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Effect of Descriptive Parameters of Slub Yarn on Strength and Elongation Properties

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Abstract
Strength and elongation have a great effect on slub yarn performance in production and usage. The main aim of this study is to determine the statistically significant descriptive parameters that have an effect on the breaking force and elongation of slub yarn using the full factorial design method. In addition, the effects of the significant parameters on the breaking force and elongation were investigated. Slub yarn samples were produced by using a ring spinning frame on which an original slub attachment was designed and mounted. After the samples were produced, dimensional measurements and image analysis were made. Then quality tests were applied to all samples and the results analysed. As a result, the parameters that have an effect on the breaking force of the slub yarn samples were obtained as the slub length, slub distance and base yarn count. The parameters affecting the breaking elongation of the slub yarn samples were obtained as the slub multiplier, base yarn count and twist coefficient. The relationship between the breaking force and elongation and the parameters selected have been explained by statistically significant regression equations. It is concluded that slub pattern parameters should also be considered for slub yarn performance.

Key words: *slub yarn, breaking force, breaking elongation, full factorial design, effective parameters.*

Introduction

Slub fancy yarn is widely used in the textile industry in order to produce primarily denim fabric, clothing and upholstery fabric. It is known that the main descriptive parameters of slub yarn (slub length, slub distance, slub multiplier, base yarn count, twist level etc.) have an effect on the strength and elongation performance of the yarn [3, 9, 10]. The importance of slub yarns for the textile industry is better understood with every passing day. In literature there have been a few studies investigating the effect of the earlier mentioned properties on yarn performance. Mahmood et al. [1] stated that the slub length, slub distance and twist coefficient have a statistically significant effect, whereas the slub multiplier has no statistically significant effect on the yarn strength. Nevertheless, it has been emphasised that slub yarn samples produced using the compact ring spinning system are stronger than those produced by the conventional ring spinning system. In addition, it is stated that some parameters of slub yarn used as the weft in woven fabric have a statistically significant effect on the weft-way strength of the fabric [1]. Lu et al. [8] analysed the influence of four dimensional parameters of slub yarns (base yarn diameter, slub diameter, slub distance and slub length) on the distribution of twist using a developed model. They stated that the twist of slub measured is always less than the theoretical twist. Here, the main effective factor is the slub multiplier. The increase in the slub multiplier decreases the twist in slub sections. The twist of base yarn is always more than the theoretical twist of slub yarn, which is mainly influenced by the ratio of the slub length to the slub distance, and anincrease in the ratio will increase the twist in base yarn sections. Generally, the strength of the yarn is influenced more by the increased fibre quantity in the yarn than by the decrease in slub twist. Therefore, the strength of the slub is higher than that of the basic yarn. The strength of the whole slub yarn is very close to that of common yarn with the same twist as base yarn [8].

The higher strength of slub yarns is required in terms of both the performance in weaving and the strength of fabric. Therefore, the weak points in slub yarn are not desired; they especially occur at the beginning and end of the slubs, arising from changing the draft level as a function of time during all production. These weak points can be determined using B-force-elongation charts plotted using tensile test results as much as possible. In literature, it is recomended to use the breaking force (B-force, cN) instead of the relative breaking force (Tenacity, cN/tex) for analysing the tensile test results of slub yarns [2]. The reason is that the two slub yarn samples, with different counts, have got extremely different breaking force levels but similar relative tenacity levels for all experiments.

The main aim of this study is to define the descriptive parameters that have a significant effect on the breaking force and elongation of slub yarns and to investigate how the parameters effect the properties. Besides this, a regression model of the relationship between the slub yarn parameters selected and the breaking force and elongation was found. In addition, the flat and slub yarns were compared to each other in terms of the breaking force and elongation. For this purpose, an experimental design was formed in accordance with the 2^k full factorial design method. The slub yarn samples required were produced, B-force and elongation tests were performed, and then the results were statistically analysed and evaluated. Consequently, the statistically significant effective parameters were defined and regression models explain the relationship between the breaking force and elongation properties. Later the main effect and interaction plots were interpreted.

Material and method

Experimental design

Firstly the six descriptive parameters of slub yarn that may have an effect on yarn strength and elongation were selected to use in the experimental design as independent variables. The dependent variables are the breaking force and breaking elongation (***Table 1***, see page 34).

The 2^k full factorial design method was used to screen the yarn parameters selected for their effect on yarn performance and to see whether or not a mathematical model could be found [7]. All statistical analysis was performed using Design Expert 6.0.1 software. The full factorial design was formed as 2^6 so that each factor had 2 levels and 64 different combi-

Table 1. Selected independent and dependent variables with level values [3].

Variable Qualification	Symbol	Variables	Unit	Levels (low – high)
Dependent	-	Breaking force	cN	-
	-	Breaking elongation	%	-
Independent	A	Slub length	mm	50 – 100
	B	Slub distance	mm	80 – 150
	C	Slub multiplier	-	1.75 – 2.75
	D	Ramp time	ms	60 – 120
	E	Base yarn count	tex	19.7 – 29.5
	F	Twist coefficient (α_m)	-	106.0 – 130.3

Table 2. Quality tests applied to slub yarn samples [3].

Experiments	Instrument name	Yarn properties	Standard
Count test	Count Measurement Wheel	Average count, tex	TS 244 EN ISO 2060
Twist test	MesdanLab Twist Measurement Device	Twist level, t.p.m.	TS 247 EN ISO 2061
Tensile test	Titan Universal Strength Device	Breaking force, cN	TS 245 EN ISO 2062
		Breaking elongation, %	

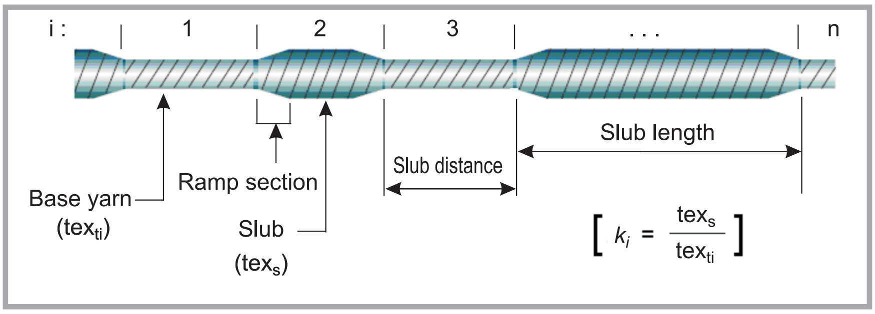

Figure 1. Schematic representation of a slub yarn sample; i - a yarn section or step number, n - the total number of steps in a pattern unit, k_i - slub multiplier, tex_s - slub count, and tex_{ti} - base yarn count. The ramp time means the delivery time of the ramp section.

nations in the design matrix. We have considered only two-factor interactions in ANOVA.

In accordance with the experimental design matrix, 64 different samples of slub yarn were produced. Besides this, flat yarn samples of 19.7 tex (α_m = 106.0 and 130.3) and 29.5 tex (α_m = 106.0 and 130.3) were also produced to compare with the slub yarn samples.

Raw material and production conditions

The raw material was 100% combed cotton blend. The means of fibre fineness, length and strength are 4.3 Mic, 28.4 mm and 29.2 cN/tex, respectively. The theoretical roving linear density and twist are 738.33 tex and 40 t.p.m, respectively. The uneveness CV_m of the roving was obtained as 4.52 %.

The climate conditions were 25 - 27 °C and 55 - 60% Rh. throughout the production of yarn samples. The travellers were number 2 at the lower level of slub lengths and number 4 at the higher level as type El 2f LB of Reinerfürst. The breaking draft was 1.15 for all the samples. The total draft was 9.1 - 25.0 for samples with 29.5 tex of base yarn count and 13.6 - 37.5 for samples with 19.7 tex of base yarn count. The spindle speed was 6000 r.p.m throughout all the production. Hence the delivery speed was 6.43 - 7.95 - 9.87 mpm depending on twist levels and yarn counts. In more detail, the speed was 6.43 mpm at 19.7 tex and α_m=130.3, 7.95 mpm at 19.7 tex and α_m = 106.0, 29.5 tex and α_m = 130.3, 9.87 mpm at 29.5 tex and α_m = 106.0 [3].

The raw material was transformed into roving with required properties by passing it through the conventional opening, blending it and preparing it in the form of a combed cotton line. The slub yarn samples were produced by using a ring spinning frame with 56 spindels which had been mecatronically modernised with an original electronically controllable slub attachment at Çukurova University Textile Engineering Department Laboratory. The rear and middle draft cylinders are directly driven by servo motors in the modernised ring spinning frame. The frame is flexible to produce different yarn types on the right and left sides of the machine at the same time. The production and slub dimensional data are entered into the system by means of a PC (Personel Computer) and the motors are controlled with the assistance of a PLC (Programming Logic Controller).

Measurements and quality tests

All the measurements and quality tests were performed under standard atmosferic conditions (temperature 20 ± 2 °C, 65 ± 2% Rh). Before the quality tests, the dimensional parameters of the slub yarn samples were measured i.e. lengths (slub lengths, slub distance) and slub multipliers. A schematic represantation of slub yarn is given with dimensional parameters in ***Figure 1***.

After dimensional measurements, other quality tests were applied to all samples, given in ***Table 2.***

In the length measurements, a yarn sample was laid on a black surface without tension, then the beginning and end points of the slubs were marked by a colour pen, and finally the lengths were measured by means of a steel ruler. A total of 20 measurements were taken in duplicate from 10 cops for each combination.

The slub multipliers were measured by both manual and image analysis methods. For manual measurement, many parts were cut from the slub and base yarn sections excluding ramp sections for the 8 different samples selected. We ensured that the total length of parts for any sample is over 1 m. The yarn parts were weighted and the sectional yarn counts calculated for the slubs and base yarns. Then we obtained the slub multipliers by calculating the proportion of slub counts (tex_s) to base yarn counts (tex_{ti}) for each sample. In the image analysis method, the diameters of the same yarn samples for base yarn and slub sections were also measured using an SDL Microscope System with Digital Camera. The average of total 20 measurements were obtained and the slub multipliers calculated as the proportion of the slub diameters to the base yarn diameters for each sample.

For measuring of the yarn count, 10 skeins (100 m per cop) from 10 cops of each sample were wrapped by a wrapping reel. The skeins were weighed by a precision balance with a 1/10000 g sensitivity, and then the average counts (tex) of all samples were obtained. Twist measurements were performed by means of a conventional twist tester designed to determine yarn twist by the untwist/retwist method. Besides this, the helix angles in the base yarn and slub sections arising from the twist were measured using the SDL Microscope System with Digital Camera.

For measuring the B-force and elongation, a total of 100 measurements of each combination of samples (10 tests from 10 cops) were taken and the means obtained. All the tensile tests were manually performed using a Titan Universal Strength Device. For all the tests, the jaw seperation was 500 mm, the test speed - 500 mm/min, and the pretension was 0.5 cN/tex.

Statistical analysis

All the statistical analysis was performed using Design Expert 6.0.1 packet software. Firstly, ANOVA was applied to the data obtained from the tests in order to define the statistically significant parameters affecting slub yarn properties. Regression models that explain the relationship between the parameters and the breaking force and elongation properties were established, and adequacy checking was made for validation. Then the 2D main factor and interaction plots were obtained. Finally all the results of the statistical and image analysis and plots were discussed and evaluated.

Results and discussion

Results of dimensional measurements

The dimensional descriptive parameters of the slub yarn, such as the slub length, slub distance and slub multiplier were measured in order to determine the deviations from theoretical values. In the measurements, the average deviation of the slub length was obtained as 8% (4 mm) at the lower level and 2.5% (2.5 mm) at the higher level of the slub length. The average deviation of the slub distance was obtained as 4% (3.2 mm) at the lower level and 6.1% (9.15 mm) at the higher level of the slub distance. In literature, it has been mentioned that a deviation in length of about 10 mm is normal for the slub length and slub distance [4]. Thus we concluded that there is not any problem with the deviation levels. Results of the measurements for slub multipliers are given in ***Figure 2***. From the plot, it seems that there are acceptable differences between the measured and theoretical slub multipliers. For all the measurements, the highest CV% was obtained as 14.11%.

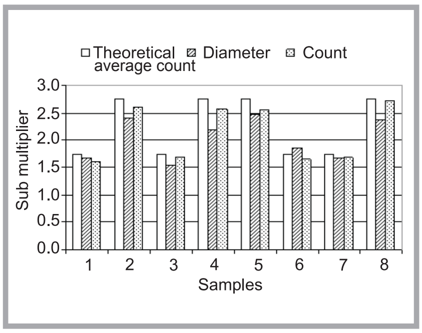

Figure 2. *Comparison plot of slub multiplier measurements.*

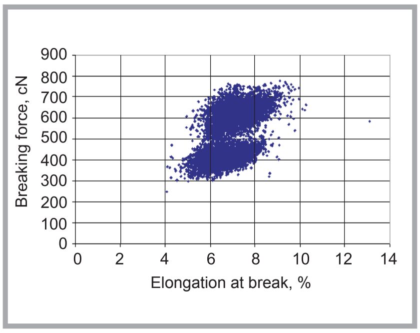

Figure 3. *Scatter plot of the breaking force versus elongation for slub yarn samples.*

Results of quality tests

Linear density measurement

To define the deviation of linear density, the theoretical count of slub yarn should be calculated. Because there have not been any suggestion in literature, a mathematical equation was developed to calculate the theoretical average counts of the slub yarn samples. Then we calculated the differences between the measured and theoretical counts [5]. The average count deviation was obtained as 5.9% for 64 the slub yarn samples and 0.9% for the flat yarn samples.

Twist measurement

When the base yarn count of the slub yarn samples and the count of the flat yarn samples were theoretically 29.5 tex, the theoretical twist levels were established as 608 t.p.m. for α_m = 106.0 and 755 t.p.m. for α_m = 130.3. When the base yarn count of the slub yarn samples and count of the flat yarn samples were theoretically 19.7 tex, the theoretical twist levels were found to be 755 t.p.m. for α_m = 106.0 and 933 t.p.m. for α_m = 130.3. The means of the twist deviations are 7.5 t.p.m. for slub yarns and 21.2 t.p.m. for flat yarns. The mean CV_m of the twists are 1.74% for the slub yarn samples and 4.7% for the flat yarn samples.

Table 3. *Results of image analysis for selected slub yarn samples.*

Sample No	Yarn properties			Base yarn section				Slub yarn section			
	Base yarn count, tex	α_m	Slub multiplier (k)	Diameter, mm	%CV	Helix angle, degree	%CV	Diameter, mm	%CV	Helix angle, degree	%CV
1	29.5	106.0	1.75	0.22	9.18	32.53	10.65	0.36	10.09	25.04	11.11
2		106.0	2.75	0.21	7.00	33.10	5.60	0.50	6.18	24.73	9.17
3		130.3	1.75	0.2	14.11	36.56	9.67	0.31	9.35	25.90	12.48
4		130.3	2.75	0.2	6.43	39.07	11.06	0.43	7.34	25.78	9.60
5	19.7	106.0	1.75	0.18	10.33	33.92	7.96	0.33	12.36	27.70	14.32
6		106.0	2.75	0.17	6.43	33.96	12.09	0.42	7.02	25.02	8.60
7		130.3	1.75	0.18	13.83	35.60	13.63	0.30	10.16	26.15	11.47
8		130.3	2.75	0.16	9.76	38.27	12.23	0.38	11.69	27.51	9.82
9	29.5	130.3	1.0	0.22	12.45	31.26	12.99				
10		106.0	1.0	0.21	14.11	28.64	11.73				
11	19.7	130.3	1.0	0.16	14.11	29.24	12.59				
12		106.0	1.0	0.19	9.56	25.68	12.82				

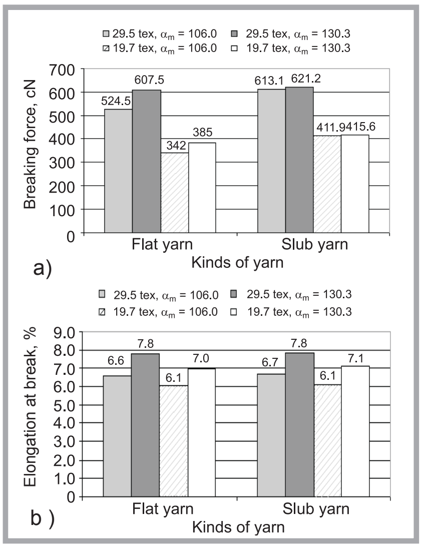

Figure 4. Comparison plots of flat and slub yarns for the breaking force (a) and elongation (b).

In the image analysis, the diameters and twist angles were measured for 8 selected samples. Therefore the slub multipliers were calculated as mentioned above, and the twist distribution over the whole slub yarn was examined. Lu et al. mentioned that there is a considerable difference between the twist levels of base yarn and slub sections [6]. This finding is supported by the results of image analysis obtained in this study. The results of diameter and twist helix measurements are given in ***Table 3*** (see page 35). As is well known, the helix angle (the angle between the helix line and yarn axis) is directly proportional to the twist level. The table shows that the sectional twist level of the base yarn is higher than the original twist level and that the sectional twist level of the slub is lower than the original twist level.

Breaking force measurement

In slub yarns, some weak points may occur at the beginning or end of slubs. The weak points have an effect on slub yarn strength, therefore we investigated the existance of weak points in all the samples to avoid any weak point effect on the results of the study. Hence we obtained a scatter plot of the breaking force versus the breaking elongation for the slub yarn samples in ***Figure 3*** (see page 35) [2]. The scatter plot indicates that there is not any weak point in all the slub yarn samples owing to there being no point close to the origin. The two clusters of points may occured due to the strong effect of the count on the breaking force.

The slub yarn samples were compared to the flat yarn samples in terms of the breaking force and elongation means. The comparison plots are given in ***Figure 4***. ***Figure 4.a*** shows that the slub yarn samples are generally stronger than the flat yarn samples. It seems that the differences in the breaking force between the slub and flat yarn samples increases with a decrease in the twist coefficient. This finding indicates that the breaking force of slub yarn has a tendency to decrease at higher levels of the twist coefficient. ***Figure 4.b*** does not indicate any significant differences in elongation between the flat and slub yarn samples.

Statistical Analysis

Breaking force

The results of ANOVA and the regression models were obtained by using factorial analysis. Variance analysis results for the breaking force are given in ***Table 4***. The table shows that the effects of the main factors A, B & E are statistically significant, whereas the effects of main factors C, D & F are statistically insignificant at $\alpha = 0.01$. Besides this, the interaction terms of AF, BE and CF have a statistically significant effect on the breaking force at $\alpha = 0.01$. The model that was established with all the terms in ***Table 4*** is statistically significant at $\alpha = 0.01$. However, the adequacy checking of the model indicated a need for transformation. After the Natural Log transformation was applied to the first model, the final log model equation with actual factors was found in ***Equation 1***.

$$\begin{aligned} \text{Ln (Breaking force)} &= 3.6865 + \\ &+ 5.709\times10^{-3}\times A - 1.032\times10^{-3}\times B + \\ &+ 0.4137\times C - 0.04677\times E + \\ &+ 0.1111\times F - 3.934\times10^{-5}\times A\times F + \\ &- 5.3591\times10^{-5}\times B\times E - 3.3976\times10^{-3}\times C\times F \end{aligned} \quad (1)$$

Factor D was not placed in ***Equation 1*** because it has not got any significant main or interaction effects. Thus we concluded that the ramp time (D) has not got any statistically significant effect on the breaking force of the slub yarn samples. Factors C (slub multiplier) and F (twist coefficient) have not got an individually significant effect on the breaking force of slub yarn, but their interaction effects are statistically significant at $\alpha = 0.01$. Therefore they are in the model to preserve the hierarchy.

The results of the ANOVA for the final log model shows that the model is significant at $\alpha = 0.01$. The coefficient of determination $R^2_{prediction}$ is obtained as 0.985 and R^2_{adj} as 0.9829. The inconsiderable difference between R^2 and R^2_{adj} indicates that no unnessesary terms have been included in the model. The model explains about 98% of the variability in the breaking force for all observations in this study. The adequacy checking does not indicate any problem for the regression model in ***Equation 1***.

The effects of the main significant factors are examined by plotting one factor plots, shown in ***Figure 5***. ***Figure 5.a*** shows that the breaking force increases significantly with an increase in the slub length. The reason may have been the increase in the fibre mass of slub portions in the yarn. ***Figure 5.b*** shows that the breaking force decreases slightly with an increase in the slub distance, indicating the importance of slub distance for yarn breakages. In fact, it is observed that all breakages in the tensile tests mostly occurred out of the slub sections. As is generally known, finer yarns have lower strength and an increase in the slub distance decreases the average count of slub yarn in tex. ***Figure 5.c*** indicates that there is a strong effect of the base yarn count on the breaking force of slub yarn. Unsurprisingly the

Table 4. Results of ANOVA for the breaking force.

Source of variance	Sum of squares	Degrees of freedom	Mean squares	F Ratio	P Ratio	Comment
Model	6.895×10^5	8	86130.85	403.66	0.0001	Significant
A	12084.88	1	12084.88	56.64	0.0001	
B	2453.59	1	2453.59	11.50	0.0013	
C	650.57	1	650.57	3.05	**0.0864**	**Insignificant**
E	6.617×10^5	1	6.617×10^5	3101.28	0.0001	Significant
F	565.55	1	565.55	2.65	**0.1092**	**Insignificant**
AF	2019.94	1	2019.94	9.47	0.0033	Significant
BE	2124.4	1	2124.40	9.96	0.0026	
CF	7416.44	1	7416.44	34.76	0.0001	
Residual	11735.53	55	213.37			
Cor Total	$7.008.10^5$	63				

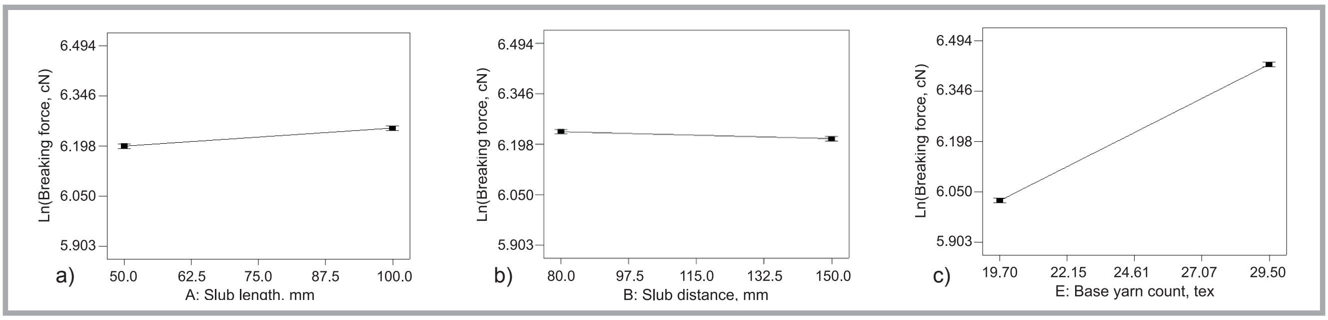

***Figure 5.** Main effect plots of significant factors for the breaking force.*

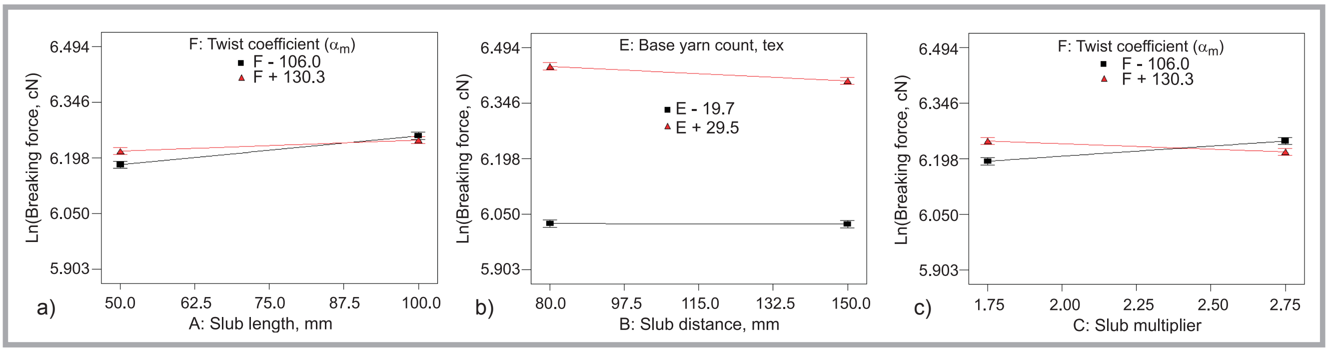

***Figure 6.** Interaction plots for the breaking force.*

breaking force increases with an increase in the base yarn count in tex.

Figure 6.a, in which there is the interaction plot of AF factors, shows that the breaking force increases with an increase in the slub length at both levels of the twist coefficient. However, an increase in the twist coefficient has a tendency to increase the breaking force at a low level of the slub length, but at a high level of the slub length the breaking force is decreased. ***Figure 6.b***, in which there is the interaction plot of BE factors, shows that the breaking force has a tendency to decrease at a high level of the base yarn count (tex), but at a low level of the base yarn count in tex with an increase in the slub distance, there is no tendency to change. ***Figure 6.c***, in which there is the interaction plot of CF factors, shows that the breaking force decreases at a high level of the twist coefficent and increases at a low level of the twist coefficent with an increase in the slub multiplier. It seems that the longer and thicker the slubs are, the more they have the tendency to decrease the breaking force with an increase in the twist. This finding supports the results of the study peformed by Lu et al. [6]. Therefore it is concluded that the irregular distribution of twist on slub yarn causes a loss of breaking force.

Breaking elongation

The results of ANOVA are given in ***Table 5***, showing that the effects of main factors A & B are not statistically significant for the breaking elongation of the slub yarn samples at $\alpha = 0.05$. The regression model is statistically significant at $\alpha = 0.05$, and the adequacy checking does not indicate any problem.

The regression model equation is given in ***Equation 2***. Factor D was not placed in ***Equation 2*** because it has not got any significant main or interaction effect. Hence we concluded that the ramp time (D) has not got any statistically significant effect on the breaking elongation of the slub yarn samples. Factors A (slub length) and B (slub distance) have not got individually significant effects on the breaking elongation of slub yarn, but their interaction effects are statistically significant at $\alpha = 0.05$. Therefore they are in the model to preserve the hierarchy.

$$\begin{aligned}\text{Breaking elongation} &= -1.66566 + \\ &- 0.0150 \times A + 0.0283 \times B - 0.158 \times C + \\ &+ 0.018928.E + 0.072597.F + \\ &+ 6.173 \times 10^{-4} \times A \times E + 2.461 \times 10^{-4} \times B \times F\end{aligned} \quad (2)$$

The coefficient of determination $R^2_{prediction}$ is obtained as 0.8937 and R^2_{adj} as 0.8804. The inconsiderable difference between R^2 and R^2_{adj} indicates that no unnessesary terms have been included in the model. The model explains about 89% of the variability in breaking elongation for all observations in this study. Later adequacy checking was performed for the regression model, revealing no apparent problem for the regression model in ***Equation 2***.

The effects of the main significant factors are examined by plotting one factor plots,

***Table 5.** Results of the ANOVA for the breaking elongation.*

Source of variance	Sum of squares	Degrees of freedom	Mean squares	F Ratio	P Ratio	Comment
Model	26.53	7	3.79	67.26	0.0001	Significant
A	9.10^{-4}	1	9×10^{-4}	0.016	**0.8999**	**Insignificant**
B	0×047	1	0.047	0.84	**0.3635**	
C	0.40	1	0.40	7.10	0.0101	Significant
E	6.59	1	6.59	116.98	0.0001	
F	18.43	1	18.43	326.96	0.0001	
AE	0.37	1	0.37	6.55	0.0132	
BF	0.7	1	0.7	12.37	0.0009	
Residual	3.16	56	0.056			
Cor Total	29.69	63				

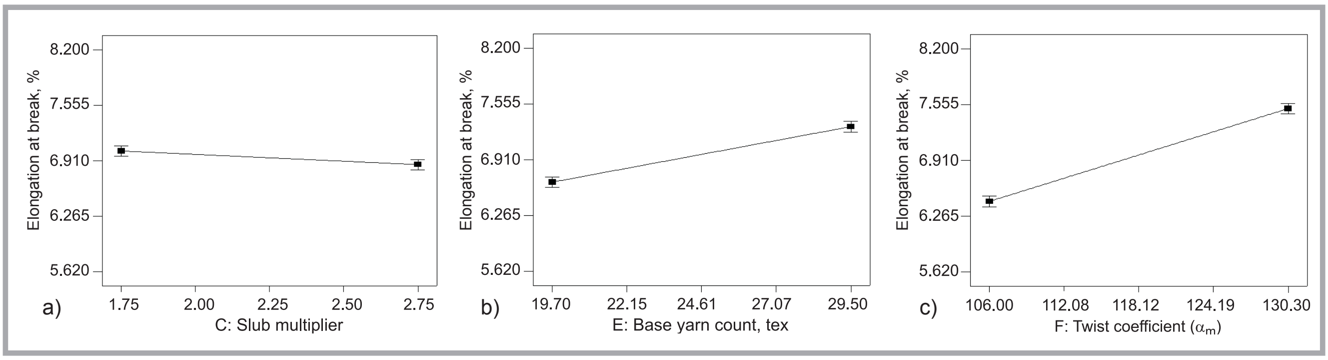

***Figure 7.** Main effect plots of significant factors for the breaking elongation.*

shown in ***Figure 7***. ***Figure 7.a*** shows that the breaking elongation decreases slightly with an increase in the slub multiplier. ***Figure 7.b*** shows that the breaking elongation increases significantly with an increase in the base yarn count in tex. ***Figure 7.c*** indicates the strong effect of the twist coefficient on the breaking elongation of slub yarn. It seems that the breaking elongation increases significantly with an increase in the twist coefficient.

Figure 8.a, in which there is the interaction plot of AE factors, shows that the breaking elongation increases at a high level of the base yarn count and decreases at a low level of the base yarn count with an increase in the slub length. ***Figure 8.b***, in which there is the interaction plot of BF factors, shows that the breaking elongation has a tendency to decrease at a high level of the twist coefficient, but at a low level of the twist coefficient with an increase in the slub distance, it has a tendency to increase.

Summary

In this study, the descriptive parameters of slub yarn that have an effect on the breaking force and elongation were practically investigated using the full factorial design method. The slub length (A), slub distance (B) and base yarn count (E) are statistically significant for the breaking force of slub yarn. The significant two-factor interactions are obtained as the slub length (A) - twist coefficient (F), the slub distance (B)-t base yarn count (E) and the slub multiplier (C) - twist coefficient (F). The relationship between the breaking force and descriptive parameters was explained by a significant regression model at $\alpha = 0.01$.

The significant parameters that have an effect on the breaking elongation were obtained as the slub multiplier (C), base yarn count (E) and twist coefficient (F). For the breaking elongation, the significant two-factor interactions are the slub length (A) - base yarn count (E) and the slub distance (B) - twist coefficient (F). The relationship between the breaking elongation and descriptive parameters was explained by a significant regression model at $\alpha = 0.05$.

It is concluded that the dimensional parameters of slub yarn should also be considered for slub yarn performance. The longer and thicker the slubs, the more the tendency for the breaking force to decrease with an increase in the twist level. Therefore the irregular twist distribution over the whole slub yarn arising from its dimensional parameter causes a loss of breaking force.

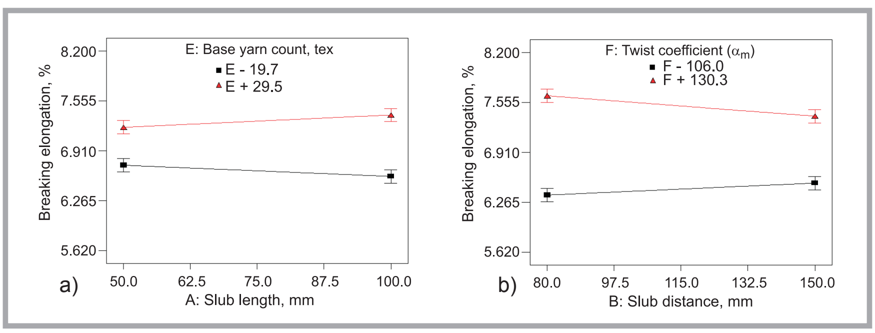

***Figure 8.** Interaction plots for the breaking elongation.*

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