 13, with increasing draw ratio, q_e decreases and if the draw ratio increases with change in temperature, the adsorption amount will decrease significantly. This is due to the orientation of the polymer chains and the crystallization of the molecular chains reduces the adsorption of the samples. In the high draw ratio with the high temperature can, the absorption is low. Then, in the samples with low draw ratio, which means more amorphous regions, more adsorption is observed. To investigate more precisely the effect of major texturing parameters on q_e, the response procedure is investigated when the texturing speed and draw ratio are constant and the first heater temperature and D/Y rate are varied and are shown in Fig. 14. The X_1 axis is the first heater temperature and the X_2 is the D/Y rate.

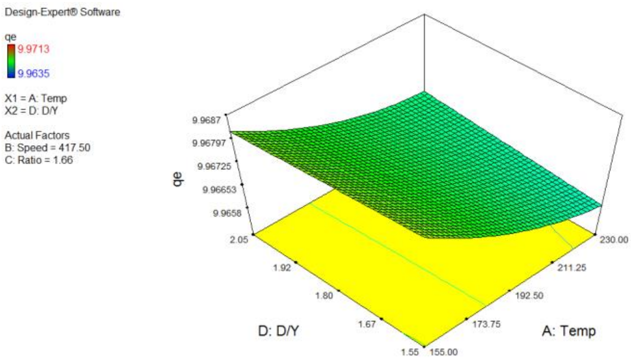

Figure 14: 3-D view of the effect of first heater temperature and D/Y rate change on the q_e

As shown in Figure 14, increasing the D/Y rate does not significantly affect the color absorption of the samples and slightly increases the color absorption. This is due to the fact that when the D/Y is increased by a certain amount, crystallinity structure of the polymer chains maybe weakness and the crystals break down and increasing the dye absorption. This is due to point that the resulting crystals break with increasing rotational speed of the discs and some breakage in the regular structure of the polymer chains increases the color absorption.

Also, due to this figure, increasing the temperature will decrease the color absorption. Finally, to complete the research on dye absorption, the simultaneous effect of draw ratio and D/Y rate changes when the first heater temperature and the texturing speed are constant are studied and is shown in Figure 15. The X_1 axis is the draw ratio and the X_2 is the D/Y rate.

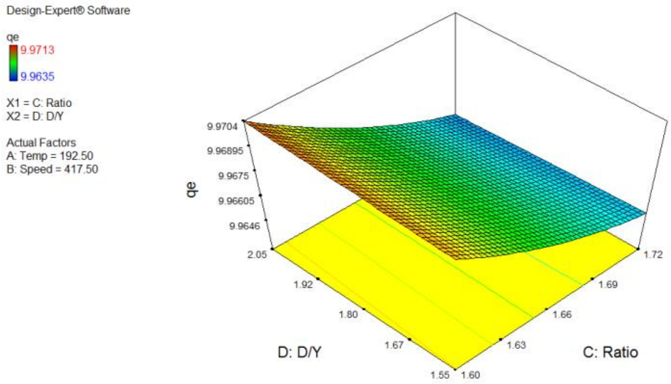

Figure 15: 3-D view of the effect of draw ratio and D/Y rate on q_e of samples

Table 12 ANOVA for Response surface Quadratic model for q_e

source	sum of squares	DF	Mean square	F Value	P-Value prob>F
Model	1.475E-004	8	1.843E-005	90.43	<0.0001
A-Temp	2.249E-005	1	2.249E-005	110.31	<0.0001
C-Ratio	1.154E-004	1	1.154E-004	565.98	<0.0001
D-D/Y	1.410E-008	1	1.410E-008	0.069	0.7959
AC	3.767E-006	1	3.767E-006	18.48	0.0006
AD	7.241E-007	1	7.241E-007	3.55	0.0777
CD	6.972E-007	1	6.972E-007	3.42	0.0830
A^2	1.205E-006	1	1.205E-006	5.91	0.0272
C^2	1.350E-006	1	1.350E-006	6.62	0.0204
Residual	3.261E-006	16	2.038E-007		
Lack of fit	2.896E-006	11	2.633E-007	3.61	0.0839
Pure Error	3.650E-007	5	7.300E-008		
cor.total	1.507E-004	24			

As shown in Figure 15, the simultaneous change in the draw ratio and D/Y rate will have a significant effect on q_e. Maximum dye absorption is when the minimum draw ratio coincides with the maximum D/Y change to the yarn produced. At this time, there are many amorphous regions in the yarn, and with increasing D/Y rates, the amount of low orientation that is also present in the polymer chains is broken and this improves the disorientation of the chains, thus increasing the absorption rate. As shown above, when the D/Y rate is low, increasing the draw ratio reduces the color absorption of the samples and minimizes the absorption at the maximum draw ratio observed. Thus, as the draw ratio increases and the D/Y rate are low, the amount of dye absorption decreases, and this is clearly illustrated in Figure 13-3. In order to analyze more precisely the results of q_e related to changes in texturing parameters for microfilament polyester yarn after dyeing, ANOVA statistical analysis was used and the relationship between color absorption changes and changes in texturing parameters was analyzed. The results of modeling the relationship between these variables are shown in Table 12.

Then the mathematical relation corresponding to these changes and the prediction of absorption value (q_e) are calculated by the changes of 4 main parameters of false-twist texturing and are reported in equation 8.

$$q_e = +(10.39506) + (2.23939E-004 \times A) + (-0.51625 \times C) + (0.020047 \times D) + (-2.44926E-004 \times A \times C) + (2.51768E-005 \times A \times D) + (-0.014930 \times C \times D) + (2.77436E-007 \times A^2) + (0.16458 \times C^2) \quad (8)$$

According to the results of Table 6-3, the values of A, C and D are the first heater temperature (C °), draw ratio (%) and D/Y rate, respectively. As it is clear from the table, the texturing speed will not have a significant effect on the color absorption and its effect is so slight that it is neglected and the other three factors will have a significant effect. The obtained model is a significant one and it is easy to express the relationship between texturing parameters and color absorption. According to the table above, the most effect was related to parameters A and C which had the most effect and the effect of parameter D was less than the other two parameters. Also, the interaction of AC, AD, and CD will have a significant effect on the amount of dye absorption most affected by the AC interaction, namely the interaction of the first heater temperature and the draw ratio which have the highest level of significance and they are very effective. Also A^2 and C^2 will have a noticeable effect on the color absorption model, which is quite significant. As it is clear from the table above, the lack of fitting is not significant, which would indicate the effectiveness and desirability of the above model. Also it shown is the Fig 16, the desirability of changing the parameters of the first heater temperature and the texturing speed when the draw ratio and D/Y rates are constant.

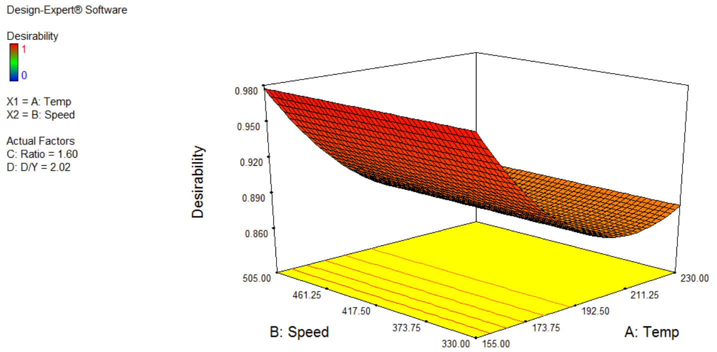

Figure 16: Desirability of changes in first heater temperature and texturing speed on q_e of samples

As shown in Fig. 16, when the temperature of the first heater increase, the desirability decreases and the maximum desirability is displayed at low temperatures. The texturing speed is not going to have a significant effect on the desirability, and we generally shown high desirability. Finally, for a more detailed examination of desirability, a diagram of the effect of 4 texturing parameters on the desirability of q_e results is shown in Fig. 17.

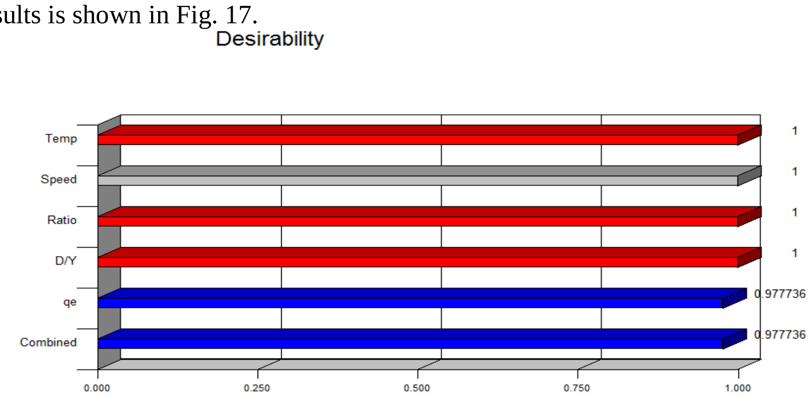

Figure 17: Influence of the major false-twist twist texturing parameters on q_e and their desirability

According to Figure 17 the main texturing factors have a high impact on q_e and their desirability is very high and the selection factors are very correct and the desirability is about 0.98 which is appropriate. Finally, according to the investigations performed, the best values of the main texturing parameters for the most appropriate dye absorption on the microfilament polyester yarn are heater temperature of 155.0 C °, texturing speed of 505.0 m/min, draw ratio of 1.60% and the D/Y rate is 2.02, that the absorption value is 9.97113 $^{mg}/_{g}$, which is acceptable and is the best and optimal value.

4. Conclusion

The effect of 4 important parameters on dyeing coordinates and dye adsoption 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. By increasing the draw ratio, $q_e$decreases and if the draw ratio increases with the increase in temperature of the first heater, the value $q_e$decreases significantly. Also, the change in the D/Y rate has a small effect on q_e and in higher values the D/Y rate is slightly increased in q_e. If the D/Y rate is low and the draw ratio is high, when the first heater temperature increase, the q_e value decrease. The simultaneous change of the draw ratio and the D/Y rate will also have a significant impact on the q_e value. The maximum value of q_e is when the minimum draw ratio and the D/Y rate are maximal. The speed of texturing will not have much effect on the q_e value, or most is due to the interaction of the other three factors. The best values of the main texturing parameters for the best value of q_e are: heater temperature of 155.0 °c, texturing speed of 505.0 m/min, draw ratio of 1.60% and the D/Y rate is 2.02, that the absorption value is 9.97113 $^{mg}/_{g}$, which is acceptable and is the best and optimal value. By increasing the temperature of the first heater and D/Y rate, %R value decreases, which is the appropriate value of %R for the average values of the first heater temperature and D/Y rate. It also decreases %R with increasing draw ratio, which is due to the increased molecular orientation of the polymer chains. The speed of texturing has little effect on the %R, and the greatest impact is due to the interaction of the other three texturing factors. Interaction between the first heater temperature and the D/Y rate will have a greater impact on %R than the rest of the factors. The best values of the main texturing parameters for the optimum value of reflectance are: heater temperature of 230.0 °c, texturing speed of 350.78 m/min, draw ratio of 1.72% and the D/Y rate is 2.05 that the absorption value is 32.1568%, which is acceptable and is the best and optimal value. Finally, it is observed that by increasing the temperature of the first heater, the value of K/S increases. Texturing speed will have a little effect on the K/S value. That is, if the temperature increases at high speed, the value of K/S increases. D/Y rate has little effect on K/S, but its interaction with the temperature of the first heater will have a great effect on K/S. Increasing the draw ratio also decreases the K/S value. The greatest impact on K/S is due to the interaction between the first heater temperature and the D/Y rate, as well as the interaction between the draw ratio and the D/Y rate.

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References

[1] Kale, R. D., Microfibre: Processing and Application, Journal of Textile Association, Jan-Feb 2010, 233-239.

[2] Rupp, J., Yonenaga, A.; Microfibres, the New Man-Made Fibre Image, I.T.B., Vol.46, (4th Issue) April 2000, 12-24.

[3] Thiel, S.; Production of Microfibres, J.T.A., Jan-Feb 1997, 213-216.

[4] Ajgaonkar, D. B.; Microfibres, M.M.T.T., Sept. 1992, 327-337.

[5] Vidur, K. L.; Micro Denier Yarns, NCM, March 1997, 9-16.

[6] Miller, H.; Microbibre Producers Still See Growth Ahead as Smaller Fibres Open New Markets, I.F.I., April 2003, 23-29.

[7] Teli, M. D.; Polyester Microfibre Fabric, J.T.A., Mar-April 1999,295-299.

[8] Vishwanath, B. A., Bhonde, H. V.; Comparative Study on Spinning of POY for Normal & Micro-Denier polyester Yarn, M.M.T.T., July 1998, 293-296.

[9] Thwaites, J. J.; The Mechanics of Friction Twisting Reassessed; part I: The Yarn Path in a Disc Spindle; The Journal of Textile Institute, 1984, 4, 285-297.

[10] Purane, S.V., Panigrahi, N. R.; Microfibers, Microfilament & Their Application, Autex R. J., September 2007, Vol. 7, No. 3, 148-158.

[11] Taghavi Deilamani, M., Rashidi, A., Yazdanshenas, M.E., Moghadam, M. B., Eskandarnejad, S.; Bulgarian Chemical Communications, 2016, Volume 48, Special Issue D, Supplement (pp. 55 – 64).

[12] Pal, S. K., Ganhi, R. S., Kothari, V, K.; Draw Texturing of Microfiber Polyester Yarn, Textile Res. j., 1996, 12, 770-776.

[13] Yildirim, K., Altun, S., Ulcay, Y.; Relationship between Yarn Properties and Process Parameters in False-Twist Textured Yarn, Jeff J. 2009, volume 4, Issue2.

[14] Gupta, V. B., Majumdar, A., Seth, k. k.; Structural Changes in Nylon 6 Yarn on Heat-Setting and Friction-Twisted Texturing, Textile Res. J., 1974, 539-544.

[15] Kveder, S. M., Rijavec, T,; Dynamic Mechanical Properties , Superstructure and Texturability of PA 6.6 Partially Oriented Yarns, Textile Research Journal, 64(9), 1994, 495-500.

[16] Pal, S. K.; Ganhi, R. S.; Kothari, V. K.; Influence of Texturing Parameters on Structural Chemical Fiber International; Textile Res.J.; October 1995, 12, 701-776.

[17] Fothergill, F.; A Nomogram to Help in the Dyeing of Fine and Coarse Filament Rayons and Spun Rayons to the Some Shade, J. Soc. Dyers and Colour, 1994, 60, 93.

[18] Parikh, M. G., Chauhan, A., Naik, S. R.; Dyeing of Microfilament Polyester Textiles, Indian Textile J., August 2008.

[19] Burkinshaw, S. M.; Chemical Principle of Synthetic Fibre Dyeing, (Blakie, Glasgow- Part of Chapmann and Hall) Chap 4, Microfibers, 1995, 194-217.

[20] Leadbetter, p., Dervan, S.; The Microfiber Step Change, Journal of Society of Dyers & colorists, 1992, 103, 369-371.

[21] Akatani,Y.; Dyeing Behavior of Disperse Dyes on Polyester Microfibers ,proceedings of SDC international Conference on Coloration-Dynamic Response and the Environment, Hong Kong, 1994.

[22] Becerir, B., Paydak, M. E.; Determination of Colour Sensivityof Different Energy Disperse Dyes to Some Dyeing Parameters, Colourage 2007, 54/8, 42-48.

[23] Chong, C. L.; Polyester Microfiber Dyeing,Textile Asia, 1994, 59-60.

[24] Farizadeh, K., Montazer, M., Yazdanshenas, M. E., Rashidi, A., Malek, R.; Extraction, Identification and Sorption Studies of Dyes from Madder on wool, Journal of Applied Polymer Science, 2009, 113, 3799-3808.