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Effect of process parameters on tensile properties of cotton sewing thread used in reinforcement layer of drafting aprons

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In this study, the influence of different process variables on mechanical properties of cotton thread to be used as reinforcement thread has been investigated and the conditions for imparting minimum elongation and maximum tenacity are identified. Single yarn twist, plied yarn twist and mercerization stretch are optimized based on the responses evaluated. The optimization of the parameters has been carried out by using response surface methodology. It is observed that the thread elongation is significantly affected by mercerization stretch setting followed by single yarn twist and plied yarn twist. Tenacity of reinforced thread is highly influenced by plied yarn twist than that of mercerization stretch setting and single yarn twist. Optimized conditions for single yarn twist, plied yarn twist and mercerization stretch are 769turns/m, 767turns/m and 2.5% respectively.

Keywords: Cotton, Drafting apron**,** Mercerization stretch setting, Plied yarn twist, Single yarn twist, Sewing thread

1 Introduction

In recent years, there is an incredible increase in ring spinning production and around 35-40% increase in spindle speed. The yarn quality created by a ring spinning machine is principally controlled by the nature of drafting; a procedure of reducing the bulk and weight per unit length of a semi-processed textile material[1-3]. Aprons along with other components in the drafting system play a critical role to enhance access and control over the fibres in the twisting triangle[4,5]. Aprons must be manufactured to a nearby tolerance to get thorough performance and acceptable yarn quality. In addition, the drafting aprons must be free from static charge, be profoundly impervious to assault by oil and have an abrasive-resistant inner working surface. The aprons must possess an inner working surface which has a lower tendency to pick, such as lint, and exhibit highest resistance to the cutting action of the knurled roller. Moreover, the apron must have a high gripping force between its own surfaces and must not grow or stretch in drafting[6,7].

Aprons used in drafting system are generally made of three layers viz outer layer, reinforcing layer and inner layer. The outer layer of the apron is finished rubber surface which provides optimum fibre guidance with its defined roughness. The inner layer provides good friction so that aprons are consistently driven during drafting. The reinforcement layer gives the apron its overall dimensional stability. Current methods with well-defined parameters for the reinforcement layer achieve very tight inner diameter tolerance. Thus, reinforcement layer plays an important role to determine top and bottom apron life span. For longevity and better performance of aprons, sewing threads used in the reinforcement layer should possess higher strength as well as lower elongation[6,8,9]. Further, the aprons have to change their degree of curvature continuously, i.e. from that of a larger curvature which they have while on the roller to that of a smaller curvature corresponding to the thickness of the nose bars. One requirement of aprons is that they have satisfactory contact at all times with the rollers as well as with the nose bars, and hence they have to be highly flexible, so that there is no bellying effect when the aprons approach and leave the nose bars. By providing aprons which maintain their proper coefficient of friction and dimensions, and thus have a good contact on the rolls at all times, variation in the uniformity of apron is reduced or completely eliminated. The aprons furthermore should be elastic so that they can stretch whenever necessary, for example during mounting them on the rollers. During running of aprons over the metallic rollers, various properties of aprons, such as

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flexibility, gripping and change in curvature from large to small, are affected by the reinforcement layer of the apron, which ultimately is affected by the elongation of the cotton sewing threads used for reinforcement[6,10].

The main objective of this study is to develop a cotton thread for reinforcement layer of the drafting apron as per demand of apron manufacturers (lower elongation of around 5% and optimum tenacity). The most commonly used thread count in the reinforcement layer is 3/33[s]. Therefore, in this study, the effect of parameters like single yarn twist(turns/m), plied yarn twist(turns/m) and mercerization stretch (%) have been studied on tenacity and elongation.

2 Materials and Methods

2.1 Materials

Cotton yarns of 3/33[s] Ne produced from DCH-32 variety cotton fibres (3.1 micronair and 33 mm length) were used in this study. The effect of parameters, viz. single yarn twist, plied yarn twist and mercerization stretch on the elongation and tenacity of threads has been studied at three different level of parameters according to Box Behnken experimental design (Tables 1 and 2).

Testing of the yarns was carried out at a gauge length of 500mm on Tensomaxx 7000 as per standard ASTM D 2256, and at a test speed of 5000 mm/min. Thirty tests are carried out for each sample and error is found less than 4% at 95% confidence limit.

2.2 Experimental Design and Data Analysis

A 3^3 fractional factorial experimental design based on Box and Behnken with five center runs was used, giving a total experimental run of 17. The effect of different parameters was studied by the response surface methodology. In order to study the individual and interactive effect of each parameter on tenacity and elongation, response surface regression equations (Table 3) were derived at the different levels of single yarn twist, plied yarn twist and mercerization stretch using backward elimination method. The results were analyzed with analysis of variance (ANOVA) by using DESIGN EXPERT 7 Software. Coefficient of determination(R^2) shows the quality of model fit quadratically with its statistical significance evaluated by F test. The 3D plots were used to study the simultaneous interaction of two factors on the responses. The contribution of different parameters affecting tenacity and elongation was evaluated to understand the influence of these parameters. Further, optimization of the parameters for minimizing elongation and maximizing tenacity was carried out using desirability function in Design Expert.

Table 1 — Box Behnken design

Variables	Levels		
	-1	0	1
Single yarn twist (X_1), turns/m	768	791	814
Plied yarn twist (X_2), turns/m	689	728	767
Mercerization stretch (X_3), %	1.5	2.0	2.5

3 Results and Discussion

Table 2 shows the tenacity and elongation values at different levels of parameters. The average of 30 readings for each sample is analyzed to develop a regression equation on statistical software DESIGN

Table 2 — Process parameters and responses

Exp. run	Variables			Responses	
	Single yarn twist turns/m	Plied yarn twist turns/m	Mercerization stretch, %	Tenacity gf/tex	Elongation %
1	-1	0	1	29.88	5.2
2	0	1	1	29.73	5.4
3	-1	-1	0	29.39	5.8
4	1	-1	0	29.50	6.1
5	1	1	0	29.56	6.15
6	0	-1	1	29.50	5.4
7	0	0	0	29.64	6
8	0	1	-1	29.73	6.3
9	0	0	0	29.64	6
10	-1	1	0	29.88	5.8
11	1	0	-1	29.69	6.4
12	-1	0	-1	29.50	6.2
13	1	0	1	29.37	5.7
14	0	0	0	29.64	6
15	0	-1	-1	29.32	6.3
16	0	0	0	29.64	6
17	0	0	0	29.64	6

Table 3 — Regression equations for tenacity and elongation

Properties	Regression equation	R^2	Adjusted R^2
Tenacity, gf/tex	$29.63 - 0.066X_1 + 0.15X_2 - 0.030X_3 - 0.11X_1X_2 - 0.17X_1X_3 - 0.045X_2X_3 - 0.059X_2^2$	0.98	0.97
Elongation. %	$6 + 0.17X_1 + 0.0062X_2 - 0.44X_3 - 0.032X_2^2 - 0.12X_3^2 + 0.075X_1X_3$	0.99	0.99

EXPERT 7. Response surface methodology is used to consider the effect of independent factors on the tenacity and elongation responses, and then the statistical model of the process is developed. The ANOVA results for responses based on the obtained model are summarized in Table 4. For each equation, the F values indicate that the models are significant.

The best-fit regression equations are developed for tenacity and elongation. The proposed models for two responses adjust very well to the experimental data, and there is logical agreement between R^2 and adjusted R^2. The regression equations show very good value of R^2 and can be used to study the effect of different parameters on tenacity and elongation.

3.1 Tenacity

Figure 1 shows the effect of single yarn twist and plied yarn twist on tenacity. Both the parameters have significant influence on the tenacity. At lower single yarn twist, increase in tenacity is observed as plied yarn twist increases. The yarn strength depends on fibre strength and inclination of fibres with respect to the yarn axis. The fibres used in all the samples are same, whereas the inclination of fibres with respect to yarn axis changes, as the twist in single yarn changes. At lower single yarn twist, as plied yarn twist increases, the tenacity increases due to higher cohesion among fibres and increased frictional forces[11,12]. At higher single yarn twist, if plied yarn twist increases, tenacity decreases. This is because, at higher single yarn twist, the fibres cohesive forces are already high; increased plied yarn twist leads to higher torsional stress in the fibres[13,14]. Due to this, fibres try to come back to original position and cannot transfer the load which reduces tenacity. Similarly, at higher level of plied yarn twist, tenacity decreases, as single yarn twist increases. The plied yarn has highest contribution (43.13%) in tenacity, followed by single

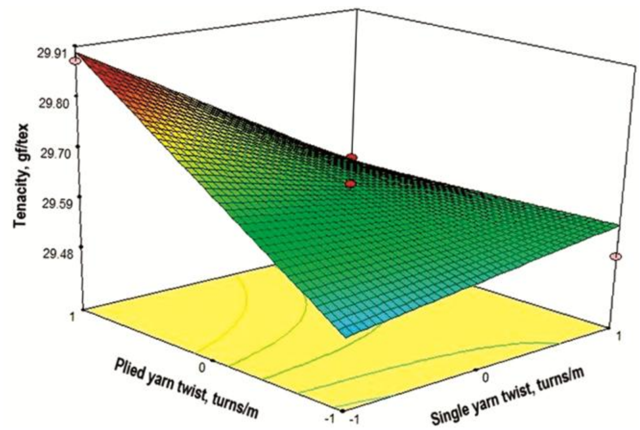

Fig. 1 — Effect of single yarn twist and plied yarn twist on tenacity

Table 4 — ANOVA results for tenacity and elongation

Property	Effect	Contribution, %	SS	Degree of freedom	MS	F-ratio	p-value
Tenacity, gf/tex	Single yarn twist, turns/m	8.55	0.035	1	0.035	39.77	0.000
	Plied yarn twist, turns/m	43.13	0.18	1	0.18	200.49	0.0001
	Mercerization stretch, %	1.75	0.0072	1	0.0072	8.15	0.024
	Single yarn twist * plied yarn twist	11.26	0.046	1	0.046	52.36	0.0001
	Single yarn twist* mercerization stretch	29.85	0.12	1	0.12	138.75	0.000
	Plied yarn twist* mercerization stretch	1.97	0.0081	1	0.0081	9.17	0.019
	Plied yarn twist * plied yarn twist	1.98	0.008	1	0.008	9.19	0.019
	Random error	1.51	0.0061	7	0.00107		
	Total	100	0.42	14			
Elongation, %	Single yarn twist, turns/m	12.39	0.23	1	0.23	689.24	0.000
	Plied yarn twist, turns/m	0.02	0.0003	1	0.0003	0.95	0.359
	Mercerization stretch, %	83.30	1.53	1	1.53	4632.73	0.000
	Single yarn twist* mercerization stretch	1.22	0.022	1	0.022	68.07	0.000
	Plied yarn twist*plied yarn twist	0.10	0.0018	1	0.0035	10.64	0.011
	Mercerization stretch*mercerization stretch	2.83	0.051	1	0.051	157.18	0.000
	Random error	0.16	0.0058	10	0.00058		
	Total	100	1.85	14			

yarn twist (8.55%). Single yarn twist and plied yarn twist both have significant interactive effect and contributes (11.26%) in tenacity (Table 4).

Figure 2 depicts that plied yarn twist and mercerization stretch have a significant effect on tenacity. With the increase in plied yarn twist, tenacity increases as discussed earlier. As mercerization stretch increases, at lower plied yarn twist, increase in tenacity is observed. At lower plied yarn twist, fibres arrangement is parallel to the yarn axis as compared to higher yarn twist. Due to the increase in mercerization stretch (%), molecular chains get aligned in the direction of the fibre axis which ultimately results in higher orientation. This leads to increase in tenacity[15,16]. At higher plied yarn twist, there is no change in tenacity as mercerization stretch increases. At higher plied yarn twist, yarn structure is in compact form as compared to that in low plied yarn twist. When this compact structure of the yarn is stretched, there are very less chance of change in molecular orientation and fibres are not able to rearrange themselves. Analysis of variance shows that mercerizing stretch has very small contribution (1.75%) in tenacity (Table 4).

3.2 Elongation

Figure 3 shows the effect of single yarn twist and plied yarn twist on elongation. Analysis of variance shows that single yarn twist has a significant effect on elongation, whereas plied yarn twist does not show any significant effect on elongation (Table 4).

With increase in single yarn twist, elongation increases. The increase in the yarn elongation can be observed due to the change in fibre inclination. So, when external force is applied, fibres realign themselves along the yarn axis, which results in higher elongation in the yarn. Single yarn twist contributes (12.39%) in elongation. Plied yarn twist does not show any significant effect on elongation. Twist in the plied yarn produces more compact yarn structure due to which stiffness of the yarn increases. Stiffness of the yarn prohibits itself to elongate. Hence, no significant impact is observed. Plied yarn twist has the smallest contribution of 0.02% in elongation.

Figure 4 shows the effect of plied yarn twist and mercerization stretch on elongation. With an increase in mercerization stretch level, elongation decreases at all levels of plied yarn twist. Mercerization stretch causes increase in molecular orientation of the polymer chains along the fibre axis and therefore the elongation decreases. Mercerization stretch is the largest contributor (83.30%) to the elongation of sewing thread (Table 4).

3.3 Optimization of Process Parameters

The optimization tool in Design Expert Software searches for a combination of different factors that

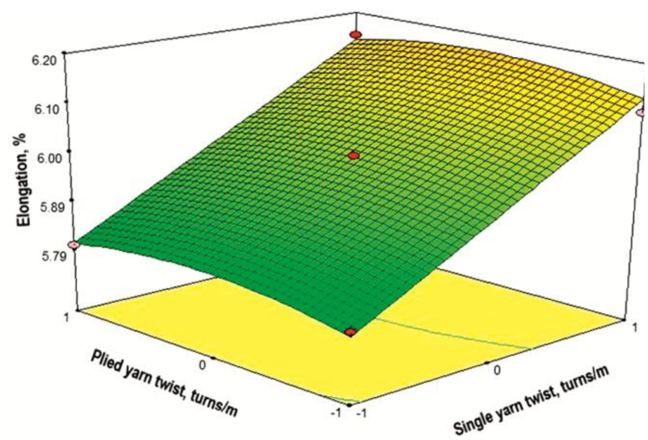

Fig. 3 — Effect of single yarn twist and plied yarn twist on elongation

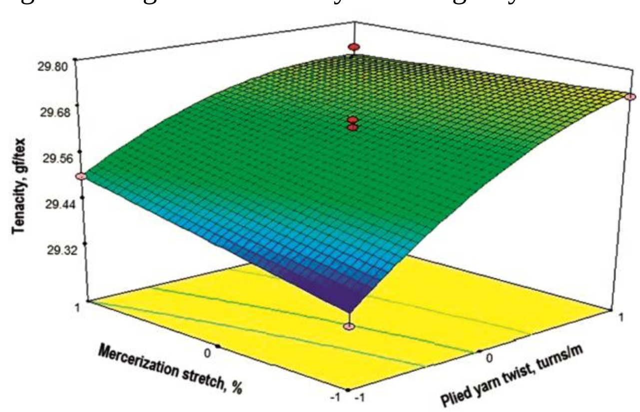

Fig. 2 — Effect of plied yarn twist and mercerization stretch (%) on tenacity

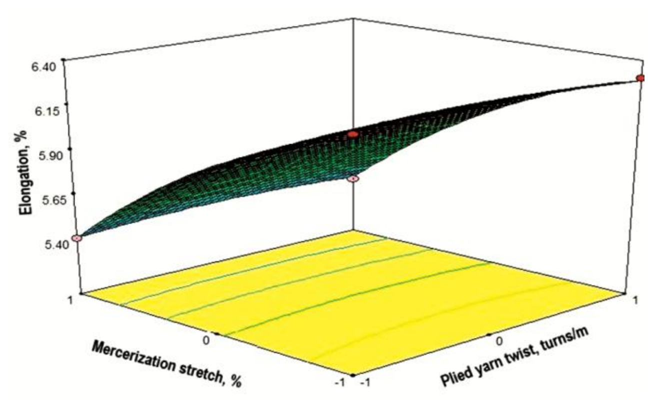

Fig. 4 — Effect of plied yarn twist and mercerization stretch on elongation

Table 5 — Possible combination for maximum desirability

Single yarrn twist turns/m	Plied yarn twist turns/m	Mercerization stretch, %	Tenacity gf/tex	Elongation %	Desirability
-0.94	0.97	0.99	30.02	5.199	1
-1.00	0.99	0.98	30.053	5.190	1
-0.97	0.85	0.99	30.028	5.196	1

satisfies the criteria placed for the various responses. The general approach for optimization is to convert responses into desirability function which generally ranges from 0 to 1. For this purpose, an optimization criterion is implemented on each response according to the requirement. Three optimized solutions are provided by the Design Expert software with a maximum desirability of 1 (Table 5).

Table 5 shows various combination by which parameters can be optimized for minimizing elongation and maximizing tenacity. According to the analysis, optimized conditions are single yarn twist 769 turns/m, plied yarn twist-767 turns/m, and mercerzation stretch 2.5%. By this otimized condition, maximum desirabity can be achived.

4 Conclusion

In this research, ANOVA table shows that the plied yarn twist followed by the single yarn twist have highest contribution on tenacity; while mercerization stretch has the smallest effect. For elongation, the mercerization stretch is the most effective parameter followed by the single yarn twist; and the plied yarn twist has no significant impact on elongation. Further, parameters are optimized to achieve the required criteria of maximum tenacity and minimum elongation. The optimized condition for the reinforcement layer of aprons are: single yarn twist 769 turns/m, plied yarn twist 767 turns/m and mercerization stretch 2.5 %. The produced sewing thread under the optimized condition have the following characteristics tenacity of 30.50 gf/tex and elongation of 5.19 %. The produced sewing thread with maximum strength and minimum elongation is suitable for manufacturing sewing thread for reinforcement layer of aprons.

References

1 Klein W, *Technology of Short Staple Spinning*, Vol. 4 (The Textile Institute), 1995, 1-64.

2 Lawerence C, *Fundamentals of Spun Yarn Technology* (CRC Publication), 2003.

3 Kane C D & Ghalsasi S G, *Indian J Fibre Text Res*, 102 (1992)78.

4 Canoglu S, *Tekstil ve Konfeksiyon*, 23(2013)213.

5 Subramaniam V & Mohamed P, *Text Res J*, 61(1991)280.

6 Hick W, *Fibre 2 fashion*, July (2004)1.

7 https://www.textilemachine.fangzhi-jixie.com/machine_1/content/?1012.html/ (accessed on 5 September 2018).

8 Hasan N, Afroz F, Islam S & Hasan R. *Eur Sci J*, 10(2014)212.

9 Gregory J. *J Text Inst*, 41(1950)1.

10 https://www.inarco.com/wp-content/uploads/2017/02/Torque-value-of-drafting-aprons-and-its-influence-on-ring-frames.pdf. (accessed on 2nd January 2019)

11 Eldeeb M, Rakha I, Fahim F, & Elshahat E, *Tekstil ve Konfeksiyon*, 26(2016)48.

12 Palaniswamy N K & Mohamed A, *Indian J Fibre Text Res*, 30(2005)258.

13 Eldeeb M, Mouckova E & Ursiny P, *Indian J Fibre Text Res*, 42(2017)386.

14 Omeroglu S, *Tekstil ve Konfeksiyon,* 23(2) (2003) 204.

15 Hebeish A, Abou-zeid N Y, El- kharadly, E A , El-aref A T, Allam E, Shalaby & El-alfy E A, *J Appl Polym Sci*, 26(8) (1981)2713.

16 Poongodi G R, Radhalakshmi Y C & Subramaniam V, *Int J Eng Technol*, 2(2) (2013)1.