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Interactions of Sewing Variables: Effect on the Tensile Properties of Sewing Threads During sewing process

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ABSTRACT

This paper aims at the study of the effect of various interactions between the sewing variables on the sewing thread strength properties during use. The work has been carried out with the concept in mind that the interactions of the sewing parameters during sewing process are influential for the resultant seam quality. The analysis of the crucial factors affecting the 100% cotton sewing thread strength in the straight, loop and knot configurations, as the sewing threads are converted into the seams, with the help of looping and knotting processes had been done. The study had revealed that the interaction of Fabric GSM with sewing speed had affected the unraveled cotton sewing threads from the seams to the highest extent among all others interactions.

Keywords: Sewing variables, sewing thread, sewing parameters, knotting, looping, unraveled

1. Introduction

Clothing manufacture is defined as a process by which two-dimensional fabric is converted into three-dimensional garments by assembling different pattern-pieces together. This transformation mainly accomplishes with sewing process. Present trends in the textile industry point to the reduction of the order sizes and to greater demands on shorter delivery times and higher quality. As the apparel industry becomes more and more automated, however, the sewing machine will be subjected to new requirements, since the operator has no longer direct control of the fabric and machine. In future manufacturing environments, the sewing machine will have to be more flexible to perform equally efficiently across a wider range of fabrics[1-3].

The market requirements for high quality products, produced from an increasing variety of materials and small batch order sizes, stressed need for flexible and reconfigurable machines, which can be quickly set-up or self-adjusted. Due to the complexity of the sewing process itself, the sewing parameters are still adjusted by 'trial and error' at each stage of operation. The new generation of industrial sewing machines needs to offer a pre-setting stage, adaptation and self-adjustment to each situation. So, the knowledge and control of sewing technology is an important aspect to consider by textile and apparel manufacturers in order to produce high-quality garments and other sewn textile end products.[4]

The last two decades of research on sewability had led to greater understanding of the complex interactions involved in joining two or more plies with sewing thread. Although, it's almost 150 years, since the invention of the sewing machine, a significant analysis of this joining system did not emerge until sewing speeds increased 3000 spm. The number of problems related to sewability increased with the higher sewing speeds used to join the newer textile materials. Use of finer gauge knits and fabrics finished with different dyes and finishes, together with the widespread acceptance of synthetic fibers in both fabrics and sewing threads, created new sewability problems[5-7].

A lot of work had been carried out on the fabric sewability[8-9], spotting the fabric related parameters affecting sewability of substrates[10-15], influence of sewing thread on seam performance[16-22], sewing dynamics[23-29], sewing thread strength reduction[23,25,26,30-34] with the consideration of independent factors. This work was performed to investigate the crucial interactive effect of sewing variables on the sewing thread tensile properties as it becomes an integral part of the seam. Thus, the present paper aims at the study of the second order interactions of sewing variables and their impact on the tensile properties of the unraveled sewing threads from the seams.

2. Materials and Methods

2.1.1. Materials

100% cotton sewing threads (C) were selected with three different counts based on their specifications and compatibility with the fabric chosen. The specifications and properties of sewing threads are detailed in Tables I& II. Three sets of plain woven cotton fabrics were taken with varying GSM for the study. The fabric details are given in Table III. For the seamed sample preparation, JUKI- DDL-8300 N (31234) Single needle Lockstitch machine was used. The selection of three different machine speeds with a uniform interval of 500 stitches per minute was done i.e. 1500, 2000 and 2500 rpm. The uppermost limit of sewing speed was decided on the capacity of the motor of the machine and also the capability of the operator for handling the high speeds without damaging the fabric and the thread specimens. For maintaining constant variable speeds of the sewing machine, a DC shunt motor with AC to DC conversion panel had been used attached to the flywheel of the machine with the help of a connecting belt. The contact sensing tachometer was used for the measurement of machine speed. Also, three levels of stitch density were chosen namely 10, 14 and 18 spi according to the type of the fabric and the sewing speeds chosen. The sewing needle of 16 needle number was selected. The SSa type of seam was chosen with the same sewing threads in both needle and bobbin respectively for each set of seamed samples. The Box- Behnken factorial design at reduced runs with 3^4 (four factors with three levels each) for all the sewing threads was formulated as shown in Table IV.

Table I. Properties of sewing threads

Code	Thread tenacity (cN/tex)	Loop strength		Knot strength		Min Knot tenacity (cN/tex)	Extension at max load (%)
		Loop tenacity (cN/tex)	Relative * loop tenacity	Knot tenacity (cN/tex)	Relative**knot tenacity		
C20	22.70	42.90	1.89	17.94	0.79	15.67	5.49
C30	24.00	46.00	1.91	20.20	0.84	19.50	6.94
C40	26.89	51.89	1.93	23.97	0.88	20.34	8.15

* ratio of loop tenacity to thread tenacity

** ratio of knot tenacity to thread tenacity

Table II. Properties of sewing threads

Property	100 % Cotton		
	C20	C30	C40
Y-Y friction coeff.	0.15	0.13	0.11
Y-M Friction coeff.	0.12	0.13	0.15
Abrasion resistance (cycles)	178	168	162

Table III. Fabric specifications

Fabric Code	Comp.	Weave	Weight g/m^2	Thickness (mm)	Linear density (tex) Warp	Linear density (tex) Weft	Thread density Ends/cm	Thread density Picks/cm	Fabric str. (kg)
f1	Cotton	Plain	110	0.12	10	15	22	19	24.43
f2	Cotton	Plain	170	0.21	10*	10*	28	27	46.50
f3	Cotton	Plain	230	0.43	15	59	16	11	51.56

* Doubled yarn

Table IV. Codes for Box- Behnken factorial design

Levels Factors	Units	-1	0	+1
Fabric type (x1)	g/m^2	110 (f1)	170 (f2)	230 (f3)
Sewing thread linear density (x2)	tex	20 (t1)	30 (t2)	40 (t3)
Sewing Speed (x3)	rpm	1500 (r1)	2000 (r2)	2500 (r3)
Stitch density (x4)	spi	10 (d1)	14 (d2)	18 (d3)

2.2 Method

Fabric samples, sewing threads and sewing needle were taken as per the required specifications. All sewing threads and fabrics were tested for the physical and tensile properties. The sewing machine was set for the sewing speed alterations. The Box-Behnken factorial design of 3^4 was formulated with the help of reduced runs. The research design for cotton sewing threads is detailed in Table V. The sewn samples were prepared with the use of pre-set runs. For evaluation of sewing thread performance, the sewing thread samples from the above described combinations were unravelled from about thirty inches long samples sewn in a highly secured manner. The properties of tenacity, elongation, loop strength and knot strength were analysed for the carefully unravelled sewing thread samples. The comparative analysis was made between the parent thread properties and the sewn-unraveled threads for all the runs to analyze the impact of different sewing parameters on the sewing thread tensile properties.

All the sewing thread properties were tested according to ASTM D 204-97 for both parent and unraveled threads. Breaking tenacity and elongation (ASTM D 2256-95a) on Instron tensile tester 4411, breaking loop tenacity and loop elongation (ASTM- 2256-95a), Knot breaking load & extension and Minimum knot strength were evaluated. Abrasion resistance of sewing threads on CSI abrasion tester, frictional characteristics (ASTM- D3412) on CTT (Constant Tension Transport) Lawson Hemphill tester were tested.

Table V. Experimental Plan of sewing variables with 3^4 Box- Behnken design for cotton sewing threads

Treatment Run	Code		Levels of variables				Actual values of variables			
			Fabric type	Sewing thread	Sewing speed	Stitch density	Fabric type	Sewing thread	Sewing speed	Stitch density
1.	OS1	f1t2r2d3	-1	0	0	+1	110	30	2000	18
2.	OS2	f2t3r2d1	0	+1	0	-1	170	40	2000	10
3.	OS3	f3t2r2d1	+1	0	0	-1	230	30	2000	10
4.	OS4	f1t2r3d2	-1	0	+1	0	110	30	2500	14
5.	OS5	f1t1r2d2	-1	-1	0	0	110	20	2000	14
6.	OS6	f1t2r1d2	-1	0	-1	0	110	30	1500	14
7.	OS7	f2t3r2d3	0	+1	0	+1	170	40	2000	18
8.	OS8	f2t2r3d1	0	0	+1	-1	170	30	2500	10
9.	OS9	f1t2r2d1	-1	0	0	-1	110	30	2000	10
10.	OS10	f3t2r2d3	+1	0	0	+1	230	30	2000	18
11.	OS11	f1t3r2d2	-1	+1	0	0	110	40	2000	14
12.	OS12	f2t1r1d2	0	-1	-1	0	170	20	1500	14
13.	OS13	f2t2r2d2	0	0	0	0	170	30	2000	14
14.	OS14	f2t3r3d2	0	+1	+1	0	170	40	2500	14
15.	OS15	f2t2r1d3	0	0	-1	+1	170	30	1500	18
16.	OS16	f2t1r3d2	0	-1	+1	0	170	20	2500	14
17.	OS17	f2t3r1d2	0	+1	-1	0	170	40	1500	14
18.	OS18	f2t1r2d1	0	-1	0	-1	170	20	2000	10
19.	OS19	f2t2r2d2	0	0	0	0	170	30	2000	14
20.	OS20	f3t2r3d2	+1	0	+1	0	230	30	2500	14
21.	OS21	f3t1r2d3	0	-1	0	+1	170	20	2000	18
22.	OS22	f3t3r2d2	+1	+1	0	0	230	40	2000	14

23.	OS23	f3t2r1d2	+1	0	-1	0	230	30	1500	14
24.	OS24	f3t2r1d1	0	0	-1	-1	170	30	1500	10
25.	OS25	f3t2r2d2	0	0	0	0	170	30	2000	14
26.	OS26	f3t1r2d2	+1	-1	0	0	230	20	2000	14
27.	OS27	f3t2r3d3	0	0	+1	+1	170	30	2500	18

* OS- Operative Samples

3. Results and discussion

The performance of the operative sewn unraveled sewing threads is detailed in Table VI. Along with, the regression equations representing the effect of sewing variables on sewing thread strength has been shown in Table VII.

3.1 Effect of sewing variables on straight strength of cotton sewing threads

It was observed that with the increase of sewing thread count (Tex values), the straight thread strength increases at all level of fabric GSM. The reason is attributed to the fact that as the sewing thread count increases, the strength of the sewing thread increased which was evident from Figure 1a. Also, with the increase of Fabric GSM (from 110 to 230), there was slight decrease in strength of the straight thread at all levels of sewing thread tex. Increase in GSM caused more abrasion to the sewing thread that had resulted in decrease in straight thread strength. With the increase of the sewing speed (from 1500spm to 2500spm), the straight strength decreased for all levels of sewing thread tex. The trend was followed due to the increased contact of the sewing thread with the machine elements per unit time. With the increased contact, the abrasion of the sewing thread increased with the increase in sewing speed. This was more prominent for the finer sewing threads as the parent straight thread strength for finer thread was lesser than the coarser sewing threads. Thus, reduction is more significant in the finer sewing threads than the coarser sewing threads as shown in Figure 1b. The straight thread strength value decreased at all levels of fabric GSM. The strength of the straight thread was dependent on the strength of the parent thread as well as the crimp of the yarn. As the stitch density increased, crimp of the sewing thread also increased; hence the straight thread strength increased with the increase in stitch density at all level of GSM (Figure 1c). The combined effect of the sewing speed and stitch density was proved to be detrimental to the straight thread strength as with the increase in the levels of the combination; the straight strength fell due to more fiber rupture because of excessive needling and abrasion with the fabric surface (Figure 1d). It can be made out that with the increase in the Fabric GSM, the straight strength reduces for all levels of sewing speed, due to the excessive abrasion of the thread with the fabric surface. And also, as the sewing speed increases, there is seen to be a reduction in the strength of the sewing thread at all the fabric GSM levels as shown in Figure 1 e.

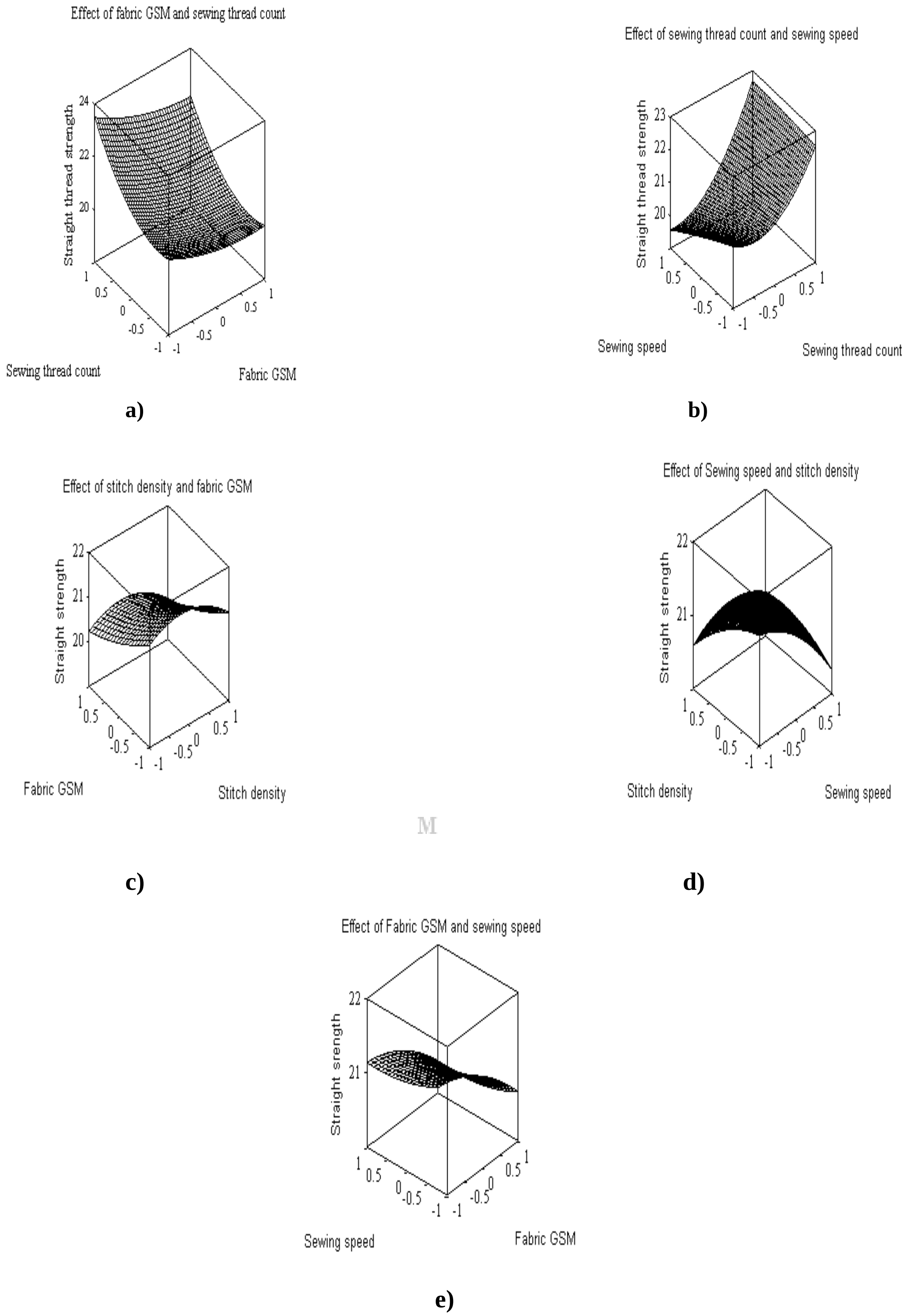
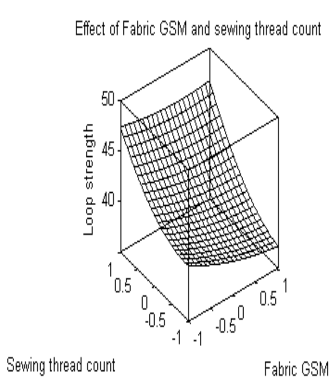


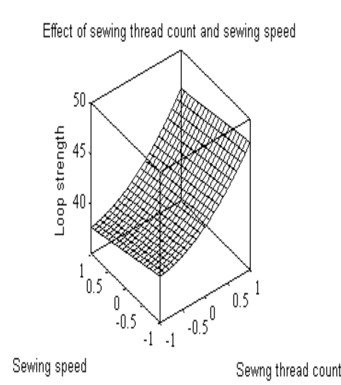
Figure 1. (a-e) Effect of sewing variables on straight thread strength of cotton sewing threads

3.2 Effect of sewing variables on loop strength of cotton sewing threads

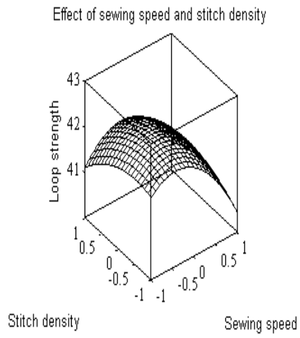
From Figure 2a**,** the impact of interaction of fabric GSM and sewing thread tex on loop thread strength was analyzed. It followed a decreasing trend with increasing fabric GSM for all sewing thread levels due to the increased abrasion with the fabric, thereby affecting the surface of the sewing threads. Also, with increasing sewing thread tex values, the loop strength increased in the unraveled threads due to the parent loop strength. The decrease in the loop strength was steeper for the coarser counts than the finer count levels due to lesser parent loop strength and proportionately higher abrasion with the fabric surface. The loop strength increased with the sewing thread tex for all the sewing speeds which was due to the parent loop strength of the sewing threads. With the increase in the sewing speed, the loop strength followed a decreasing trend for all the sewing thread tex levels due to the increased abrasion and thus the roughening of the sewing thread surfaces, which in turn accounted for the decreased adherence between loops of the threads (Figure 2b). It was evident that the combined effect of the sewing speed and stitch density was detrimental to the loop thread strength as with the increase in the level of the combination, the loop strength fell due to more fiber rupture because of excessive needling and abrasion with the fabric surface (Figure 2c). Figure 2d, shows the effect of relationship of stitch density and fabric GSM on loop strength. It decreased as the fabric GSM increased for all the stitch density values but the fall was steeper for the fabric GSM 230 at stitch density 18 spi because of the reason that with the increased fabric GSM and stitch density, the abrasion of the thread with the fabric increased per unit times, which led to reduced loop strength. There was lesser impact of the stitch density alone but the combination of the two had a prominent effect on the loop strength reduction. There was an interesting fact revealed that the loop strength increased for the fabric GSM 110 with increase in the stitch density because of the reason that the crimp generated due to increase needling helped in the improved anchorage of the loops. The effect of the relationship of fabric GSM and sewing speed on the loop thread strength is shown in Figure 2 e . It shows the abrasion with the fabric that leads to the reduction of the loop strength of threads for all the levels of sewing speeds, i.e. with the increase in the fabric GSM, loop strength decreases for all sewing speeds. On the other, it increases with the increasing levels of sewing speed at all the levels of fabric GSM.



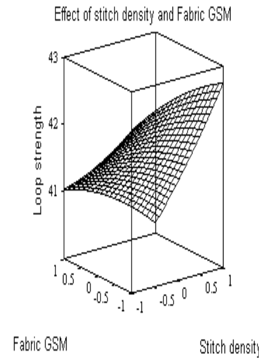
a)



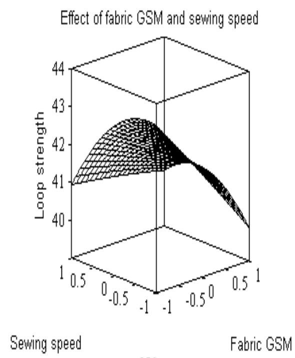
b)



c)



d)



e)

Figure 2. (a-e) Effect of sewing variables on loop strength of cotton sewing threads

3.3 Effect of sewing variables on knot strength of cotton sewing threads

Figures 3 (a-e) had shown the impact of various sewing variables on knot strength of sewing threads. Figure 3a had shown the impact of the relationship of Fabric GSM and sewing thread tex on the knot strength. It could be analyzed that with the increase in the fabric GSM (for all the sewing thread counts), the knot strength increased due to the roughening of the sewing thread's surface with the fabric. This led to better adherence of the threads in the knot. The knot sewing strength was the highest for highest count due to the highest parent knot strength for 40 tex thread. The knot strength follows the same trend for all the fabric GSM at each sewing thread tex level. Figure 3b depicted the impact of relationship of thread tex and sewing speed on the knot strength. It was evident that the knot strength increased with the increasing thread count due to the increased parent knot strength and also, for increasing sewing speed (from 1500spm-2500spm), the knot strength increases for all the sewing thread count because of more and more abrasion with the fabric and the sewing needle. Due to this increased abrasion, the surface of the sewing thread is supposed to have become rougher, which led to increased adherence resulting in higher knot strength for all the counts of sewing threads as shown in Figure 3 c & d. The combined effect of the fabric GSM and sewing speed, on the knot strength is shown in Figure 3 e. The combination greatly affects the knot strength of the cotton sewing threads. With the increased level of sewing speed and fabric GSM, the abrasion of the sewing threads lead to reduced strength and thereby the knot anchorage strength also. As with the increase in the fabric GSM, the knot strength falls for all levels of sewing speed. And also, the similar trend can be seen with the increasing sewing speed for all levels of fabric GSM. But the greatest drop for 100% cotton sewing thread is seen for the combination of the heaviest fabric and highest sewing speed due to the overall reduction in the sewing thread strength, which leads to the reduced knot strength as well.

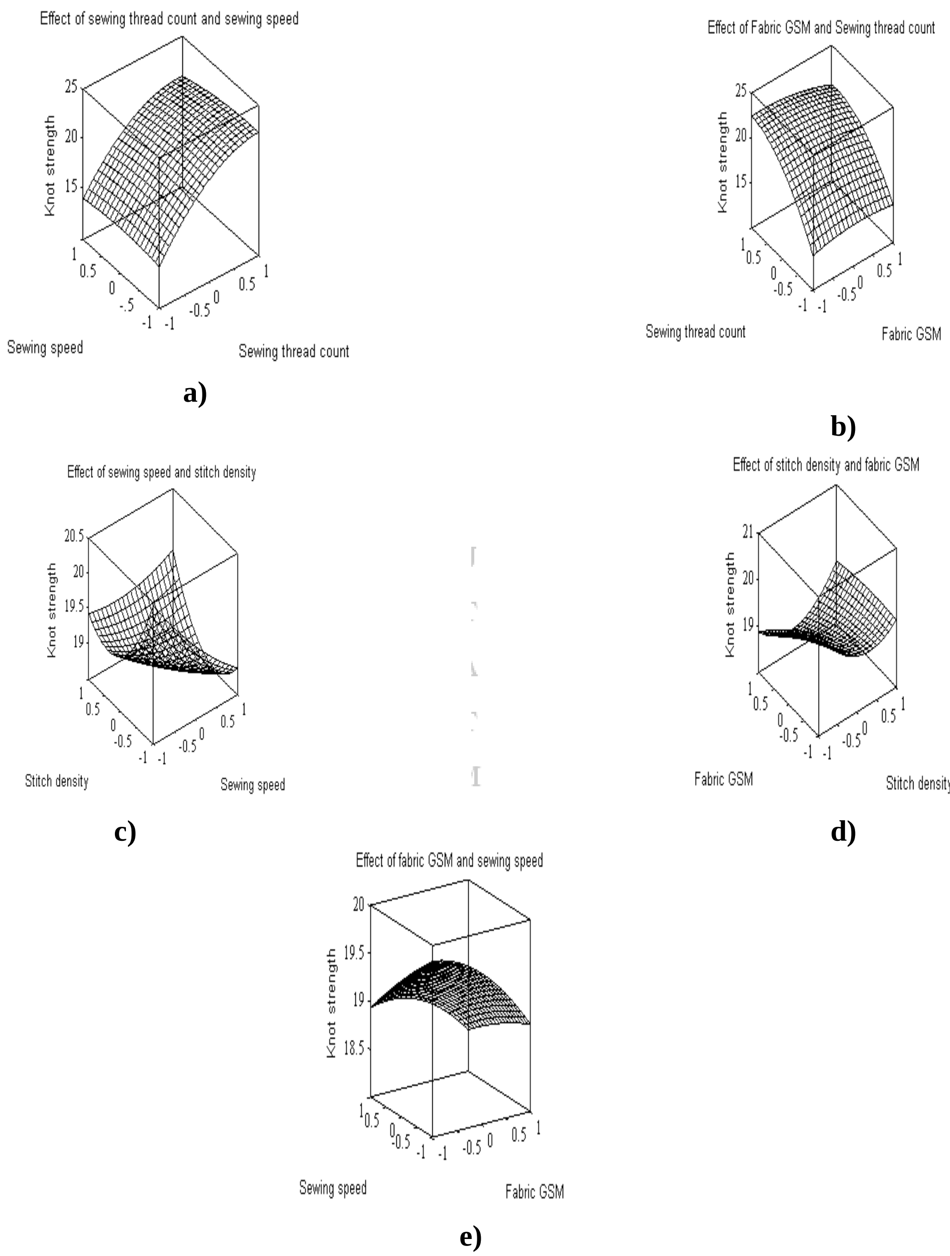


Figure 3. (a-e) Effect of sewing variables on knot strength of cotton sewing threads

Table VI. Performance of unraveled cotton sewing threads

TC	Code	Coded values of variables				Sewing thread performance of the unraveled threads					
						Straight thread strength		Loop strength		Knot strength	
				x_3	x_4	Obser	Predic	Obser	Predic	Obser	Predic
1.	OS1	-1	0	0	1	21.69	21.58	42.22	42.47	19.72	19.89
2.	OS2	0	1	0	-1	22.44	22.78	46.61	47.06	22.34	22.45
3.	OS3	1	0	0	-1	20.77	20.83	41.78	40.75	19.23	19.32
4.	OS4	-1	0	1	0	21.05	21.04	40.65	40.57	19.16	19.29
5.	OS5	-1	-1	0	0	20.54	20.81	39.61	40.44	14.38	13.90
6.	OS6	-1	0	-1	0	21.73	21.43	43.47	43.04	20.15	20.19
7.	OS7	0	1	0	1	22.40	22.42	46.72	46.67	22.12	22.15
8.	OS8	0	0	1	-1	20.56	20.09	39.71	40.03	19.14	19.35
9.	OS9	-1	0	0	-1	21.16	21.07	42.78	42.14	20.72	20.64
10.	OS10	1	0	0	1	19.63	19.68	40.01	39.87	19.45	19.79
11.	OS11	-1	1	0	0	23.19	23.43	47.35	47.44	22.32	22.51
12.	OS12	0	-1	-1	0	20.82	20.79	39.33	38.67	13.45	14.30
13.	OS13	0	0	0	0	20.22	20.22	40.55	40.51	20.71	20.71
14.	OS14	0	1	1	0	22.60	22.59	46.14	46.02	21.71	21.13
15.	OS15	0	0	-1	1	20.11	20.35	40.11	40.69	20.42	19.91
16.	OS16	0	-1	1	0	19.42	19.47	37.83	37.48	13.99	14.20
17.	OS17	0	1	-1	0	22.53	22.44	47.14	46.71	22.37	22.42
18.	OS18	0	-1	0	-1	20.09	20.35	38.71	38.65	14.79	14.77
19.	OS19	0	0	0	0	20.22	20.22	40.55	40.51	20.71	20.71
20.	OS20	1	0	1	0	19.19	19.77	39.79	40.11	18.82	18.79
21.	OS21	0	-1	0	1	20.14	20.08	39.05	38.49	14.89	14.79
22.	OS22	1	1	0	0	22.62	22.12	46.66	46.74	20.54	20.72
23.	OS23	1	0	-1	0	20.29	20.57	39.55	39.52	19.38	19.27
24.	OS24	0	0	-1	-1	21.37	21.28	40.44	41.41	21.27	20.93
25.	OS25	0	0	0	0	20.22	20.22	40.44	40.51	20.71	20.71
26.	OS26	1	-1	0	0	20.45	19.98	36.34	37.15	14.76	14.27
27.	OS27	0	0	1	1	20.51	20.37	40.27	40.20	20.07	20.11

Table VII. Regression equations representing the effect of the sewing variables on sewing thread strength

Sr	Parameters	Regression equations	R^2
1.	Straight thread strength	$20.22 - 0.534x_1 + 1.193x_2 - 0.293x_3 - 0.159x_4 + 0.374x_1^2 + 0.99x_2^2 + 0.108x_3^2 + 0.195x_4^2 - 0.12x_1*x_2 + 0.3675x_2*x_3 + 0.3025x_3*x_4 - 0.4175x_4*x_1.$	0.946
2.	Loop strength	$40.51 - 0.99x_1 + 4.14x_2 - 0.471x_3 - 0.137x_4 + 0.51x_1^2 - 1.91x_2^2 - 0.21x_3^2 + 0.28x_4^2 + 0.64x_1*x_2 - 0.12x_2*x_3 - 0.22x_3*x_4 - 0.30x_4*x_1.$	0.977
3.	Knot strength	$20.71 - 0.355x_1 + 3.76x_2 - 0.345x_3 - 0.068x_4 - 0.742x_1^2 - 2.113x_2^2 - 0.58x_3^2 - 0.051x_4^2 - 0.054x_1*x_2 - 0.3x_2*x_3 - 0.3x_3*x_4 + 0.44x_4*x_1.$	0.988

* Lack of fit (Prob>F)

Straight thread strength = 0.0459 (Not significant); Loop strength = 0.210 (Not significant); Knot strength = 0.011 (Not significant)

Thus, for loop and knot retention of threads; sewing thread count, sewing speed, interactions between thread tex and speed, stitch density and fabric GSM had been outstanding. On the other, the interactive effect of sewing speed and fabric GSM had a profound effect on the straight thread strength.

Conclusions

It was concluded that increase in Fabric GSM (x1) and sewing speed (x3) had exerted a detrimental impact on cotton sewing threads due to the increased abrasion of the sewing threads, which resulted in reduction of the straight thread strength as the surface fibers of the threads got rubbed off with the machine components and fabric surface at the same time. This resulted in fall of overall load bearing capacity of all the cotton threads due to the extensive abrasion of sheath fibers with the increased contact of the greater thickness of the fabric, as the fabric GSM was increased. But, it was observed that the reduction of all tensile properties was greater for finer counts than coarser counts; due to their lower parent thread strength and also lesser surface area to be offered to the machine abrasion. The loop thread strength of sewing threads also reduces with the increased fabric GSM and sewing speed (either in interaction with the other variables or independently); the interaction of the increased fabric GSM along with the sewing speed at different levels results in improvement of the loop strength but the overall loop strength falls with the increased abrasion of sewing threads at the higher levels of sewing speed and fabric GSM. The interactive effects of the sewing speed and fabric GSM at high levels proved to be somewhat detrimental to the cotton sewing threads due to the excessive rubbing and exposure of the core fibers to abrasion and also knot retention.

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