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Influence of Needle Heat during Sewing Process on Tensile Properties of Sewing Thread

Vpliv segrevanja šivalne igle med procesom šivanja na natezne lastnosti sukanca

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Abstract

In this work, the tensile properties of a sewing thread, i.e. tenacity, breaking elongation and initial modulus of two common industrial sewing polyester-polyester core spun threads, were studied at four sewing stages. Firstly, the needle heat was measured at different speeds from 1000 rpm to 4700 rpm of an industrial lockstitch sewing machine with the inserted thermocouple method. Secondly, the tensile properties of a thread were compared at different predefined sections of the sewing thread in the sewing process. The results show that the needle heat and bobbin thread interaction has a great impact on the sewing thread tensile strength, while the tensile strength is minimal at the point when the machine stops and the thread is in direct contact with the hot needle. Tenacity, breaking elongation and initial modulus decrease substantially with a higher speed of the machine as the needle temperature increases. At 4000 rpm of the sewing speed, the sewing thread loses 50% of its tenacity as the needle temperature reaches nearly 250 °C, the impact being higher for higher count (linear densities) threads.
Keywords: sewing needle, sewing thread strength, needle heat, thermocouple method

Izvleček

V članku je predstavljena raziskava nateznih lastnosti sukanca, kot so trdnost, pretržni raztezek ter začetni modul dveh v industriji pogosto uporabljenih poliestrskih sukancev iz oplaščenene preje, in sicer v štirih fazah šivanja. Na začetku smo izmerili temperaturo igle pri različnih hitrostih, in sicer od 1000 do 4700 vrtljajev na minuto na industrijskem šivalnem stroju s pomočjo metode vstavljenega termočlena. Natezne lastnosti sukanca smo nato primerjali pri različnih vnaprej določenih delih šivalne niti med samim procesom šivanja. Izsledki raziskave so pokazali, da ima interakcija med segrevanjem igle in sukancem na navitku velik vpliv na natezno trdnost sukanca, medtem ko je natezna trdnost najmanjša na točki, ko se stroj ustavi in je sukanec v neposrednem stiku z vročo iglo. Trdnost, pretržni raztezek in začetni modul se znatno zmanjšajo pri večji hitrosti stroja, ko se poviša tudi temperatura igle. Pri hitrosti 4000 vrtljajev na minuto izgubi sukanec 50 % trdnosti, saj se temperatura igle povzpne na skoraj 250 °C. Vpliv je večji pri sukancih z višjo linearno gostoto.
Ključne besede: šivalna igla, trdnost sukanca, segrevanje igle, metoda s termočlenom

1 Introduction

During high speed sewing, the sewing thread is subjected to friction, heat, pressure, torsion and bending. These forces act on the thread repeatedly, and its tensile properties decrease substantially [1]. The thread has to pass through the needle eye, fabric and bobbin case mechanism 50–80 times before becoming a part of the seam [2]. Local abrasion and cutting of the needle thread can occur due to the

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rubbing at the top of the needle eye [3]. In an early research work, Crow and Chamberlain [4] reported that there is a reduction of up to 60% in the thread strength after the sewing. Later, a number of researchers observed that there could be a 30–40% strength reduction in the cotton thread after the sewing and various reasons assigned included structural damage, dynamic and thermal loading [5–9]. In a recent study on the tensile properties of mercerized cotton threads, around 30% in strength reduction, about 20% loss in both breaking elongation and initial modulus, and 45% loss in breaking energy was reported [10]. Furthermore, a closer estimation of the seam strength was also possible after considering the loss in thread strength [11, 12]. The damage is mostly concentrated at the interlocking portion of the needle thread in the stitch, where maximum tension, bending and thread-thread abrasion take place [5, 8]. A number of researchers also studied the thread tensions during the sewing process and it is well known that the highest thread tension force occurs at the moment of stitch tightening [13–16].

Nevertheless, earlier studies are based on the effect of mechanical abrasion [17] as a cause of the thread tensile loss. In this work, we measured needle heat at different speeds of the sewing process and made sections of the sewing thread from the cone to the seam to measure the tensile properties of the sewing thread. We used two most common polyester core spun threads and measured the tenacity, initial modulus and breaking elongation of the thread at different stages of the thread, including the impact of needle heat.

For our research, we used the inserted thermocouple method invention by Hes [18] to measure the needle heat from 1000–4700 rpm of the machine. In this method, a thermocouple by Omega (K type 5SC-TT-(K)-36-(36)) is inserted inside the needle groove and the sewing is done while the thermocouple is inside the needle groove. The needle temperature values can be obtained through a wireless device on a computer.

2 Methodology

2.1 Sewing thread and material properties

The details of the sewing thread and textile material used for the experiment are listed below.

- Thread polyester-polyester core spun (for details cf. Table 1)
- Denim fabric, two layers (for details cf. Table 2)

2.2 Sewing machine and needle temperature measurement

The devices used for the experiments are listed below:

- lockstitch machine (Brother Company, DD7100-905),
- thermocouple by Omega (K type 5SC-TT-(K)-36-(36)) for the inserted method,
- Omega – wireless device and receiver (MWTC-D-K-868) and
- needles (Groz-Beckert 100/16) R- type.

The needle temperature was measured using the inserted thermocouple method and the sewing process

Table 1: Physical properties of sewing threads

Thread type	Producer/ product name	Fineness [tex]	Twist [t/m]	Twist direction [ply/ single]	Tenacity [cN/tex]	Elongation at break [%]	Initial modulus [N/tex]	Coefficient of friction [–]
Poly-poly core spun	AMANN/ Saba C-35	40 × 2	534	Z/S	50	18	4.4	0.16
Poly-poly core spun	AMANN/ Saba C-80	22.2 × 2	660	Z/S	45	21	3.26	0.14

Table 2: Fabric used for experiments

Fabric type	Weave	Mass/Unit area [g/m^2]	Warp density [ends/cm]	Weft density [picks/cm]	Fabric thickness [cm]
100% cotton denim	2/1 twill	257	25	20	0.035

was performed at 1000–4700 rpm. The total of 150 observations was taken for each thread. The maximum time of sewing was 30 seconds for all speeds of the machine from 1000 rpm to 4700 rpm. The needle thread tension was adjusted to 140 cN to obtain a balanced stitch. The stitch length was kept constant at 5 stitches/cm. The conditions for all experiments were kept constant at 26 °C and 65% RH. Figure 1 shows the placement of the thermocouple for measuring the needle temperature at different speeds of sewing.

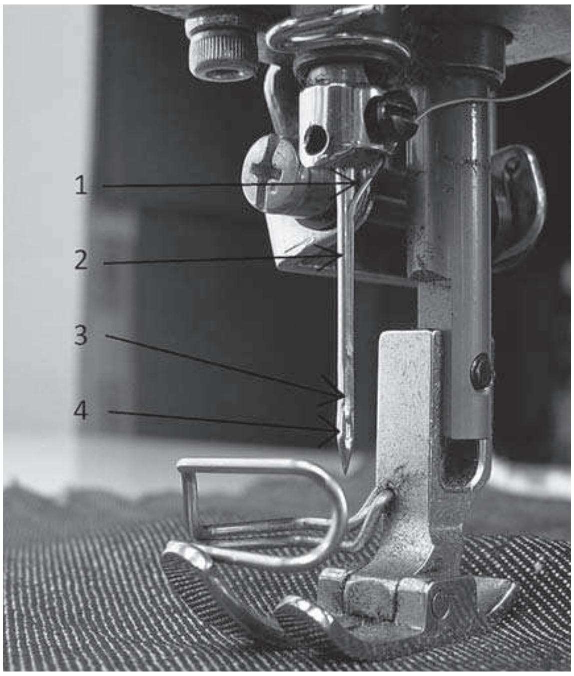

Figure 1: Sewing needle with inserted thermocouple
Legend: 1 – thermocouple wire, 2 – needle groove, 3 – thermocouple measuring point, 4 – needle eye

2.3 Stages of sewing thread for tensile properties measurement

The sewing thread was divided into four sections as shown in Figure 2. For the tensile testing of the sewing thread, an Instron tensile tester as per ASTM standard D2256 was used. The tensile testing of the parent thread corresponds to that of the section S1. For the tensile testing of the thread in the section S2, 250 mm length of thread from mark A towards G2 was mounted in the jaws. For the tensile testing of the thread in the section S3, a length of 250 mm from mark A towards point B was mounted in the jaws. A sufficient length of the thread was removed from the seam for gripping in the lower jaw, whereas the section S4 thread was pulled out precisely from the seam by cutting the bobbin thread. 30 samples of each section (S1, S2, S3, S4) were tested for tensile properties at each speed of the machine.

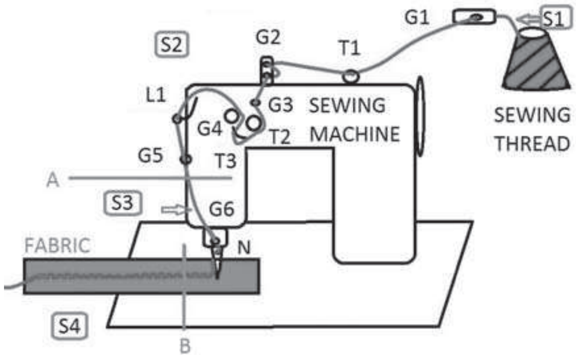

Figure 2: Passage of sewing thread through sewing machine
Legend: S1 – same as parent thread, G1 to G6 – guides for thread, T1 to T3 – tension devices, S2 – section of thread from A towards point G1, S3 – section of thread from point A towards point B, point A – 12 cm from needle eye, point B – 22 cm from needle eye in the seam, S4 – thread in the seam (pulled out precisely by cutting bobbin thread), L – take-up lever, N – needle eye

The change (%) in tensile properties at different stages is calculated with the following equation:

$$Change\ (\%) = \frac{T_n - T1}{T1} \cdot 100 \qquad (1),$$

where Tn is the tensile property at different sewing stages, with n = 2, 3 and 4, corresponding to the sewing stage S2, S3 and S4, respectively. T1 is the tensile property of the parent thread at the sewing stage S1. A negative (–) change (%) indicates the loss in tensile property.

3 Results and discussion

3.1 Influence of sewing thread on needle temperature

Needle temperature is higher when a higher count thread is used as shown in Figures 4 and 5. At 4700 rpm of the sewing speed, the thread Saba C-35 showed the maximum temperature of 305 °C as compared to 285 °C for the thread Saba C-80; this might be a consequence of the increase in friction between a thicker thread and the needle eye. Figure 3 shows the needle temperature without the thread at a different speed of sewing, where the needle reached 112 °C at the maximum speed of 4700 rpm of the machine and for all speeds, the needle temperature stabilized after 15 seconds of continuous sewing. After 15 seconds, the rise in temperature was minor.

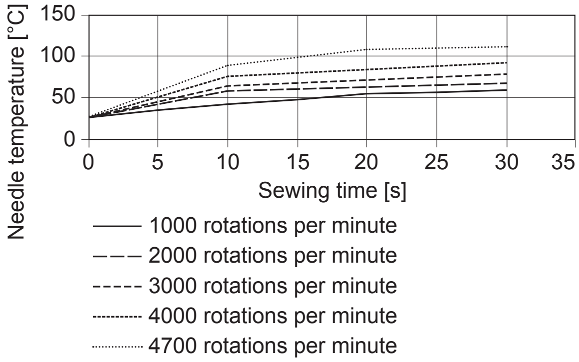

Figure 3: Needle (without thread) temperature

Figure 4 shows the needle temperature with the thread Saba C-80, which increased the needle temperature much more as compared to the needle temperature without the thread – at 4700 rpm of the machine after 30 seconds of sewing, the needle reached the maximum temperature of 285 °C. Nevertheless, the thread did not break or fuse as the thread was continuously moving and the needle heat was not fully conducted to the thread (a comparison of tensile strength at different speeds is discussed in continuation, cf. Figures 6–11).

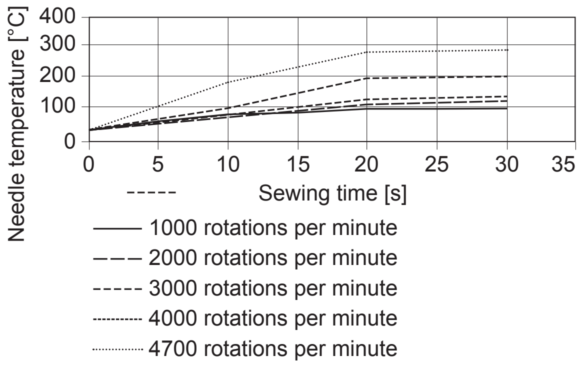

Figure 4: Needle temperature (with thread Saba C-80)

Figure 5 shows the needle temperature with the thread Saba C-35 (40 × 2 tex). The needle temperature rose to 305 °C at 4700 rpm of the machine. The temperature of the needle despite being higher than the melting temperature of polyester did not break the thread as the contact time of the thread with the needle was short.

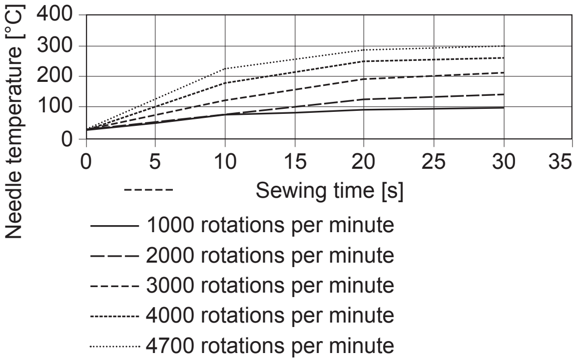

Figure 5: Needle temperature with thread Saba C-35

3.2 Effect of sewing speed on tenacity of threads

For 1000–2000 rpm of the machine, the minimum tenacity was noted for the section S4, which shows that the thread underwent mechanical abrasion especially from the bobbin mechanism and friction between the fabric and thread, whereas for 3000–4000 rpm of the machine, the minimum tenacity was observed at the section S3, which was due to the high temperature of the needle (the needle temperature at different speeds is shown in Figures 4 and 5). The effect was smaller for the section S4, as the machine was running at high speed and the contact time between the thread and needle was much shorter, whereas when the machine stopped, the thread was

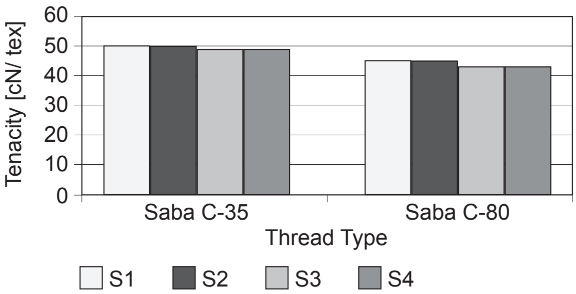

Figure 6: Tenacity of thread at 1000 rpm of machine

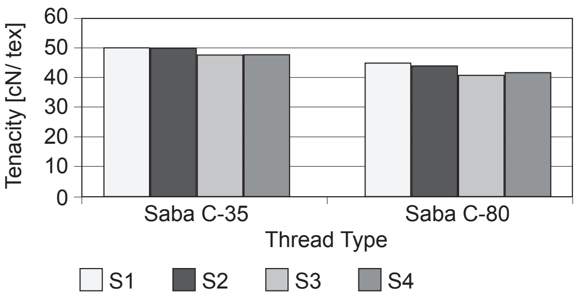

Figure 7: Tenacity of thread at 2000 rpm of machine

in direct contact with the needle eye and caused minimum tenacity at the section S3. This effect has always been neglected by other researchers, since for the tensile strength of the thread only the seam thread strength has been evaluated, which is not correct as the thread from the section S3 finally becomes part of the next seam and causes a weaker seam.

The tenacity of the thread was measured at different sections of the thread (S1, S2, S3 and S4). Figures 6 and 7, representing the machine speed of 1000 and 2000 rpm, demonstrate that the needle temperature was lower than 100 °C. The latter shows that the minimum tenacity of the thread was at the section S4, which underwent all abrasion and mechanical forces, yet the needle heat impact was not dominant.

It can be seen in Figures 8 and 9, displaying the speed of 3000 rpm and 4000 rpm, respectively, and the needle temperature rising to nearly 200 °C (needle temperature is shown in Figures 4 and 5), that the tenacity of the sewing thread started to play the dominant role in decreasing the strength of the sewing thread. It is to be noted that S3 had less tenacity than the section S4, which was due to the S4 thread being a part of the seam when the machine was running at high speed whereas the section S3 suffered more damage after the sewing finished and the thread remained on the hot needle eye.

Figure 11 shows the tenacity of threads at 4700 rpm of the machine where the needle reached 305 °C for the Saba C-35 thread and 286 °C for Saba C-80. The section S3 got the maximum damage and in the case of Saba C-35, the thread tenacity decreased by 70%, showing that the thread did not receive all the needle heat during high speed sewing.

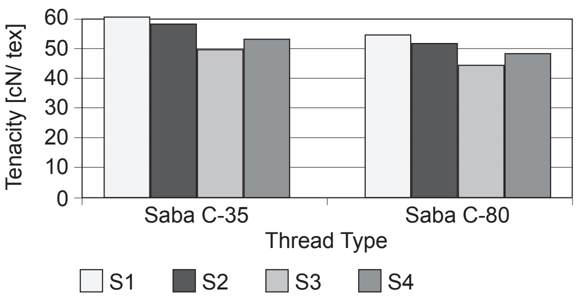

Figure 8: Tenacity of thread at 3000 rpm of machine

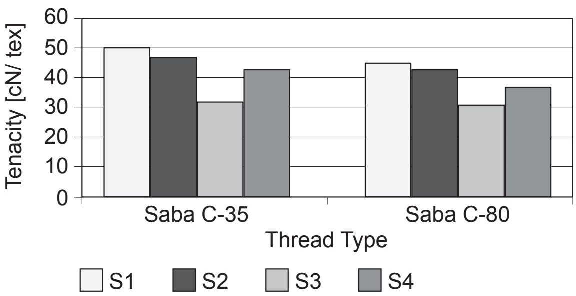

Figure 9: Tenacity of thread at 4000 rpm of machine

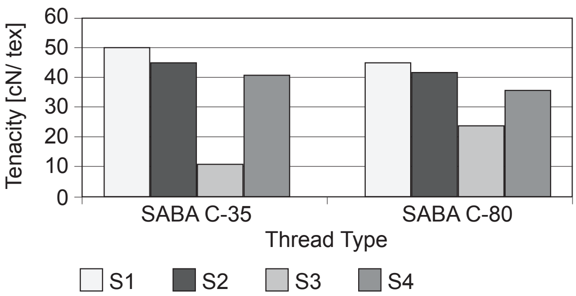

Figure 10: Tenacity of thread at 4700 rpm of machine

3.3 Effect of needle temperature at section S3

The section S3 thread underwent maximum needle heat after the machine stoppage as the thread was in direct contact with the hot needle. The tenacity of

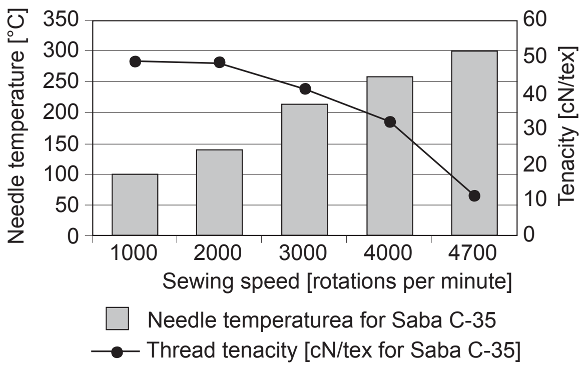

Figure 11: Needle temperatures and tenacity of thread at section S3 for thread Saba C-35

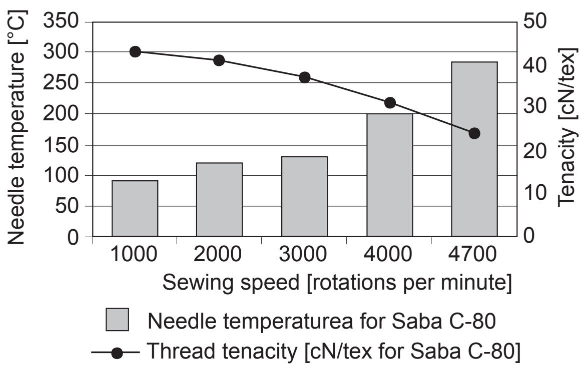

Figure 12: Needle temperatures and tenacity of thread at section S3 for thread Saba C-80

the thread was more affected at a higher count thread (Saba C-80) as the needle temperature was higher with higher count threads. Figures 11 and 12 show the needle temperature and the tenacity of the thread at the section S3 for different speeds of sewing. It can be observed that the needle temperature caused a great damage to the sewing thread tensile property. For Saba C-35, the thread tenacity decreased by 78%, followed by Saba C-80, which shows a 46% decrease in tenacity at 4700 rpm of the sewing speed. Saba C-35 is a higher count thread and showed higher needle temperature which might be a consequence of greater friction between the needle eye and the thread. The graph shows the needle temperature on the primary left axis, while the secondary axis on the right side of the graph shows the tenacity of both threads at different speeds of sewing.

3.4 Effect of sewing speed on thread tensile properties

Table 3 shows tenacity, initial modulus and breaking elongation for both threads, Saba C-35 and Saba C-80, at different speeds of the sewing machine and different sections of the sewing thread (S1, S2, S3 and S4). The change (%) is calculated according to Equation 1, and as Table 3 shows, the maximum loss in the tensile property was at the section S3, where the thread tenacity for Saba C-80 decreased to 46.7% and for Saba C-35, it decreased by 78% at 4700 rpm of the machine. The thread at the section S3 incurred the maximum needle heat after the machine stoppage, which resulted in the biggest change in the thread tensile properties.

The breaking elongation [%] property decreased more for Saba C-35 as compared to Saba C-80, but

Table 3: Mean values of mechanical properties of sewing threads

		Saba C-35 (80 tex)					Saba C-80 (44 tex)				
		Speed of machine					Speed of machine				
		1000 rpm	2000 rpm	3000 rpm	4000 rpm	4700 rpm	1000 rpm	2000 rpm	3000 rpm	4000 rpm	4700 rpm
Tenacity [cN/tex]	S1	50	50	50	50	50	45	45	45	45	45
	S2	50	50	48	47	45	45	44	43	43	42
	Change with respect to S1 (%)	0	0	−4	−6	−10	0.0	−2.2	−4.4	−4.4	−6.7
	S3	49	48	41	32	11	43	41	37	31	24
	Change with respect to S1 (%)	−2	−4	−18	−36	−78	−4.4	−8.9	−17.8	−31.1	−46.7
	S4	49	48	44	43	41	43	42	40	37	36
	Change with respect to S1 (%)	−2	−4	−12	−14	−18	−4.4	−6.7	−11.1	−17.8	−20.0
Breaking elongation [%]	S1	18	18	18	18	18	21	21	21	21	21
	S2	18	17.9	17.6	17.2	17	20.8	20.4	20.1	19.2	19
	Change with respect to S1 (%)	0.0	−0.6	−2.2	−4.4	−5.6	−1.0	−2.9	−4.3	−8.6	−9.5
	S3	17.5	17.2	13.6	12.2	5	20	19.5	17.4	14.5	12.4
	Change with respect to S1 (%)	−2.8	−4.4	−24.4	−32.2	−72.2	−4.8	−7.1	−17.1	−31.0	−41.0
	S4	17.6	16.2	16	15.7	14.3	19.6	19	18.2	17.3	16.8
	Change with respect to S1(%)	−2.2	−10.0	−11.1	−12.8	−20.6	−6.7	−9.5	−13.3	−17.6	−20.0
Initial modulus [N/tex]	S1	4.5	4.5	4.5	4.5	4.5	3.2	3.2	3.2	3.2	3.2
	S2	4.5	4.45	4.4	4.5	4.35	3.2	3.15	3.183	3.1	3
	Change with respect to S1 (%)	0.0	−1.1	−2.2	0.0	−3.3	0.0	−1.6	−0.5	−3.1	−6.3
	S3	4.4	4.3	4	3.1	2.7	3.1	3.1	2.85	1.8	1.4
	Change with respect to S1 (%)	−2.2	−4.4	−11.1	−31.1	−40.0	−3.1	−3.1	−10.9	−43.8	−56.3
	S4	4.4	4.4	4.2	3.6	3.3	3.1	3.1	3	2.2	2.1
	Change with respect to S1 (%)	−2.2	−2.2	−6.7	−20.0	−26.7	−3.1	−3.1	−6.3	−31.3	−34.4

again the impact was maximal at the section S3 where breaking elongation showed a 72% decrease for Saba C-35 and 41% for Saba C-80 at 4700 rpm of the machine.
The initial modulus of Saba C-80 decreased by 51% as compared to the 40% of Saba C-35 at the section S3 for 4700 rpm of the machine.

3.5 Relation between sewing speed, needle temperature and tenacity of sewing thread

Figure 13 shows that there is a strong linear relation between the needle temperature and the speed of the machine, whereas the experimental result shows a strong negative linear relationship between the speed of the machine and the tenacity of the sewing thread; at 4700 rpm of the machine, the sewing thread exhibited a nearly 70% decrease in tenacity.

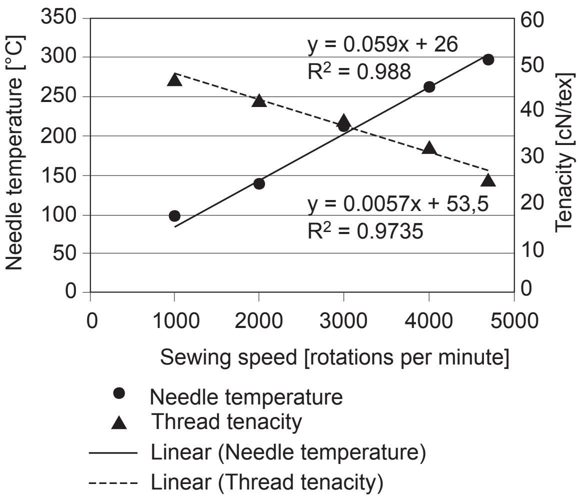

Figure 13: Needle temperature and tenacity of sewing thread

4 Conclusions

This research shows that the needle temperature has a dominant influence on the strength of the sewing thread. The hot needle mainly damages the thread when the machine stops after the sewing and when the needle is in direct contact with the thread. This needle-heat damaged thread eventually becomes a part of the next seam and leads to the loss in the seam strength. It is recommended to waste 20 cm of the thread after complete sewing in order for the thread damaged at the needle eye after the machine stoppage not to become a part of the next seam.

As thread moves from the cone to the seam, it undergoes various stresses and strain such as dynamic stress at the section S2. There is a marginal decrease in the tensile strength for the thread at 1000 and 2000 rpm of the machine, whereas the loss in the tensile strength of the thread is much more significant at 3000 rpm of the machine and higher.
The bobbin thread interaction and the needle heat are the two main causes for the reduction in the tensile strength, breaking elongation and initial modulus of the thread. The loss was greater for Saba C-35 (80 tex) polyester core spun thread, followed by Saba C-80 (44 tex) thread (cf. Table 3). The latter can be a consequence of higher friction between the needle and thicker thread, causing the needle temperature to increase. The needle temperature was by nearly 20 °C higher for Saba C-35 for all observations as compared to Saba C-80.
The thread at the section S3 underwent maximum needle heat after the machine stoppage, leading to the biggest change in the thread tensile properties. Therefore, this section thread exhibited the maximum loss in tensile property. For Saba C-80 thread, tenacity decreased to 46.7% and for Saba C-35, tenacity decreased by 78% at 4700 rpm of the machine. Breaking elongation decreased more for Saba C-35 as compared to Saba C-80, but again the impact was maximal at the section S3, where breaking elongation showed a 72% decrease for Saba C-35 and 41% for Saba C-80 at 4700 rpm of the machine.
The initial modulus of Saba C-80 decreased by 51% as compared to the 40% of Saba C-35 at the section S3 for 4700 rpm of the machine.
The section S4 thread is the seam thread pulled out precisely by cutting the bobbin thread. In this section, the loss of tensile strength was mainly due to the bobbin thread interaction and the friction of guides and tension devices on the machine; however, due to the high speed of the machine, the contact time between the thread and needle had a much smaller impact. Hence, the thread at the section S4 showed better tensile properties as compared to the section S3.

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