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Predicting twist contraction in chenille yarn using mathematical and statistical approaches

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In this study, the effective factors on twist contraction of chenille yarn that is a kind of fancy yarn were investigated with theoretical and statistical approaches. The aim of this investigation was to develop a model to predict the twist contraction in chenille yarn before production. In the theoretical approach, we developed a mathematical model by geometrical methods. Twenty-seven different chenille yarn samples were produced according to an experimental design containing different levels of effective factors. In statistical approach, the data sets were divided into two parts as 20 and 7. A stepwise regression analysis was applied to 20 of all and acquired a significant model. The remaining data sets were used for verification. Finally, the mathematical and statistical models were verified and compared their performance to estimate twist contraction. As a result, it has proved that the performance of regression model is slightly better than the mathematical model. However, both of the models can give acceptable predicted values for twist contraction in chenille yarns.

Keywords: chenille yarn; twist contraction; prediction; mathematical model; statistical model

Introduction

Fancy yarns have been getting more interest due to their specific and variable properties for fashionable and high value-added products in textile. Chenille yarn, which is a type of fancy yarn, consists of cut pile yarns compacted by twisting of two binder yarns. While the binder yarns provide the strength to the yarn, the pile yarns give fluffy hand, bulky structure, and specific appearance to chenille yarn. Usage areas of chenille yarns vary from garments (sweaters, outerwear fabrics) to decorative fabrics, upholstery, bedspreads (Maros, Vladimir, & Caner, 2011).

In the literature, researchers mostly investigated physical properties of chenille yarn and fabric such as abrasion resistance, dimensional stability, seam slippage. İlhan and Babaarslan (2007) studied on pile yarn-shedding mechanism of chenille yarn by a theoretical approach. Çeven and Özdemir (2006) investigated structure of chenille yarn and put forward an expression for prediction of count by performing theoretical and practical studies. Çeven, Tokat, and Özdemir (2007) predicted abrasion resistance of chenille yarns and fabrics using statistical and ANN models. However, there is not any study to investigate twist contraction in chenille yarn in the literature.

Twist level is an effective factor on count and strength of chenille yarn and production efficiency in manufacturing process. As with all yarns, the insertion of twist in chenille yarn also causes a small increase in count and contraction in the yarn length (Lawrence, 2003). So, the prediction of twist contraction can assist in production planning and increase the efficiency. In this study, the effective factors on twist contraction of chenille yarns were investigated using theoretical and statistical approaches. All the samples were produced from 100% cotton fibers. Finally, mathematical and statistical models were established and compared their performance to each other for the estimation of twist contraction in chenille yarn.

Materials and methods

In this study, we used primarily a theoretical approach to predict twist contraction in chenille yarn. For the theoretical approach, the following assumptions were accepted:

1. The binder yarns in chenille yarn are cylindrical and their radius are constant,
2. before chenille yarns are twisted, pile yarns are cylindrical 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 linearly wrapped 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. The

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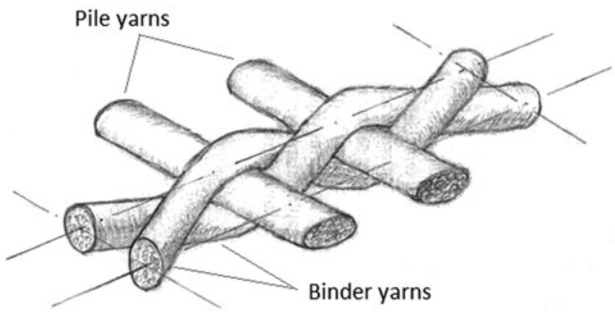

Figure 1. Assumption model of chenille yarn.

geometrical structure of chenille yarn was simplified and idealized in order to develop the mathematical model.

To evaluate performance of the models, 27 data sets that belong to the chenille yarn samples were produced in accordance with an experimental design. In the experimental design, the dependent variable is twist contraction (%) in chenille yarn and the independent variables that are effective on twist contraction were determined as diameter of binder yarns (mm), diameter of pile yarns (mm), and twist of chenille yarn (T/m). Both of the binder and pile yarns are compact ring spun yarns with three count levels as Ne 30, 36, 40. The physical characteristics of ring spun yarns such as count, twist level, unevenness are given in Table 1. The twist levels of chenille yarns have selected as 650, 750, 900 T/m. The averages and CV% values of twist levels were measured, respectively, as 583.13, 725.29, 873.78 and 4.92, 3.97, 2.75. The raw material was kept constant as cotton (combed) because it is used widely and some equations (Mogahzy, 1993; Pierce, 1937) were available to calculate the spun yarn diameters theoretically (Rantasalo, 2014). In this work, the effect of fibers on contraction is tried to be minimized using yarn diameter as a geometrical factor instead of count. In the statistical analysis, a significant correlation was found between chenille yarn count and pile yarn diameter at $\alpha = 0.01$ ($R = -0.818$, Pearson), so chenille yarn count was excluded from the dependent variables in order to eliminate collinearity problem. In addition, it has been thought that pile density could be an effective factor on the contraction. The pile density has been calculated theoretically because of many difficulties in measuring. However, there has been significant correlation ($R = -0.943$, Pearson) and natural collinearity (VIF = 13 > 10.0) between pile density and twist factor at $\alpha = 0.01$, so pile density was also eliminated. Pile length is an effective factor on chenille yarn count but has not any effect on yarn contraction. Because the length of protruding pile yarns from twisted core yarns cannot be effective on contraction level. So, pile length was also kept constant in this study using 1.0 mm caliper for all samples.

The binder and pile yarns were provided by a cotton spinning factory, and the chenille yarn samples were produced in operation conditions by a chenille yarn manufacturer in industry. The yarn samples were not passed through any finishing treatment. The physical properties of chenille yarn such as count, twist level, and twist contraction were measured. Before production of chenille yarn samples, the diameters of the binder and pile yarns had been measured in order to use for establishing the statistical model. All the measurements of actual diameters were performed using Motic stereomicroscope (10×–40×). In measurement of diameters, CV% values for Ne 30/1, 36/1 and 40/1 were, respectively, 5.67, 5.36, and 6.83. For developing the mathematical model, the diameters were calculated theoretically using the formula developed by Mogahzy (1993). The actual diameter of binder and pile yarns were used as input variables together with the twist level of chenille yarn in regression analysis for developing the statistical model.

For measuring of twist contraction, the yarn extensions due to untwisting were measured by Uster Zweigle Twist Tester 5. Then, the twist contraction ratios were calculated using Equation (1) (Khanum, Ahmed, Mahabubuzzaman, Ehsan, & Asaduzzaman, 2011) as follows:

$$C\ (\%) = \frac{\text{Yarn extention due to untwisting}}{\text{Yarn extention due to untwisting} + \text{Test length}} \times 100. \tag{1}$$

The actual $\%C$ values were used to assess the performance of the mathematical and statistical prediction models. For developing statistical model, we applied stepwise linear regression analysis to 20 of all data sets. After the prediction models were established, the predicted values of $C\%$ were derived using both of the models. In order to evaluate performance of the

Table 1. Physical characteristics of ring spun yarns used in chenille yarn samples.

Theoretical yarn count (Ne)	Average of count (Ne)	CV%	Average of twist level (T/m)	CV%	Unevenness CV$_m$%
30/1	29.85	0.48	711	2.39	11.78
36/1	35.78	0.56	815	2.99	12.14
40/1	39.80	0.96	868	1.81	12.63

models, we used the remaining seven data sets that have never been seen by the models before. Finally, we have compared the performance of the models for the evaluation using the actual and predicted values. The performance criteria were preferred as R, MSE, RMSE, and MAPE. All the statistical analyses were performed using SPSS 20.0 software package.

Prediction models

Mathematical approach

We have established a mathematical model based on the assumptions mentioned above using the theoretical approach. The cross section illustration of the chenille yarn model is given in Figure 2. Where d_b equals $2x|BG|$ and d'_p equals $2x|GF|$.

The length of chenille yarn in a twist helix (L_T) can be formulated with Equation (2).

$$L_T = \frac{1000}{T_C}. \tag{2}$$

The angle of twist helix (α_c) formulated from ABF triangle in Figure 2 is as follows:

$$tg\ \alpha_c = \frac{|BF|}{|AF|} = \frac{2x\ (d'_p + d_b)}{L_T},$$

$$\alpha_c = \text{Arc}\ tg\left(\frac{2x\left(d'_p + d_b\right)}{L_T}\right). \tag{3}$$

In Equation (3), the maximum height of flattened pile yarn (d'_p) occurred after pile yarns are cut and chenille yarn is twisted because it is observed that the pile yarns are flattened due to the twisting operation. The flattening of pile yarns can be explained that the pile yarns have to be cut in short pieces (mostly 0.7–3 mm) and the twist that holds the fibers together in pile yarns is eliminated after cutting operation (İlhan, 2004). Therefore, pile yarns are spread into the space between two binder yarns and will no longer have a circular cross section. It can be clearly observed in Figure 3(a). So, the pile yarns are flattened so as to have a certain height and held together by binder yarns. In this case, d_p has to be reduced to (d'_p) (Figure 3(b)). So, we should have derived an equation to calculate the maximum height of flattened pile yarn (d'_p). For this aim, the maximum height line $|C'F|$ has been accepted at the center point of pile yarn.

Theoretically, it can be stated that the circular cross section area of pile yarn with d_p should be equal to the triangle area with lower diameter (d'_p) (Δ ACF), i.e., maximum height in Figure 3(b). So, we have the following equation:

$$\frac{1}{4}x\frac{d_p^2}{4}x\pi = \frac{1}{2}x\frac{d'_p}{2}x\frac{L_T}{4}\quad d'_p = \frac{d_p^2 x\pi}{L_T}. \tag{4}$$

As seen in Figure 2, the length of untwisted binder yarns in a twist helix (S) can be formulated as follows:

$$S = |AB| + |BC| + |CD| + |DE|. \tag{5}$$

In Figure 2, we have accepted that all the line segments are equal to each other based on the assumptions mentioned above. So, the length of $|AB|$ can be formulated as follows:

$$\cos\ \alpha_c = \frac{|AF|}{|AB|}$$

and

$$|AF| = \frac{L_T}{4},$$

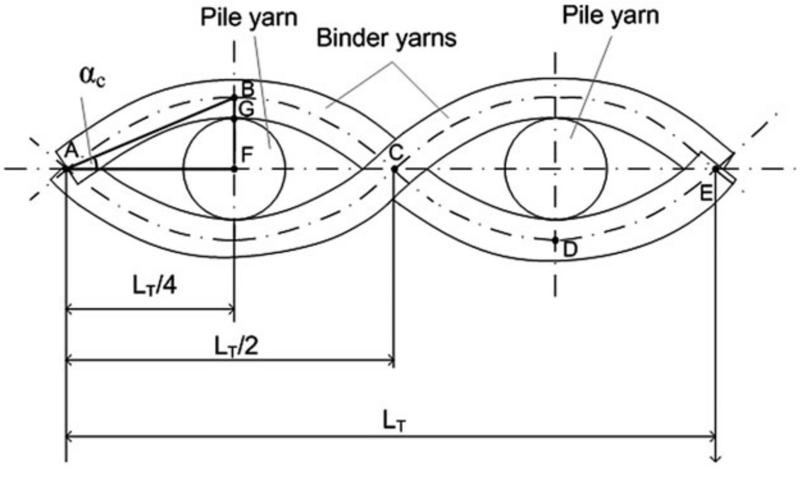

Figure 2. Cross section appearance of chenille yarn model.

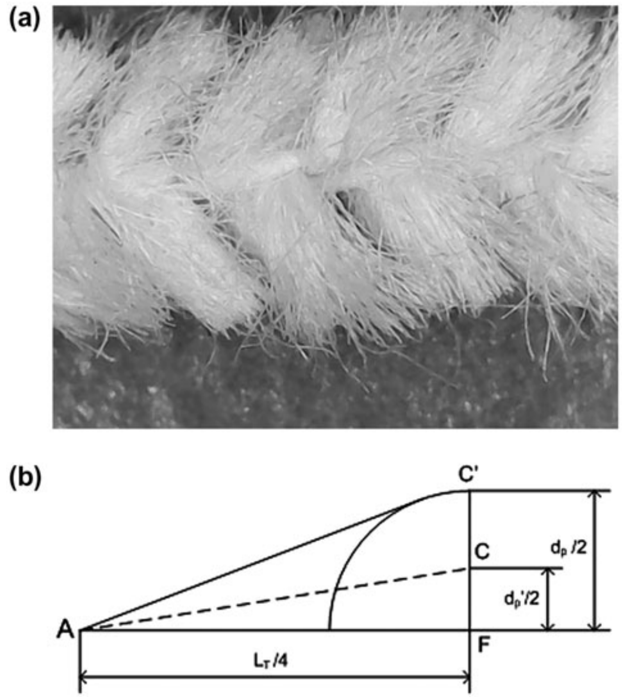

Figure 3. (a) Appearance of twisted chenille yarn and (b) changes in diameter of cut pile yarns in twisted chenille yarn.

$$|AB| = \frac{|AF|}{\cos \alpha_c} = \frac{L_T/4}{\cos \alpha_c},$$

$$|AB| = \frac{L_T}{4x \cos \alpha_c}.$$

Because $S = 4x\ |AB|$, we can formulated S as follows:

$$S = \frac{L_T}{\cos \alpha_c}, \tag{6}$$

As seen in Figure 4, since the binder yarns are wrapped around each other, an axial dislocation is occurred as an angle of θ. In this figure, S' means the corrected length of untwisted binder yarns in a twist helix by eliminating the axial dislocation. Now, the angle of θ can be easily formulated (Figure 4) as follows:

$$tg\ \theta = \frac{d_b}{S} = \frac{d_b}{\frac{L_T}{\cos \alpha_c}} = \frac{d_b x \cos \alpha_c}{L_T},$$

$$\theta = \text{Arc } tg\left(\frac{d_b x \cos\alpha_c}{L_T}\right). \tag{7}$$

The corrected S is formulated in Equation (8) as follows:

$$\cos \theta = \frac{S}{S'},$$

$$S = S' x \cos \theta. \tag{8}$$

If we combine Equation (6) and (8), the corrected length of untwisted binder yarn in a twist helix (S') is obtained as follows:

$$S' = \frac{L_T}{\cos \alpha_c x \cos \theta}. \tag{9}$$

At last, the twist contraction ratio in chenille yarn can be formulated in accordance with Equation (1) as follows:

$$C(\%) = \frac{S' - L_T}{S'}\ x\ 100. \tag{10}$$

Statistical approach

Stepwise linear regression analysis was applied to 20 of all data sets to establish statistical model. The remaining seven data sets were used to measure

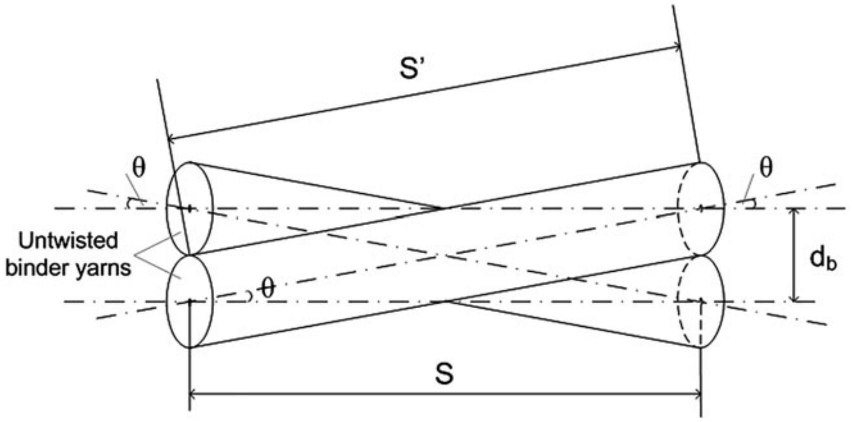

Figure 4. Displacement of binder yarns due to twisting.

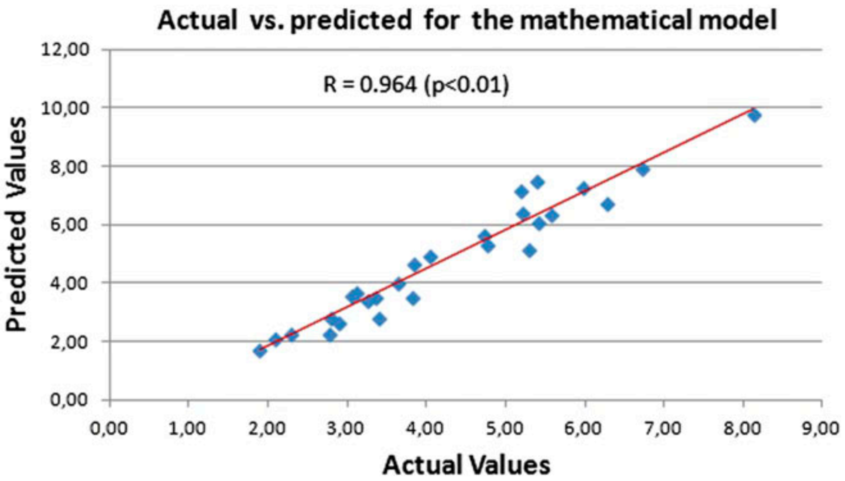

Figure 5. Correlation between the actual and predicted values for the mathematical model.

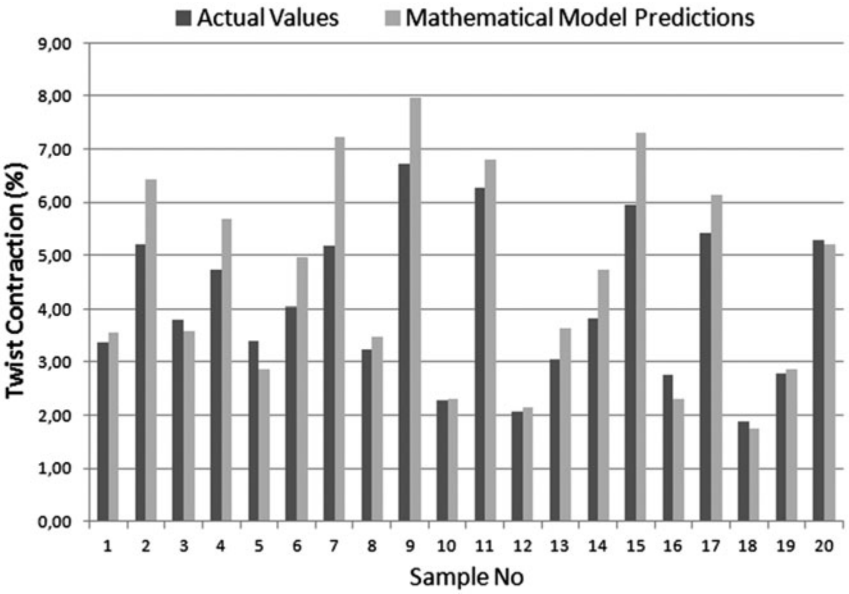

Figure 6. Comparison of the actual and predicted contraction values for the mathematical model.

performance of the regression model. In regression analysis, it is found that the normal P–P plot gives a linear relationship and the residuals are normally distributed. There was not any collinearity amongst the dependent variables (VIF = 1.01–1.022). The resulting model is statistically significant at $\alpha = 0.01$ with $R = 0.969$ and $R^2 = 0.939$. The regression model is given below in Equation (11).

$$\%C = -7.616 + 0.011xT_c + 14.933xd_b + 9.622xd_p. (11)$$

Results and discussion

Evaluation of the models

The accuracy of the mathematical model was investigated using the measured values of twist contraction. We investigated the relationship between the actual and predicted values using correlation analysis. As seen in Figure 5, a strong linear relationship was found between the actual and predicted values with $R = 0.964$.

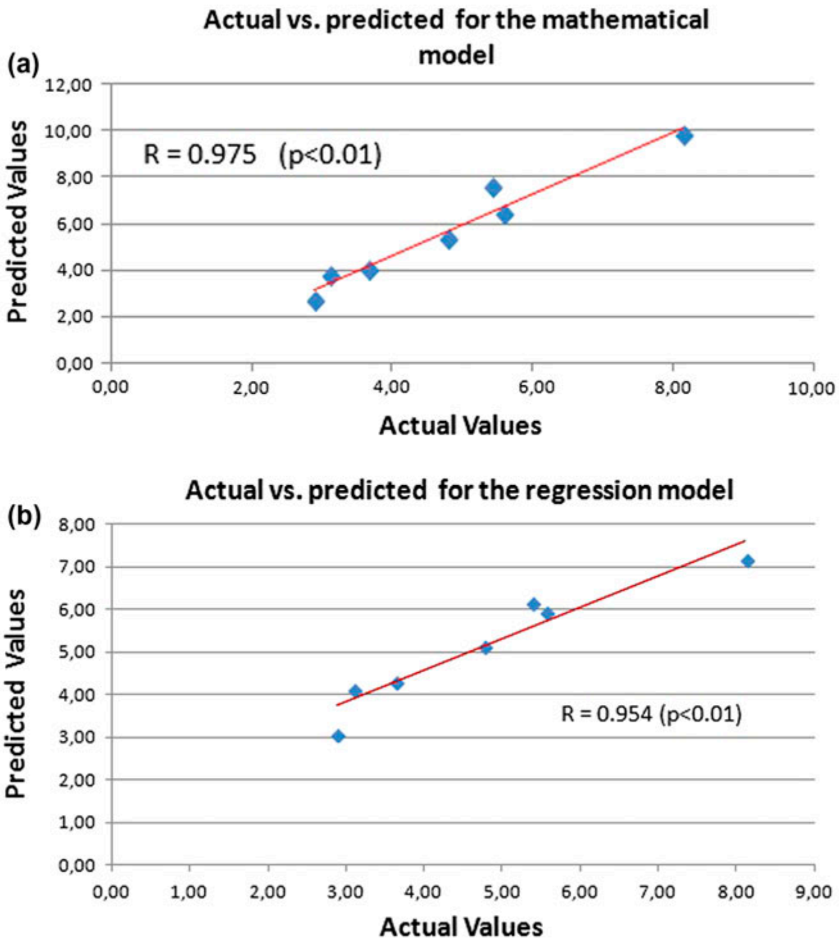

Figure 7. The correlations between the actual and predicted values for the mathematical (a) and regression models (b).

Table 2. Values of performance criteria for comparison of the models.

Performance criteria	Mathematical model	Regression model
R	0.975	0.954
MSE	1.310	0.470
RMSE	1.140	0.690
MAPE	18.100	14.140

The predicted values acquired from the mathematical model were compared with the actual values. We obtained MSE, RMSE, and MAPE, respectively, 0.84, 0.92, and 15.04 for 27 data sets. These values sign that the prediction error is at acceptable level. The graph in Figure 6 shows the comparison of the predicted and actual contraction values for the mathematical model. In this graph, it seems that at least half of the predicted values are higher than the actual values and the remaining values are very close to the actual values. This fact indicates generally a positive deviations and possibility for improving the model. The positive deviations seen in Figure 6 are larger than the remaining deviations that are very close to the actual values. This result can be explained by the flattened pile yarns have slightly higher heights in the mathematical model. According to our observations, the pile yarn fibers nearly spread throughout entire binder yarns. Therefore, the proportions of the maximum height of flattened pile yarns to the original diameters should have been lower than that used in the mathematical model. Our trials show that the lower heights of flattened pile yarns may improve the performance of the mathematical model. The explanation is consistent with the lowest effect of pile yarn diameter factor on contraction in statistical analysis. For these reasons, it is thought that the flattening ratio of pile yarns is a significant factor for developing mathematical model. Since we used only cotton fibers as raw material in the study, the usage of the models limited to cotton. However, the effective factors in the models are independent from types of fiber. Thus, it is expected that types of fiber make a

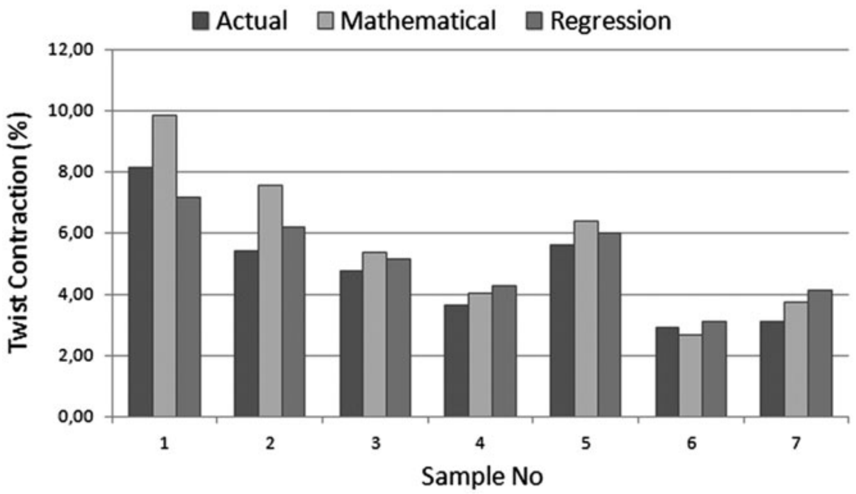

Figure 8. Comparison of the predicted and actual values for the models.

minimal effect on prediction results in case of using other types of fibers.

In the stepwise regression analysis, we used only 20 of all data sets to establish the statistical model. The remaining seven data sets were used for validation of the statistical model and comparison of the mathematical and statistical models. In regression analysis, we acquired partial regression plots. These plots show that the contraction ratio increases with increasing twist level and the diameters of binder and pile yarns. In addition, the twist factor has the strongest positive effect on the contraction with $R = 0.915$ and $R^2 = 0.929$ at $\alpha = 0.01$. The binder and pile diameter factors have lower positive effect on contraction with $R = 0.363$, $R^2 = 0.538$ and $R = 0.083$, $R^2 = 0.335$, respectively. In this case, the lowest impact of pile diameter could have been raised from the flattening of pile yarns due to twisting.

Comparison of the models

Correlation analysis was applied to the seven data sets which have never been used in statistical analysis in order to evaluate the performance of the mathematical and statistical models. Four criteria, *R*, MSE, RMSE, and MAPE, were selected for comparison of the predicted and actual values. The plots in Figure 7 show the correlations between the actual and predicted values for mathematical and regression models.

The correlation analyses indicate strong linear relationship between the actual and predicted values for both of the models. *R*, MSE, RMSE, and MAPE as performance criteria were calculated and given in Table 2.

Table 2 shows that the regression model has a slightly better performance than the mathematical model. While *R* values of two models are very similar, the criteria MSE, RMSE, and MAPE values of regression model is slightly lower than the others. The predicted and actual values of evaluation data sets are plotted in Figure 8. It seems that the regression model gives slightly better predicted values than the mathematical model. It is clear that both of the models can give acceptable predicted values for twist contraction in chenille yarns.

Conclusions

The prediction of twist contraction can assist in production planning and increase the efficiency. In this study, the effective factors on the twist contraction were investigated by mathematical and statistical approaches. Nevertheless, it is aimed to develop a predictive model for twist contraction in chenille yarn.

Firstly, it was developed a mathematical procedure to predict twist contraction by geometrical methods based on the mentioned assumptions. Then, the chenille yarn samples were produced according to the experimental design that contains different levels of effective factors. The physical properties of samples such as count, twist level, and contraction were measured.

All data were divided into two parts as 20 and seven for statistical analysis. First part was used in regression analysis, and the other part was used for validation and comparison. In stepwise regression analysis, a significant model is acquired with $R^2 = 0.939$ at $\alpha = 0.01$. The significant effective factors are twist level of chenille yarn and diameter of binder and pile yarns. It is found that the most effective factor is twist level, but the least effective factor is diameter of pile yarn. Besides, it is also observed that pile yarns are flattened by twisting and all the cut pile yarns nearly spread throughout entire binder yarns. It is thought that the flattening ratio has significant effect on performance of the mathematical model.

Finally, the mathematical and statistical models were verified using the actual and predicted values. The measured values for contraction were highly correlated with the predicted values derived from the mathematical model ($R = 0.964$) and statistical model ($R = 0.969$). Then, the models were compared to each other for the evaluation of prediction performance. As a result, it has proved that the performance of regression model is slightly better than the mathematical model. However, both of the models can give acceptable predicted values for twist contraction in chenille yarns.

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)
N_b	Count of binder yarns (Ne)
N_p	Count of pile yarns (Ne)
T_c	Twist level of chenille yarn (T/m)
C	Twist contraction ratio in chenille yarn (%)
S	Length of untwisted binder yarns in a twist helix (mm)
S	Corrected length of untwisted binder yarns in a twist helix (mm)
α_c	Angle of twist helix in chenille yarn (°)
θ	Angle arises from displacement of binder yarns (°)

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Disclosure statement

No potential conflict of interest was reported by the authors.

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