EFFECT OF THREAD STRUCTURE ON TENSION PEAKS DURING LOCK STITCH SEWING

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Abstract:

A dynamic sewing tension study was carried out with a tension probe on sewing threads with different structures, physical and tensile characteristics in a single needle lock stitch sewing machine. The needle thread recorded four major tension peaks corresponding to events occurring during sewing; bobbin thread withdrawal, stitch tightening, needle piercing the fabric and tightening of the needle thread around the shuttle, among which stitch tightening caused the maximum tension for all threads. Polyester filament and spun polyester threads exhibited the highest and lowest tightening tension, respectively. Multiple regression analysis showed that pre-tension and elastic modulus show positive influences while tex, bending, rigidity and compressibility of threads show negative effects on tension peaks during tightening and needle piercing. Sewing speed shows a positive impact only on the tension peak due to needle piercing. Pre-tension showed a prominent influence on tension peaks on all threads while the number of fabric layers failed to show any effect.

Key words:

Tension peaks, needle, bobbin, spun, filament, bonded, textured.

Introduction

The variety of sewing threads available in the market has multiplied due to the diverse demands of the sewing industry. Better understanding of the sewing process and its requirements specific to the each thread type is essential to achieve the best possible seam quality from them. Regardless of the distinguishing attributes which a sewing thread may possess, they are of little value if the sewing thread cannot be efficiently placed (stitched) in the seam, i.e. with less damage inflicted on them during sewing. During sewing, the threads, especially the needle thread is subjected to repeated tensile stresses at a very high rate and these forces create within the thread a negative effect on the processing and functional characteristics [5, 8]; mainly, there is a significant reduction in strength. But the individual thread's structure and properties determines its behaviour during stitch formation, i.e. sewing tension peaks [11]. A similar study shows has shown that the kind of sewing thread [1] influences the sewing cycle tension pattern.

A study [9] of thread properties on sewing tension revealed that the tension generated during sewing is determined by the modulus, the shape of the load-elongation curve, the coefficient of thread-metal friction and the linear density of the thread. Cotton threads exhibit lower tightening tension due to its low extension property while spun polyester threads exhibit higher values. Polyester and cotton threads [11] become tight at different arm shaft angles, the result of reversing the order of their disengagement from the rotating hook. Polyester thread is tight; while on the other hand, cotton thread is slack. This means that the length of the cotton thread under the throat plate is longer than that of the polyester thread. Clearly, the difference is due to the tensile properties of the two sewing threads. In sewing with cotton threads, therefore, the average tightening tension is low which results in a large tightening ratio.

In a study [2] of the effect of different sewing thread qualities on the tensions generated on the needle and bobbin thread, it was found that the thread tension traces obtained with 100% cotton sewing thread presented different timing, i.e. during the sewing cycle, the different peak tensions started later and finished earlier, but the maximum tension on each peak occurred at the same time as the other sewing thread peak tensions. It was also noticeable that peaks 1 and 4 for the experiment made with 100% polyester sewing thread exhibited very large variations. Using glass fibre thread with epoxy resin [10] in pre-form stitching, the tension peak 1 and the maximum tension peak 2 were influenced by the dynamic thread behaviour and friction between threads. Also, with different threads [3], prominent trends were noticed on the relationship between seam balance and the tensions generated on both the needle thread and the bobbin thread. The results confirmed that, according to the properties of the thread, different values of pre-tension are required in order to obtain balanced seams.

Though previous studies have indicated that thread properties influence the tension peaks during sewing, there is a lack of information regarding the behaviour of different types/structures of threads in terms of tension during sewing. In this study, six categories of commercial sewing threads of similar tex with different structures and fibres were selected and the tension peaks generated by them during sewing under constant sewing conditions were compared and analysed. Online sewing tension was measured in a single needle lock stitch (SNLS) sewing machine by a strain gauge-based tension probe [7] kept above the needle in the thread path.

Experiments

Materials

The dimensional characteristics of threads of similar tex (40 ± 5) with different structures selected in this study used are given in Table 1.

The optical thread diameter was measured using a microscope while tensioning the thread at 20 cN/tex. The threads were kept parallel to each other on a card board, pasted at their ends (while keeping the tension on the threads at 20

Table 1. Thread categories and specifications.

Threads	Tex	Ply	Twist, TPI	Diameter, mm		Flat width, mm
			Single/ ply	at 20cN/cm^2	Optical	
Spun polyester	39	3	21/13	0.16	0.2125	0.2784
PC core	40	2	28/17	0.18	0.1875	0.1987
Polyester filament	45	3	19/13	0.17	0.2125	0.2635
Polyester textured	35	-	-	0.12	0.2375	0.4750
Nylon filament	37	3	14/10	0.17	0.1875	0.2100
Nylon bonded	37	3	14/10	0.17	0.1875	0.2100

cN/tex), from which windows were prepared. Using fabric thickness tester, the thickness of threads was measured at a pressure 20 cN/cm2. The degree of flattening of thread was calculated as the ratio between the optical diameter of thread and diameter of thread measured using the thickness tester. To obtain the flattened width of the thread, optical diameter was multiplied by the degree of flattening of the thread under compression. The tensile and bending properties of the threads are given in Table 2. The tensile strength of the threads was tested based on ASTM standard D2256. The bending rigidity of the threads was tested on a Shirley ring loop instrument. The thread friction was tested on a Lawson-Hemphill friction tester. Grey cotton plain weave fabric with a warp of 34 tex (single), a weft of 45 tex (single), EPI/PPI-50/42, 0.27mm thickness and 120 gcm-2 was used for stitching.

Table 2. Thread properties.

Thread	Tenacity, cN/Tex	Initial modulus, cN/Tex	Breaking extension, %	Specific work of rupture, cN/Tex	Bending rigidity, cN cm^2	Coeff. of friction	
						Thread to metal	Thread to thread
Spun polyester	30.05	2.56	17.80	2.06	0.00426	0.15	0.60
PC core	45.67	4.19	23.59	5.25	0.00898	0.16	0.62
Polyester filament	66.10	6.67	18.82	5.46	0.00804	0.18	0.66
Polyester textured	36.28	3.50	26.17	4.68	0.00695	0.18	0.62
Nylon filament	61.96	2.97	22.91	5.21	0.00477	0.18	0.64
Nylon bonded	61.20	3.78	17.09	4.48	0.01296	0.18	0.58

Methods

Online sewing tension was measured on a Sunstar-KM 250 model SNLS sewing machine. The selected variables are given in Table 3. The selected needle was DB x 1 # 14 and standard feed timing was set. The bobbin thread pre-tension (25cN), and stitch density (8 spi) were kept constant.

Results and discussion

The measured needle thread tension indicated that there are four prominent tension peaks generated within a sewing cycle.

Table 3. Variable levels.

Variable	Levels			
	1	2	3	4
Needle thread pretension, cN	75	100	125	150
Number of fabric layers	1	2	3	4
Machine speed, rpm	200	600	1000	1400

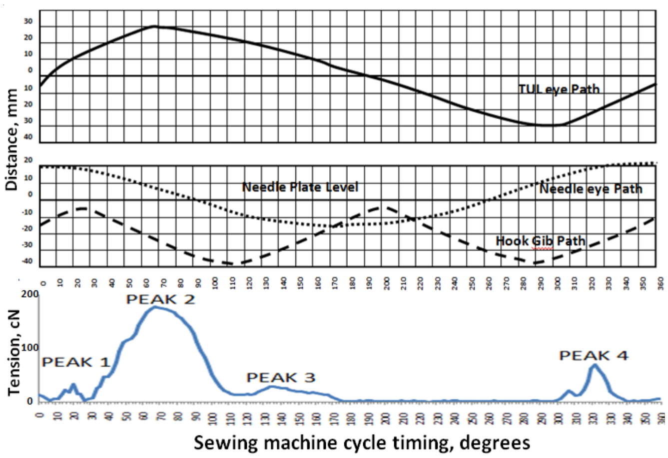

Figure 1. Machine sewing elements path profile and typical tension peaks in a cycle.

Peak 1 is due to bobbin thread withdrawal, peak 2 is due to stitch tightening, peak 3 is due to needle penetration and peak 4 is due to tightening of the thread around the shuttle (Figure 1). The tightening tension, peak 2 shows the highest value among all tension peaks. For all the threads, as a confirmation of the previous study [6] that the numbers of fabric layers do not show any effect on these tension peaks. The sewing speed showed an effect only on tension peak 3 in some threads. Since there was high variation in all the tension peak values, a t-test was done between the tension peak values of the threads to verify that the differences were statistically significant.

Tension peaks analysis

In this study, the maximum of tension peak 2 among all the threads tested was found to be close to 300 cN (Figure 3). Since the threads were subjected to a maximum tension of 300 cN during sewing, their tensile behaviour up to a load of 300 cN is of importance when comparing the threads with respect to their sewing tension peak 2 values. After tension peak 1, needle thread tension goes to zero and starts to gain tension at 35° of the sewing cycle; the check spring becomes flat due to tension. At 65° of the sewing cycle, the take-up lever

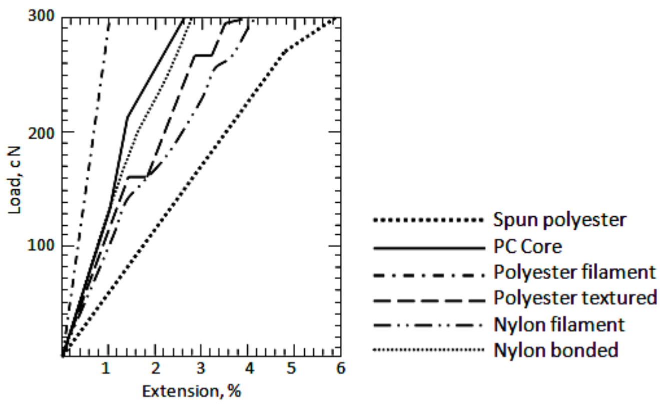

Figure 2. Load-extension curves of six threads up to 300 cN load.

(TUL) reaches its top dead point (TDP), and the tension build-up on the needle thread is very high from 35° to 65° (Figure 1).

Because the thread is held by fabric at one end and by a tensioner at the other end, i.e. the active tension region (ATR) is then stretched by the TUL. The length of thread in the ATR at 35° is 30.9 cm and this length is stretched by 3.3% by the TUL up to 65° of the sewing cycle, assuming that there is no robbing off of needle thread from the previous stitches. Mean while, fresh thread equivalent to the stitch length is drawn in through the tensioner, but that length is absorbed by the movement of fabric which is also equivalent to the stitch length.

Figure 2 shows the load-extension curves of all the threads up to 300 cN load. From the load-extension graphs and the elastic modulus data given in Table 2, the descending orders of modulus of the threads are: polyester filament, polyester-cotton core spun, nylon-bonded, polyester textured, nylon filament and spun polyester threads. A thread with a higher elastic modulus would experience higher tension during stitch tightening for a given length of robbing off of the needle thread from the previously formed stitches. The robbing off effect ensures supply of thread from the fabric to the TUL and, hence, the measured needle thread tension would be lower. It has been demonstrated that the robbing off effect depends on the thread friction coefficient [4].

Regression analysis is done to see the effect of various factors on sewing tension peaks. Since all the threads showed non-significant differences in their friction coefficients, except for the thread to metal friction coefficient of spun polyester to the rest, the friction coefficients did not show a good correlation and were excluded from the regression analysis. Table 4 shows the regression analysis of the thread properties as input variables affecting tension peak 2.

Table 4. Regression analysis for tension peak 2.

The regression equation: Peak-2, cN = [299.868] + [1.232 x Needle Pretension] – [7.209 x Tex] + [20.328 x Modulus] - [1511.522 x Bending rigidity] - [66.081 x Flat width]					
Predictor	Coeff.	SE Coeff.	Std. Coeff., Beta	T	P
(Constant)	299.868	46.876	-	6.397	0.000
Pre-tension, cN	1.232	0.045	0.786	27.154	0.000
Tex	-7.209	1.253	-0.524	-5.752	0.000
Modulus	20.328	2.932	0.620	6.932	0.000
Bending rigidity	-1511.522	721.292	-0.100	-2.096	0.037
Flat width, mm	-66.081	20.299	-0.145	-3.255	0.001
R=0.827, R^2=0.684, Adjusted R^2=0.679, Std. Error of the Estimate=24.844					
Analysis of Variance					
Source	SS	DF	MS	F	P
Regression	503919.521	5	100783.904	163.290	0.000
Residual	233304.437	378	617.208	-	-
Total	737223.958	383	-	-	-

All the input parameters showed significance at the 99% confidence level ($p < 0.01$) except bending rigidity (95%, $p < 0.05$). Among the significant input parameters, pre-tension and modulus showed a positive correlation and tex, bending rigidity and flattened width showed a negative correlation. It can be understood that the increase in pre-tension leads to increase in tension peak 2 by restricting the supply of fresh thread into the ATR, so the thread length available within the ATR is less, which leads to tension build-up on the needle thread. The threads with larger tex and bending rigidity are less flexible and form a lesser angle of wrap around the machine parts, especially through the TUL eye and thus lesser friction; the same causes less tension build-up on the needle thread during tension peak 2 formation. The threads with a larger elastic modulus would experience greater resistance to stretching during stitch tightening.

The threads with a larger flattened width are highly compressible and can easily rearrange themselves into the restricted spaces inside the fabrics and are subjected to less friction and hence experience lower tension. Among the three variables, only pre-tension showed considerable effect on tension peaks 2 and 4. Pre-tension showed a positive correlation with tension peak 2 (Figure 3). This validates the earlier finding [2, 4] that pre-tension is the primary cause of peak 2. Pre-tension does not show a significant effect on tension peak 1.

Figure 4 shows the positive correlation between pre-tension and peak 4 for polyester cotton core spun and nylon filament threads, which are highly extensible. At higher pre-tension, the thread stretches during peak 2 and the amount of thread intake takes place at a reduced rate, which causes higher tension at peak 4. With shorter length (than required) of thread in the ATR, as the thread goes around the shuttle, it gets tightened up during peak 4, and the peak tension increases because it causes early initiation and longer duration of the peak (from zero to highest tension). As observed, at 150 cN pre-tension the peak 4 duration was 110° to 130°, compared to 120° to 130°, in the case of lowered pre-tension.

Table 5 shows the regression analysis for tension peak 3. All the factors affecting tension peak 2 showed a similar effect on tension peak 3 as well. After tension peak 2, the tension does not go to the zero level before tension peak 3. So, the effect of tension peak 2 would still affect tension peak 3. The sewing speed, which did not show a prominent effect on tension peak 2, showed a positive correlation with tension peak 3.

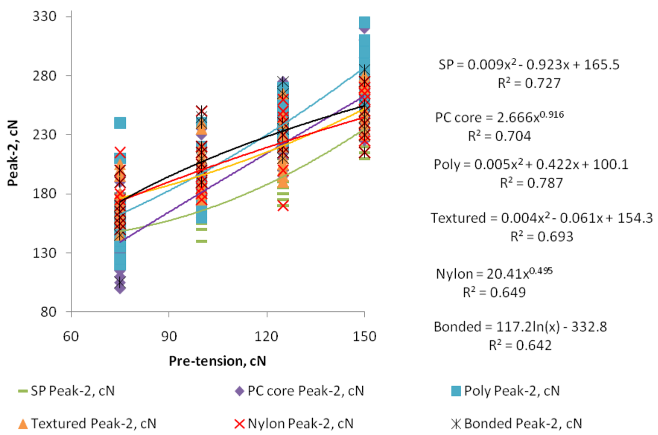

Figure 3. Effect of pretension on tension peak 2.

At the time of the needle piercing the fabric, the thread is under tension despite the fact that the TUL starts descending, because of the compensating action of the check spring. When the needle pierces the fabric, one end of the thread passing through needle eye is gripped by the fabric and the other end is gripped by the tensioner. Since the thread cannot be drawn from the fabric, the length of the thread required for the needle

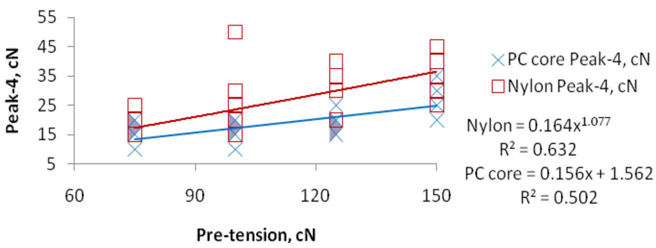

Figure 4. PC core and nylon filament threads: pre-tension vs. peak 4.

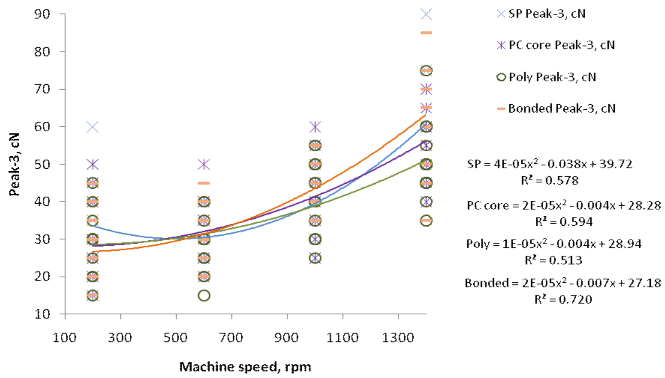

Figure 5. Spun polyester, pc core, polyester filament and bonded nylon threads: machine speed vs. Peak 3.

Table 5. Regression analysis for tension peak 3.

The regression equation: Peak-3, cN = [131.935] + [0.240 x Needle Pretension] – [3.296 x Tex] + [5.508 x Modulus] + [0.023 x Machine speed] - [1910.826 x Bending rigidity] - [50.423 x Flat width]					
Predictor	Coeff.	SE Coeff.	Std. Coeff., Beta	T	P
(Constant)	131.935	17.724	-	7.444	0.000
Pre-tension	0.240	0.017	0.421	14.035	0.000
Tex	-3.296	0.473	-0.657	-6.963	0.000
Modulus	5.508	1.107	0.461	4.974	0.000
Machine speed	0.023	0.001	0.635	21.186	0.000
Bending rigidity	-1910.826	272.410	-0.347	-7.015	0.000
Flat width	-50.423	7.666	-0.303	-6.577	0.000
R=0.813, R Square=0.661, Adjusted R Square=0.656, Std. Error of the Estimate=9.383					
Analysis of Variance					
Source	SS	DF	MS	F	P
Regression	64744.237	6	10790.706	122.573	.000
Residual	33189.096	377	88.035	-	-
Total	97933.333	383	-	-	-

stroke through the fabric is supplied by the deflection of the check spring and by the downward stroke of the TUL. Out of the total 35 mm stroke of the needle, it makes a 20 mm stroke above the machine bed during 0° to 100° of the sewing cycle and the needle tip touches the fabric at a velocity of 36 m/min and 108 m/min at machine speeds of 500 rpm and 1500 rpm, respectively. So, it can be understood that while the needle is piercing the fabric, the thread movement through the fabric and through the needle eye happens at the same velocity as the needle itself. Since the speed at which the thread being drawn into the fabric increases proportionately with machine speed, the tension the thread experiences at that point in time also shows a positive correlation with machine speed.

Similar to the observation made earlier [4], sewing speed had a positive correlation with tension peak 3 for four threads; textured polyester and nylon filament threads were the exceptions. The spun polyester, polyester cotton core spun and polyester filament threads showed moderate correlations while that of the bonded nylon was better the others (Figure 5).

When the needle penetrates the fabric, the twist-less filaments of textured thread spread out and, without much resistance, accommodate themselves easily within the spaces of the fabric. This caused no remarkable variation in tension peak 3, irrespective of sewing speed. For the same reason, the least compressible thread (nylon bonded) would find it difficult to penetrate into the fabric, and hence, it was very sensitive to speed (high correlation observed in Figure 5). The nylon filament thread, because of its better extension and elasticity (at the 300 cN level) compared to other threads, stretched higher at peak 2 and it stuck too close to the needle (similar to textured thread) while still retracting after peak 2, therefore it offered less resistance for penetration through the fabric irrespective of needle velocity.

Conclusions

This study demonstrated the role of different thread structures and properties in sewing tension peaks. The elastic modulus of thread plays a positive role in determining the stitch tightening tension; the high modulus twisted filament polyester thread showed the highest tightening tension whereas the low modulus spun polyester and nylon twisted filament showed the lowest tightening tension. Permanent extension of spun threads during sewing leads to reduction in tightening tension build-up and the loss of its extension could lead to deteriorated performance of the stitch in the seam. The needle thread pre-tension is a prominent factor which showed a positive correlation with stitch tightening tension, while the tex, bending rigidity and compressibility of the threads showed the opposite trend. The sewing speed failed to show any effect on the tightening tension peak, but it did show a positive correlation with the tension peak during needle penetration for many threads. The rigid threads like nylon bonded may experience more damage at higher sewing speeds because of the positive correlation between speed and needle piercing tension. The numbers of fabric layers showed no effect on tension peaks. The behaviour of each category of threads described here could be used as input information in selecting predetermined sewing parameters for industrial sewing, especially in the case of automated sewing to avoid costly trial and error procedures.

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