(REFEREED RESEARCH)

AN EXPERIMENTAL INVESTIGATION ON STRENGTH AND ELONGATION PROPERTIES OF CHENILLE YARN

ŞÖNİL İPLİĞİN MUKAVEMET VE UZAMA ÖZELLİKLERİ ÜZERİNE DENEYSEL BİR ÇALIŞMA

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ABSTRACT

Tensile characteristics of yarn have a great effect on performance of textile products. In this study, tensile characteristics (i.e. breaking force and elongation properties) of chenille yarns are investigated using theoretical and statistical approaches. The aim of this investigation is to explain the effect of selected production parameters and yarn components on tensile properties of chenille yarn and to develop some practical models to predict the tensile properties before production. In theoretical approach, a mathematical prediction model was developed by using geometrical methods for breaking force of chenille yarn. 27 different chenille yarn samples were produced according to an experimental design which contains different levels of effective factors. In statistical approach, the data sets were divided into two parts of 20 and 7 sets. First data group was used in stepwise regression analysis and second data group was used for verification. Finally, the mathematical and statistical models were evaluated and compared their performances in terms of estimating tensile properties. As a result, it has proved that breaking force of chenille yarn can be estimated by theoretical and statistical methods. The significant effective factors on breaking force of chenille yarn are count of binder yarn and twist level of chenille yarn. It was not obtained a strong statistical model for elongation of chenille yarn but the model was quite succesfull in verification.

Keywords: Chenille Yarn, Breaking Force, Breaking Elongation, Prediction, Mathematical Model, Statistical Model

ÖZET

İpliklerin mukavemet özellikleri tekstil ürünlerinin performansı üzerinde büyük etkiye sahiptir. Bu çalışmada, şönil ipliğin mukavemet özellikleri olan kopma kuvveti ve uzama, teorik ve istatistiksel yaklaşımlar kullanılarak araştırılmıştır. Çalışmanın amacı; seçilmiş üretim parametreleri ve iplik bileşenlerinin şönil iplik mukavemet özellikleri üzerindeki etkilerini açıklamak ve üretim öncesinde mukavemet özelliklerini tahmin edecek bazı pratik modeller geliştirmektir. Teorik yaklaşım kapsamında, geometrik yöntem kullanılarak şönil ipliğin kopma kuvvetini tahmin edecek bir matematik model geliştirilmiştir. Etken faktörlerin farklı seviyelerini içeren bir deneysel tasarıma uygun olarak 27 farklı şönil iplik örneği üretilmiştir. İstatistik yaklaşım kapsamında, veri seti 20 ve 7 elemanlı iki gruba ayrılmıştır. Birinci veri grubu, stepwise regresyon analizi için, ikinci grup ise doğrulama amacıyla kullanılmıştır. Sonuçta, matematik ve istatistik modeller değerlendirilmiş ve mukavemet özelliklerini tahmin etme açısından performansları karşılaştırılmıştır. Böylece, şönil ipliğin kopma kuvvetinin teorik ve istatistik modeller ile tahmin edilebileceği kanıtlanmıştır. Şönil ipliğin kopma kuvveti üzerinde anlamlı olan etken faktörlerin, bağ iplik numarası ve şönil ipliğin büküm değeri olduğu belirlenmiştir. Şönil ipliğin uzama oranını tahmin etmek için güçlü bir istatistik model elde edilememesine karşın bu model doğrulamada oldukça başarılı sonuçlar vermiştir.

Anahtar Kelimeler: Şönil İplik, Kopma Kuvveti, Kopma Uzaması, Tahmin, Matematik Model, İstatistik Model

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1. INTRODUCTION

The mechanical behavior of yarns affects their suitability in most end uses. The most important mechanical property of yarns is tensile properties (1). Many studies on tensile properties of standard yarn types can be found in literature but there is a lack of studies on chenille yarn as a type of fancy yarn. In literature, researchers mostly investigated physical properties of chenille yarn and fabric such as abrasion resistance, dimensional stability, seam slippage. Chenille yarn, which are a type of fancy yarns, consists of cut pile yarns compacted by twisting of two binder yarns. In literature, it is mentioned that the binder yarns provide the strength to the yarn and the pile yarns give fluffy hand, bulky structure and specific appearance to chenille yarn. Usage areas of chenille yarns varies from garments (sweaters, outerwear fabrics) to decorative fabrics, upholstery, bedspreads (2).

Ülkü et al. (2003) examined the effect of chenille yarn properties, pile length, twisting rate, and weaving construction on the abrasion resistance of upholstery fabrics (3). Özdemir and Çeven (2004) investigated experimentally effect of chenille yarn manufacturing parameters on yarn and upholstery fabric abrasion resistance. They found an improvement in abrasion resistance with increasing twist, gauge (pile length), and the use of natural fibers as pile materials (4). Babaarslan and İlhan (2005) investigated experimentally the effects of pile length on abrasion resistance of chenille fabrics (5). Çeven and Özdemir (2006) characterised the basic parameters describing the structure of chenille fancy yarns produced on a chenille yarn machine. They produced chenille yarn samples in different pile lengths, twist levels, yarn counts of component yarns, and derived an expression to determine the final count of the chenille yarns (6). Çeven, Özdemir (2007) investigated the effects of yarn parameters on the boiling shrinkage behaviour of chenille yarns and used a fuzzy logic system to predict the boiling shrinkage ratio of chenille yarns (7). Çeven et al. (2007) studied on an intelligent modeling methodology based on ANNs for predicting the abrasion resistance of chenille yarns and fabrics (8). Kavuşturan et al. (2010) studied the effects of pile and core yarn material types on the abrasion and bending behaviour of chenille knitted fabrics (9). Recently, there are some studies intended to expand the usage of chenille yarn such as denim industry. Babaarslan and Telli (2013) investigated possibilities to use chenille yarns in denim fabric (10). In this study, it is mentioned that the ring spun carded cotton yarn samples have about three times more breaking force values (N) and one and half times more breaking elongation than cotton chenille yarn samples of almost the same count. The study shows that inserting chenille yarn into denim fabric decreases fabric breaking force about three times and tearing strength about four times but did not effect breaking elongation. These findings indicate that tensile properties of chenille yarns must be investigated on and improved in order to use chenille yarn in further areas like denim industry.

Therefore, the aim of this study is to investigate the effect of production factors on breaking strength and elongation of chenille yarns. Thus, it is expected that the work will contribute to the scientific literature and provide information to manufacturers about chenille yarn in fabric design and production. The yarn samples were produced from 100% combed cotton fibers according to an experimental design and tensile properties of all yarn samples were measured. Then, test results were analysed by using mathematical approach and statistical analysis in order to investigate tensile properties of chenille yarn samples. Finally, a mathematical model was established to predict breaking force of chenille yarn and the effect of factors on tensile properties was described with statistical models.

2. MATERIAL AND METHOD

In this study, we used primarily a theoretical approach to predict breaking force (N) of chenille yarn. Pile yarn constitutes about 70-75% of total mass in chenille yarn (11). Therefore, pile length is effective on count of chenille yarn but it doesn't contribute to strength of the yarn. Because the pile yarn ends are protruded from chenille yarn, its length can not make a contribution to strength of chenille yarn. So, using breaking strength with cN/tex unit could mislead the results of the study. Then, pile length was kept constant by using 1 mm caliper and breaking force (cN) was considered as tensile strength.

For the purpose of the theoretical approach, the following assumptions were made:

1. Cross-section of the binder yarns are circular and their radius are constant.
2. Before chenille yarns are twisted, cross-section of pile yarns are circular and their radius are constant, but they are flattened in twisted chenille yarn,
3. Twist is distributed uniformly and equally along the yarns,
4. Two pile yarns are gripped in a twist helix of chenille yarn,
5. Binder yarns are wrapped linearly around each other to compact pile yarns.

In Figure 1, a general illustration of the assumption model of chenille yarn used in this work is given.

To evaluate performance of the models, 27 data sets belong to the chenille yarn samples were produced in accordance with an experimental design. The variables used in the experimental design are given along with level values in Table 1. The dependent variables were breaking force (N) and elongation (%) of chenille yarn. The independent variables that are production parameters and properties of yarn components were selected as count of chenille yarn (Nm), twist of chenille yarn (T/m), count of binder yarn (Ne), strength of binder yarn (cN/tex), count of pile yarn (Ne) and strength of pile yarn (cN/tex).

We produced all the yarn samples from 100% combed cotton fibers. Combed cotton was preferred due to its wide usage as raw material. So, the effect of fiber properties on tensile characteristics was not considered and raw material has been kept constant. Both the binder and pile yarns used in chenille yarn samples were compact ring spun yarns having three theoretical yarn counts of Ne 30, 36, 40. The physical characteristics of the ring spun yarns used in chenille yarn samples such as production parameters, results of uneveness and tensile tests are given in Table 2. Uneveness and tensile tests were carried out using Uster Tester 4-FX and Uster Tensorapid 4 instruments.

The twist levels of chenille yarns have been selected as 600, 750, 900 T/m. The measured physical properties of chenille yarn samples were given in Table 3. The numbers of repetitions performed for the tensile tests of single and chenille yarn samples, the twist level measurements of chenille yarn samples and the measurement of chenille yarn counts were 20, 10 and 5, respectively.

The binder and pile yarns were provided by a cotton spinning factory and the chenille yarn samples were produced in operating conditions by a chenille yarn manufacturer in industry. The yarn samples were not passed through any finishing treatment. The model of chenille machine used in all production was AC 91/E produced by GIESSE s.r.l. The climatic conditions along all production was about 45% RH and 29 ^{0}C temperature. The production parameters that are head speed, spindle speed and feed speed were ranged between 12500-17000 rpm, 4020-6000 rpm and 60-67 rpm, respectively.

Table 1. The variables with level values in the experimental design

Variable Qualification	Symbol	Variables	Unit	Levels
Dependent	BF	Breaking Force	cN	-
	BE	Breaking Elongation	%	-
Independent	CC	Count of Chenille Yarn	Nm	-
	TC	Twist of Chenille Yarn	T/m	600 - 750 - 900
	CB	Count of Binder Yarn	Ne	30 - 36 - 40
	CP	Count of Pile Yarn	Ne	30 - 36 - 40
	SB	Strength of Binder Yarn	cN/tex	-
	SP	Strength of Pile Yarn	cN/tex	-

Table 2. Physical properties of ring spun yarns used in chenille yarn samples

Average Yarn Count (Ne)	CV% of Yarn Count	Twist Level (T/m)	CV% of Twist Level	Coefficient of Twist (α_e)	Uneveness (CVm)	Thin Places (-50 % /km)	Thick Places (+50 % /km)	Neps (+280 % /km)	Hairiness Value (H)	Breaking Strength (cN/tex)	Breaking Elongation (%)
29.85	0.48	720	2.39	3.34	11.78	0	15	6	4.65	18.06	6.54
35.78	0.56	800	2.99	3.39	12.14	0	22	12	4.14	16.54	5.53
39.80	0.96	850	1.81	3.41	12.63	0	23	5	4.08	17.05	5.59

Table 3. Physical properties of chenille yarn samples

Sample No	Theoretical Pile Yarn Count (Ne)	Theoretical Binder Yarn Count (Ne)	Measured Twist Level of Chenille Yarn (T/m)	CV% of Twist Level	Count of Chenille Yarn (Nm)
1	30	30	583.8	1.94	4.41
2	30	30	743.8	2.58	4.26
3	30	30	886.0	4.04	4.12
4	30	36	630.5	13.89	4.64
5	30	36	757.0	3.64	4.78
6	30	36	848.0	2.60	4.76
7	30	40	604.3	2.34	4.23
8	30	40	746.4	2.66	4.28
9	30	40	863.2	1.77	4.36
10	36	30	579.0	3.37	4.70
11	36	30	737.6	3.13	4.93
12	36	30	874.0	3.61	4.97
13	36	36	564.6	3.05	4.79
14	36	36	711.8	2.05	4.78
15	36	36	880.2	3.07	4.65
16	36	40	578.2	2.72	4.65
17	36	40	713.8	3.02	5.24
18	36	40	893.2	2.30	5.16
19	40	30	568.8	8.94	4.43
20	40	30	727.2	3.41	5.34
21	40	30	878.2	3.41	5.27
22	40	36	585.6	4.36	4.78
23	40	36	714.8	3.35	5.80
24	40	36	881.0	2.38	5.63
25	40	40	553.4	3.63	5.24
26	40	40	675.2	1.92	5.33
27	40	40	860.2	1.61	4.90

After the theoretical model were established geometrically, we used all data sets to assess the performance of the model. For developing statistical models, we applied stepwise linear regression analysis to 20 of all data sets. After the prediction models were established, the predicted values of breaking force and elongation were derived using the models. In order to evaluate performance of the statistical models, we used the remaining 7 data sets that have never been seen by the models before. For evaluation, we have compared the performance of the models using the actual and predicted values. The performance criteria were preferred as R and MSE. All the statistical analysis were performed by using SPSS 20.0 software package.

3. RESULTS AND DISCUSSION

Data sets used in mathematical and statistical analysis are given in Table 4.

Table 4. Data sets used in mathematical and statistical analysis

	Sample No	Chenille Yarn Samples				Plied Yarn Samples (without pile)		
		Measured B-Force (N)	Predicted B-Force (N)	Measured Elongation (%)	Predicted Elongation (%)	Measured Twist Level (T/m)	Measured B-Force (N)	Measured Elongation (%)
Regression Analysis	1	6.87	6.86	8.26	8.95	569	7.15	6.49
	2	7.75	7.18	9.30	9.19	741	7.16	5.97
	3	7.58	7.46	11.48	9.41	861	8.19	6.54
	5	7.53	7.17	8.80	8.35	569	7.15	6.49
	6	7.67	7.44	9.87	8.38	744	7.44	5.94
	7	7.05	6.83	8.75	9.24	861	8.19	6.54
	8	7.55	7.15	7.51	9.16	569	7.15	6.49
	10	5.07	5.76	8.38	8.48	729	7.63	6.16
	12	6.60	6.19	7.21	8.04	861	8.19	6.54
	13	5.50	5.63	7.73	8.33	581	5.59	6.35
	15	6.23	6.26	9.70	8.56	764	6.21	5.70
	16	6.00	5.67	7.46	8.56	875	6.53	5.46
	17	5.82	5.93	6.89	7.61	581	5.59	6.35
	19	5.37	4.91	9.70	8.91	717	6.14	5.77
	20	5.49	5.19	6.80	7.44	868	6.46	5.98
	21	5.67	5.43	5.07	7.56	575	5.55	5.40
	23	5.55	5.13	7.19	6.70	733	6.26	5.96
	24	5.69	5.49	8.94	6.98	868	6.46	5.98
	25	5.17	4.81	8.17	7.61	583	5.18	5.49
	27	5.63	5.42	8.42	8.15	767	5.84	5.24
Verification	4	6.93	6.85	8.59	8.57	847	6.09	5.19
	9	7.71	7.45	9.55	9.03	583	5.18	5.49
	11	6.38	6.01	7.82	8.11	728	5.81	5.45
	14	5.49	5.92	7.01	8.35	870	5.92	5.44
	18	6.32	6.26	8.41	7.73	583	5.18	5.49
	22	5.21	4.86	7.54	8.35	735	5.62	6.33
	26	5.17	5.05	8.55	7.46	870	5.92	5.44

3.1. Mathematical Approach

We have geometrically established a mathematical model based on the assumptions mentioned above by using the theoretical approach to predict breaking force of chenille yarn. For this purpose, angle of twist helix should be primarily calculated. The formulation of twist angle in chenille yarn had been given in previous study (2). The following formula (Eq. 1) which had been derivated in the previous study was used to calculate the angle of twist helix in this study.

$$\alpha_c = Arc\ tg\left(\frac{2x\left(d_p^{'} + d_b\right)}{L_T}\right) \quad (1)$$

In Figure 1, a general illustration of the assumption model of chenille yarn used in this study is given. The geometrical model of chenille yarn was simplified and idealized in order to develop a mathematical model (2). As seen in Figure 1, tensile strength of a binder yarn (T_1 or T_2) can be decomposed into horizontal (x) and vertical (y) components.

When the load on chenille yarn in tensile test overcome the total horizontal (axial) components of tensile strength of binder yarns (T_{tx}) and the yarn to yarn frictional forces arised from binder and pile yarns (F_s), the yarn specimen will extent and break at last. Here, we neglected the difference between two frictional forces (binder yarns to binder yarns and binder yarns to pile fibers) in order to simplify the model. So, the tensile strength (i.e. breaking force) of chenille yarn is mathematically defined as follows:

Total horizontal components of tensile strength of binder yarns (T_{tx}):

$$T_{tx} = T_{1x} + T_{2x} = T_1 x Cos\ \alpha_c + T_2 x Cos\ \alpha_c$$

Where; $T_1 = T_2$,

$$T_{tx} - 2xT_1 x Cos\ \alpha_c \qquad (2)$$

Total frictional force:

$$F_s = \mu_s x N$$

$$F_s = \mu_s\ x T_{1y} \qquad (3)$$

If we combine Eq. 2 and 3, the tensile strength of chenille yarn can be derived in Equation 4.

$$T_{tx} = 2xT_1 x Cos\ \alpha_c + \mu_s x T_{1y} \qquad (4)$$

At first, we calculated twist helix angles (α_c) for all chenille yarn samples by Eq. 1 (Figure 1). Then, tensile strength of chenille yarn samples (T_{tx}) was obtained by Eq. 4. We used the static friction coefficient of yarn to yarn for cotton in Equation 3, because the chenille yarn components have static position in tensile test and μ_s is always higher than μ_k. Besides, the load on yarn during tensile test varies and many factors effects the frictional forces of yarn to yarn. Therefore, we had to assume an optimal value for friction coefficient. For selection of the friction coefficent, we neglected the effect of twist level on friction coefficient of yarn to yarn. So, we assumed that the kinetic (μ_k) and static (μ_s) friction coefficient of yarn to yarn for cotton fibers are 0.25 and 0.50, respectively (12, 13, 14, 15). After calculating the predicted breaking force of chenille yarn by Eq. 4, we compared the predicted values with the actual values in Figure 2.

In statistical analysis, there were very strong significant correlation (R=0.906) and very small mean square error (MSE=0.221) between the actual and predicted values. Although, they have statistically significant difference (p=0.003) in paired-samples t test, it seems that the differences between the actual and predicted values are practically acceptable in Figure 2.

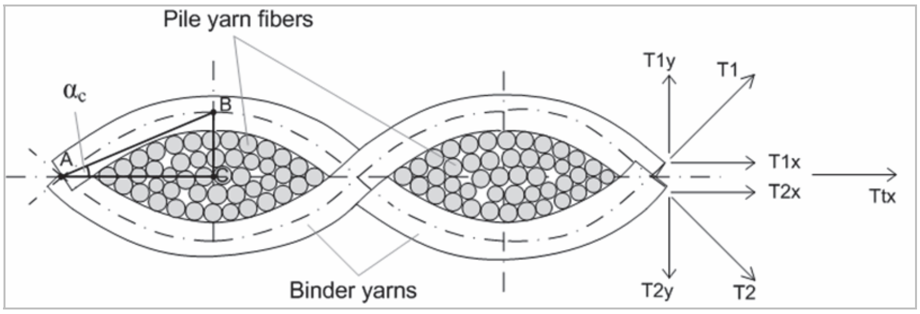

Figure 1. General illustration of the chenille yarn model

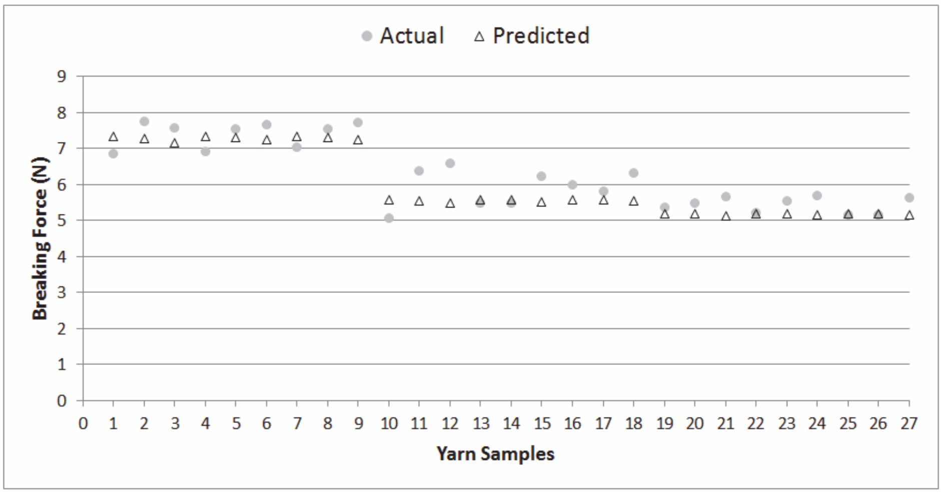

Figure 2. Comparing the actual and predicted values of mathematical model for breaking force of chenille yarn samples

3.2. Statistical Analysis

Breaking Force

Stepwise linear regression analysis was applied to 20 of all data sets and the remaining 7 data sets were used for verification. In regression analysis for breaking force, it is found that the normal P-P plot gives a linear relationship and the residuals are normally distributed. There was not any collinearity among the dependent variables (VIF=1.00-1.002). The resulting model is statistically significant at α=0.01 with R=0.955 and R^2=0.911. The significant factors are count of binder yarn (*CB*) and twist of chenille yarn (*TC*). The regression model is given below in Equation 5.

$$BF = 11.661 - 0.199xCB + 0.002xTC \qquad (5)$$

The effect of factors on breaking force was investigated by drawing 3-D plot in Figure 3. The plot shows that breaking force has tendency to decrease with increasing binder yarn count (Ne) and decreasing twist level (T/m).

For verification, the obtained predicted values by Eq. 5 were compared with the actual B-force values for the 10 data sets had not been used in regression analysis. Statistically significant correlation coefficient (R) and mean square error (MSE) between the actual and predicted values has been found as 0.958 and 0.00296, respectively. Paired-samples t test was applied to the test data and the deviations found were not statistically significant (p=0.303). Comparison of the actual and predicted values of breaking force is given in Figure 4. The plot in this figure shows that the predicted values indicate very small deviations from the actual values.

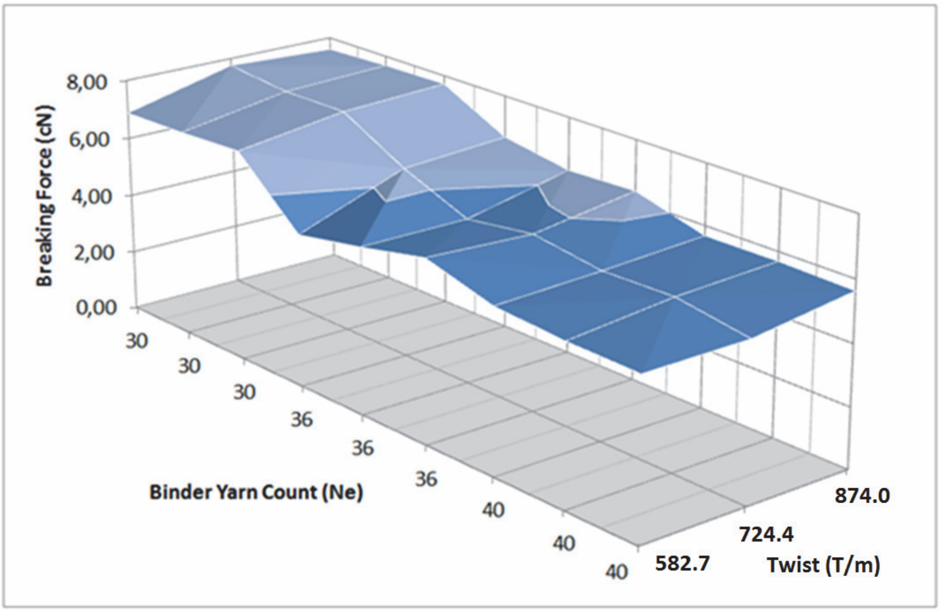

Figure 3. Relationship among breaking force, twist level of chenille yarn and binder yarn count.

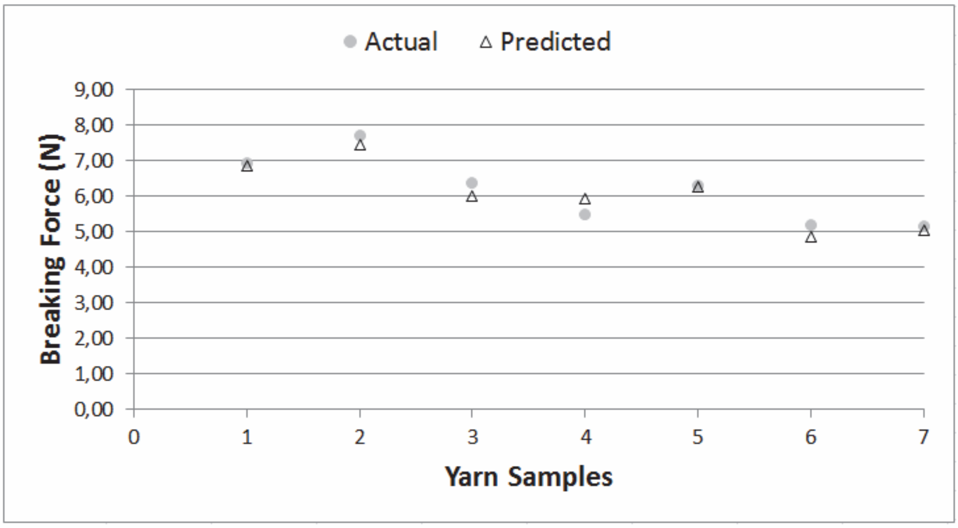

Figure 4. Comparing the actual and predicted values of B-force of chenille yarn samples

All findings indicate that binder yarn properties are the most effective factors on breaking force. Therefore, we investigated the relationship between binder yarn properties and breaking force of chenille yarn to obtain more practical prediction model. For this purpose, we reproduced all chenille yarn samples without pile yarns under the same conditions and obtained plied binder yarn samples as 27 data sets. Then, breaking force and elongation of all plied binder yarn samples were measured. Breaking force of chenille yarn and plied binder yarn samples were compared in Figure 5. The plot in this figure indicates that the deviations between predicted and actual values are very small.

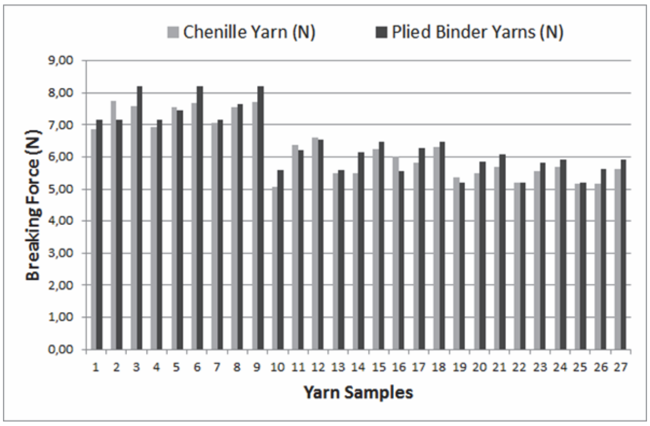

Figure 5. Comparing the breaking force of chenille yarn and plied binder yarn samples.

Breaking force values of chenille and plied binder yarns have a strong linear relationship (R=0.945) with each other. However, paired-samples t test indicate that there is a statistically significant difference (p=0.006) between two variables. Then, we carried out a regression analysis to obtain a simpler statistical model that explains relationship between the breaking forces of chenille and plied binder yarns. The obtained model is given in Eq 6. The model is statistically significant (p=0.000) with R^2 =0.894. It seems that breaking force of chenille yarn can be estimated from breaking force of plied binder yarns without production of chenille yarn. It may be practically useful to manufacturers in chenille yarn design.

$$BF = 0.271 + 0.930 x BF\ of\ Plied\ Binder\ Yarn \quad (6)$$

The findings show that the effect of pile yarn properties on breaking force is minimal. However, the count of binder and pile yarns in chenille yarn may be varied in production process according to the design of chenille yarn. Therefore, we analysed the relationship between the breaking force of chenille yarn samples and the ratio of pile yarn count (Ne) to binder yarn count (Ne) as a new parameter (Rpb). As a result, when Rbp value increases (i.e. the thinner pile yarn relative to the binder yarn) the breaking force of chenille yarn tends to increase linearly at all twist levels. It can be clearly observed in Figure 6, 7, 8. However, Rpb has not been found statistically significant factor in regression analysis.

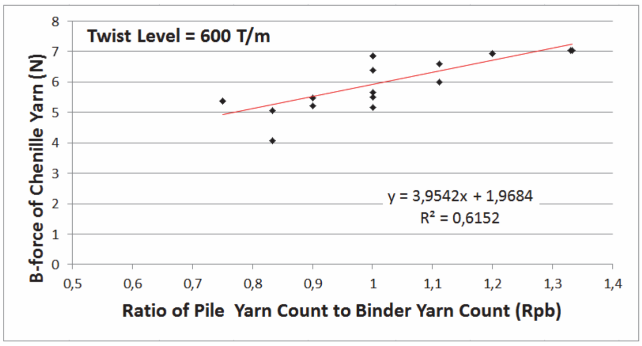

Figure 6. Relationship between B-force of chenille yarn and Rpb values at 600 T/m.

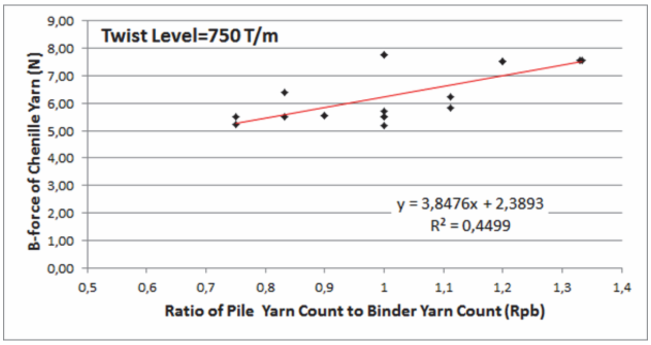

Figure 7. Relationship between B-force of chenille yarn and Rpb values at 750 T/m.

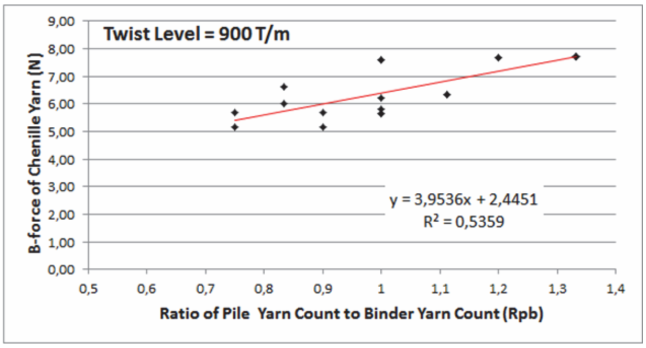

Figure 8. Relationship between B-force of chenille yarn and Rpb values at 900 T/m.

Breaking Elongation

We carried out linear and curvilinear regression analysis for breaking elongation of chenille yarn samples. The obtained curvilinear models were not stronger than the linear model. In linear regression analysis, it is found that the normal P-P plot gives a linear relationship and the residuals are normally distributed. The resulting model is statistically significant at α=0.05 with R=0.550 and R^2=0.302. The significant factor was only count of chenille yarn. The model doesn't indicate a strong relationship between the breaking elongation and the effective factors. We thought that nonlinear analysis methods (e.g. neural networks, fuzzy logic etc.) should be used with more data in order to analyse relationship between breaking elongation of chenille yarn and effective factors. The obtained linear regression model is given below in Eq. 7.

$$BE = 16.063 - 1.614xCC \quad (7)$$

For verification, we compared the actual and predicted elongation values for test data. The actual and predicted values have very weak linear relationship (R=0.254) with each other. However, paired-samples t test indicated that there was not any statistically significant difference (p=0.956) between two variables. The plot in Figure 9 shows that the predicted values indicate quite small deviations from the actual values.

We also investigated relationship between the breaking elongation values of chenille yarn and the plied binder yarns. The breaking elongation values of chenille and plied binder yarns have a moderate linear relationship (R=0.560 and p=0.02) with each other. However, paired-samples t test indicates that there is a statistically significant difference (p=0.000) between two variables. The breaking elongation values of chenille and plied binder yarns have been compared in Figure 10. In the figure, it can be clearly observed significant differences in accordance with the statistical findings. The chenille yarn samples have considerably higher elongation values than the plied binder yarns for all samples. This result may be due to the specific geometric structure of the chenille yarn.

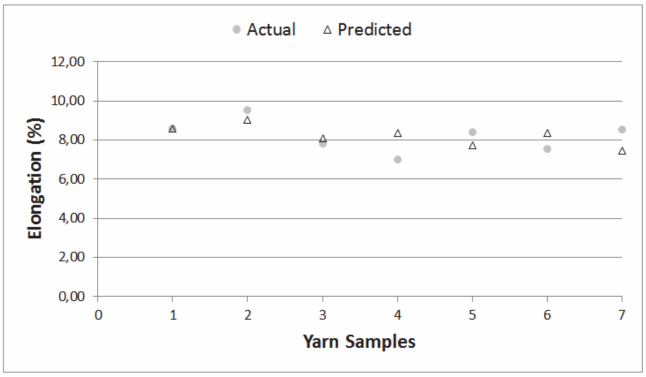

Figure 9. Comparing the actual and predicted values of breaking elongation of chenille yarn samples

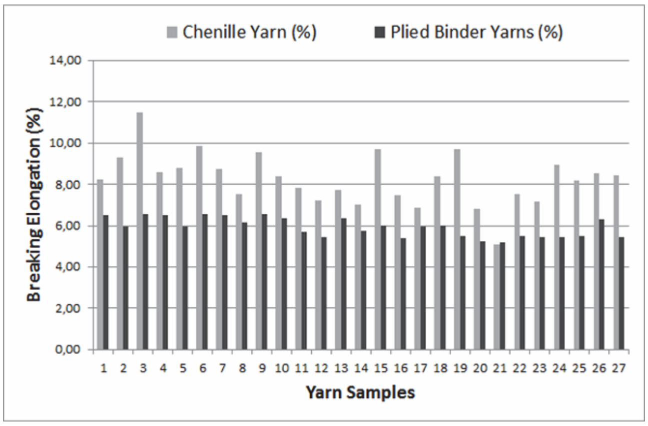

Figure 10. Comparing the breaking elongation of chenille yarn and plied binder yarn samples.

We carried out a regression analysis to investigate the relationship between the breaking elongation of chenille and plied binder yarns. So, we obtained a simpler model in Eq 8. The model is statistically significant (p=0.002) with R^2 =0.314. It seems that breaking elongation of chenille yarn can be estimated from breaking elongation of plied binder yarns without production of chenille yarn. Nevertheless, it is clear that the model needs to be developed.

$$BE = -0.805 + 1.533xBE\ of\ Plied\ Binder\ Yarn \quad (8)$$

4. CONCLUSIONS

In this study, we investigated relationship between the tensile properties (i.e. breaking force and elongation) of chenille yarns produced from combed cotton fibres and the effective factors using theoretical and statistical approches. For this aim, 27 sets of chenille yarns were produced according to an experimental design including different levels of effective factors.

In theoretical approach, a mathematical model was geometrically established to predict breaking force of chenille yarn. For mathematical model, there were very strong significant correlation (R=0.906) and very small mean square error (MSE=0.221) between the actual and predicted values. The plot that was formed to compare the predicted values obtained from mathematical model with the actual values shows very small deviations to be acceptable practically.

In statistical approach, stepwise regression analysis was applied to 20 data sets and the remaining 7 data sets were used for verification. The regression analysis for breaking force shows that the significant factors are count of binder yarn and twist of chenille yarn. The obtained regression model was statistically significant at α=0.01 with R=0.955 and R^2=0.911. We also found that breaking force has tendency to decrease with increasing binder yarn count (Ne) and decreasing twist level (T/m). In verification, correlation coefficient (R) and mean square error (MSE) between the actual and predicted values were found as 0.958 and 0.00296, respectively. The comparison plot shows that the deviations of predicted values from the actual values are minimal. It is shown that the ratio of pile yarn count (Ne) to binder yarn count (Ne) should be considered as a new parameter (Rpb). Because, when Rbp value increases (i.e. the thinner pile yarn relative to the binder yarn) the breaking force tends to increase linearly at all twist levels.

The regression analysis shows that the count of chenille yarn was the only significant factor for breaking elongation. The resulting model was statistically significant at α=0.05 with R=0.550 and R^2=0.302. In verification, the actual and predicted values had a very weak linear relationship (R=0.254) with each other. However, the comparison plot shows that the predicted values indicate quite small deviations from the actual values. We suggest that nonlinear analysis methods (e.g. neural networks, fuzzy logic etc.) should be used with more data in order to analyse relationship between breaking elongation of chenille yarn and effective factors.

In addition, it is proved that breaking force of chenille yarn can be estimated from breaking force of plied binder yarns (i.e. chenille yarn without pile yarns) without production of chenille yarn. It may be practically useful to manufacturers in chenille yarn design.

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NOTATION

L_T : Chenille yarn length corresponds to a twist helix (mm)

d_b : Diameter of binder (lock) yarns (mm)

d_p : Diameter of pile yarns (mm)

d_p' : Maximum height of flattened pile yarns in twisted chenille yarn (mm)

α_c : Angle of twist helix in chenille yarn (^{0})

T_1, T_2 : Tensile strength of binder yarns (cN/tex)

μ_s : Static frictional coefficient of yarn to yarn for cotton

μ_k : Kinetic frictional coefficient of yarn to yarn for cotton

N : Total normal force between binder yarns in chenille yarn (N)

F_s : Total frictional force in chenille yarn (N)

Rpb: The ratio of pile yarn count (Ne) to binder yarn count (Ne)

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