Influence of Sewing Speed on the Changes of Mechanical Properties of Differently Twisted and Lubricated Threads During the Process of Sewing

Andreja Rudolf, Ph.D.
Prof. **Jelka Geršak**, Ph.D.
University of Maribor, Faculty of Mechanical Engineering
Department of Textiles
Maribor, Slovenia
e-mail: andreja.rudolf@uni-mb.si

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This paper presents a research into the influence of the stitching speed on changes of the mechanical properties of the polyester core-spun sewing threads, which were twisted by different number of thread turns, and different lubrication method (in apparatus and on the galette). The dynamic loading of the threads arises during the sewing process depend on the stitching speed, that causes greater or smaller changes of the threads' mechanical properties. It was found that the expressive changes appear when the sewing process was performed at higher stitching speed, and depend also on the twist intensity and on the lubrication method employed. It was established that with increasing stitching speed increases changes in the breaking tenacity, breaking extension and elasticity modulus of the thread-twisted fibres that provokes also changes of the threads' mechanical properties after the sewing process. On the basis of the research of the threads' resistance on the dynamic loading during the sewing process at the same stitching speed it was found, that the greatest resistance offers the threads twisted with smaller number of the thread turns and threads treated with apparatus lubrication method.

Key words: *sewing thread, lubrication method, dynamic load, mechanical properties*

1. Introduction

Dynamic loading of threads caused by tensile forces, as well as resulting frictional forces during the process of sewing, have a detrimental influence on the processing properties of the threads. In the course of stitch formation process, needle thread is particularly exposed to tensional, frictional and bending loads.

The analysis of machine/technical solutions of stitch formation, including connected thread movement over guiding elements and working mechanisms of the sewing machine, shows that the thread is exposed to friction forces on the guiding elements in the area of sewing needle eye, when penetrating the fabric, and when interlacing with the bobbin thread [1].

The loads to which thread is exposed, because of bending in stitch formation process, are determined by its movement through thread guiding elements, tension regulator, take-up lever, sewing needle eye, the fabric and bobbin parts. The deformations that occur are of a problematic nature at the bend of the thread in the area of the sewing needle eye, and in the area of needle and bobbin thread interlacing [2].

Apart from the dynamic loading, the needle thread is, during the stitch formation, exposed to numerous friction loads and bending with a small bending diameter, pressure, torsion and wearing as well as to high speeds and acceleration [2, 3].

The thread must, therefore, have such properties that can overcome dynamic and thermal loads, which originate due to cyclic loads at different stitching speeds. They must not cause significant changes in thread strength.

The mechanical properties of the thread, in addition to the other constructional parameters, depend on the mechanical properties of the thread-twisted fibres, and on the twist intensity. Intensive twist imparts the necessary smoothness to the thread and resistance to rubbing, and additionally specific strength and elasticity, which the thread needs for overcoming the technologically induced forces of the sewing process.

2. The influence of thread dynamic load on the changes in mechanical properties

The analysis of stitch formation forces associated with dynamic loads, shows that thread is exposed to numerous loads on its way from the package to the formed stitch. This is reflected in the form of strength fluctuation [1]. Fluctuation in thread strength is closely connected with thread passages over the guiding elements of the sewing machine. Friction and bending occur between the needle thread and the touching areas, as well as friction with the bobbin thread. It is well known that the highest thread tension force occurs at the moment of stitch tightening [1, 4]. Analysis of the impact of stitching speed on thread dynamic load shows increased stitching speed means higher thread tensile force and higher friction between guiding elements and sewing machine working mechanisms. The consequence of this are noticed fluctuations in thread strength after the sewing process [3-5].

The range of thread strength fluctuation is a function of the acting dynamic loads on the thread and its ability to offer resistance to the effecting load. Any fluctuation in thread breaking tenacity can be assigned to the changes in the fibre mechanical properties, in regard to dynamic loading and/or in regard to the changes in thread structure. The majority of these loads are by nature cyclical, therefore thread fatigue results, associated with the fatigue of the individual fibres in the thread [6-8].

Fatigue in the fibres twisted into the thread can lead to excessively low, or, on the other hand, unacceptably high twist intensity. Too low twist intensity can, because of unsuitable coherence, cause thread flatness at transversal loading in the area of the sewing needle eye, where a number of thread fibres are directly exposed to bending and frictional forces. Thread entanglement, ties and knots, are associated with excessive intensity of the twists, leading to unacceptable deformations. An excessive number of thread twists also leads to critical transversal loading and to a lower than acceptable thread breaking tenacity. This is reflected in lower resistance to dynamic loads. An optimal number of thread twists ensures a more circular shape of the thread cross-section. Minimal contact areas between the thread and sewing needle are thus achieved, which reduces thread deformation due to the friction and rubbing with the sewing needle [5]. On the other hand, an optimal number of thread twists ensures suitable viscoelastic properties for the thread, which are necessary for proper resistance to dynamic loads during the process of sewing, as well as for resistance to loads in use, especially in wearing.

All the above indicates that the final value of breaking tenacity and extension cannot be decisive characteristics in projecting thread properties. The thread, however, should have appropriate viscoelastic properties, which are important for its behaviour at the lower loads, so that dynamic conditions can be transmitted in sewing. It is, therefore, important for the sewing process that the threads dynamic tension, which is defined as a quotient of tensile force and thread fineness, does not exceed the value of the tension at the yield point. Tensile force, when acting on the thread in the stitch formation process, causes elastic thread deformation. If dynamic thread tension exceeds the tension at the yield point, plastic deformations of the thread occur, which are reflected as fluctuations in the thread viscoelastic properties [9].

3. Experimental

The influence of the different stitching speed on its resistance to dynamic loads was investigated. The investigations included considering the changes in thread mechanical properties, as well as the properties of the fibres twisted into the thread, after the process of sewing. The influence of thread dynamic loads, dependent on stitching speed, on the changes in thread mechanical properties, as well as on the changes of individual fibres in the thread, was recorded for the purpose.

Preparing process and properties of the researched threads for this analysis are described in the paper [10]. The threads specimens, designated as ST1, ST2, ST3, were surface treated in apparatus, while the threads designated as ST4, ST5, ST6 were treated on the galette. Research of the dynamic loads on threads was performed on the same material and parameters described by [10], while the sewing process was performed at three different stitching speeds: n_1 = 2000 rpm, n_2 = 3000 rpm and n_3 = 4000 rpm, with a predetermined thread tension, which assured a faultless seam at all speeds. The needle thread was carefully taken out of the seam after sewing and individual fibres were separated from the thread filament core for measuring the changes in the threads viscoelastic properties, if any.

Measurements of dynamic loads as related to the thread tensile force were carried out on a Brother DB2 B737-913 sewing machine, using a specially developed device for measuring thread tensile force. The results obtained are given as average values of the 50 characteristic tensile force peaks at the moment of stitch tightening. Thread dynamic tension was calculated for each particular stitching speed. Measurements of the thread mechanical properties were carried out on a measuring system for measuring thread tensile loads, developed in the Laboratory for Clothing Engineering at the Faculty of Mechanical Engineering in Maribor. The average tension-extension curve was defined on the basis of these measurement results using a VILSUK

Tab.1 Static pre-tension, tensile force and dynamic tension of the analysed threads

Thread type	Stitching speed (rpm)	Static pre-tension F_{st} (N)	Tensile force F_t			Dynamic tension σ_D ($cNtex^{-1}$)
			Average value F_t (N)	Standard deviation s (N)	Variation coeff. CV (%)	
ST1	2000	1.6	1.23	0.09	7.46	4.03
	3000		1.23	0.09	7.07	4.06
	4000		1.24	0.06	4.88	4.08
ST2	2000	1.4	0.97	0.14	14.23	3.15
	3000		1.02	0.21	20.27	3.31
	4000		1.08	0.08	7.63	3.48
ST3	2000	1.4	1.06	0.15	13.75	3.36
	3000		1.07	0.20	18.72	3.39
	4000		1.07	0.08	7.66	3.40
ST4	2000	1.4	1.07	0.09	8.75	3.72
	3000		1.09	0.16	14.44	3.79
	4000		1.13	0.09	8.34	3.93
ST5	2000	1.9	1.07	0.14	12.70	3.69
	3000		0.92	0.23	25.12	3.16
	4000		1.13	0.08	7.19	3.90
ST6	2000	1.6	1.05	0.11	10.72	3.57
	3000		1.08	0.13	12.16	3.65
	4000		1.10	0.09	8.56	3.74

special computer programme, and the viscoelastic parameters of the sewing thread were evaluated [11, 12]. Measurements of the fibre mechanical properties were carried out on a Vibrodyn 400 electronic feeding dynamometer, connected to a Vibroskop 400 linear density measuring device. The dynamometer used a suitable programme to record linear density, breaking force and breaking elongation, and automatically calculated breaking tenacity, breaking extension and elasticity modulus E_0 at 1% extension. All the measurements were carried out under standard testing conditions: temperature 20 ±2 °C and 65 ±2% relative humidity, according to the ISO 2062 norm [13] for measuring the tensile loading of threads and ISO 5079 [14] for measuring the tensile loading of fibres.

4. Results and discussion

Measurement results for thread tensile force at the moment of stitch tightening, Tab.1, show that thread tensile force increases with stitching speed. The values of dynamic tension, which is a quotient of tensile force and thread linear density, show that for threads with different twist dynamic tension drops at the same stitching speed with more intensely twisted threads. This is probably due to the higher smoothness of the threads with higher twist. Alternatively, dynamic tension results of the analysed threads show an influence of the method of lubrication. Comparisons between the apparatus-lubrication and galette-lubrication show lower values of dynamic tension for the apparatus-lubricated threads. The only exception is the apparatus lubricated thread designated ST1, which has the highest friction coefficient value, static pre-tension and tensile force at all three stitching speeds.

Measurement results for the mechanical properties of the analysed threads before and after sewing are presented in Tab.2 and Fig.1, whilst Tab.3 and Fig.2 present measurement results for the mechanical properties of the fibres separated from the threads. These measurement results show the influence of stitching speed, thread twist intensity, and lubrication method on the thread mechanical properties and the separated fibres.

Analysis of the measured results for the thread mechanical properties show that the increase in stitching speed causes a decrease of the breaking tenacity value, breaking extension and, especially, elasticity modulus, see Fig.1, which also shows the highest level of change after sewing for all the analysed threads, Tab.4. The tension at the yield point is decreases after the sewing process. Furthermore, it can be seen that the tension at the yield point decreases gradually with increased stitching speeds in the cases of the threads designated ST2, ST4 and ST5, see Fig.1 and Tab.2. However, the tension at the yield point after sewing at the stitching speed of 4000 rpm is lower than before sewing for all the three threads analysed.

Similar influence of the stitching speed is also shown in the changes of the mechanical properties of the fibres twisted into threads, Tab.4. A decrease in breaking extension values and an increase in the initial elasticity modulus for the fibres of the analysed threads was perceived when increasing stitching speed, but no greater changes were caused for breaking tenacity, Fig.2 and Tab.3.

The analysis of the alterations in the threads mechanical properties after sewing shows that the changes depend on thread twist intensity, see Fig.1. The apparatus lubricated

Tab.2 Mechanical properties of the galette lubricated threads before and after sewing

Analysed properties of the threads		Thread type											
		ST4				ST5				ST6			
		Before sewing	Stitching speed (rpm)			Before sewing	Stitching speed (rpm)			Before sewing	Stitching speed (rpm)		
			2000	3000	4000		2000	3000	4000		2000	3000	4000
Breaking tenacity σ_b (cNtex^{-1})	σ_b	43.24	40.07	39.96	39.61	42.88	39.37	38.22	37.99	40.04	38.71	38.30	37.28
	s	2.97	2.94	3.12	2.42	2.59	3.12	2.78	2.81	2.80	2.58	2.63	2.53
	CV	6.87	7.34	7.80	6.10	20.84	7.93	7.26	7.39	13.83	6.67	6.85	6.78
Breaking extension ε_b (%)	ε_b	18.85	17.99	17.92	16.81	19.18	18.59	17.66	16.77	20.23	19.86	19.18	18.76
	s	0.39	0.46	0.43	0.64	0.54	0.49	0.67	0.67	0.44	0.45	0.46	0.51
	CV	2.05	2.55	2.41	3.82	1.25	2.61	3.81	4.02	2.18	2.26	2.40	2.71
Tension in yield point σ_y (cNtex^{-1})		6.13	5.75	5.72	5.87	5.97	5.73	5.91	5.97	5.62	5.75	5.58	5.61
Extension ε_y (%)		2.11	2.49	2.52	2.70	2.29	2.70	2.89	2.92	2.39	3.13	3.04	3.09
Elasticity modulus E_0 (cNtex^{-1})		3.04	2.40	2.36	2.25	2.72	2.22	2.13	2.14	2.41	1.90	1.90	1.8794
Extension ε_0 (%)		0.94	1.22	1.25	1.40	1.04	1.37	1.51	1.64	1.06	1.54	1.54	1.61
Modulus E_1 (cNtex^{-1})		0.80	1.00	1.21	1.27	0.78	1.02	1.19	1.39	0.75	0.88	0.94	1.07
Extension ε_1 (%)		4.64	4.94	4.95	4.84	5.00	5.22	5.14	4.88	5.33	5.91	5.71	5.54
Modulus E_2 (cNtex^{-1})		3.89	3.83	3.82	3.79	3.85	3.60	3.58	3.55	3.39	3.35	3.36	3.34
Extension ε_2 (%)		15.35	14.90	14.85	13.78	16.41	15.18	14.41	13.46	17.10	16.58	16.13	15.59

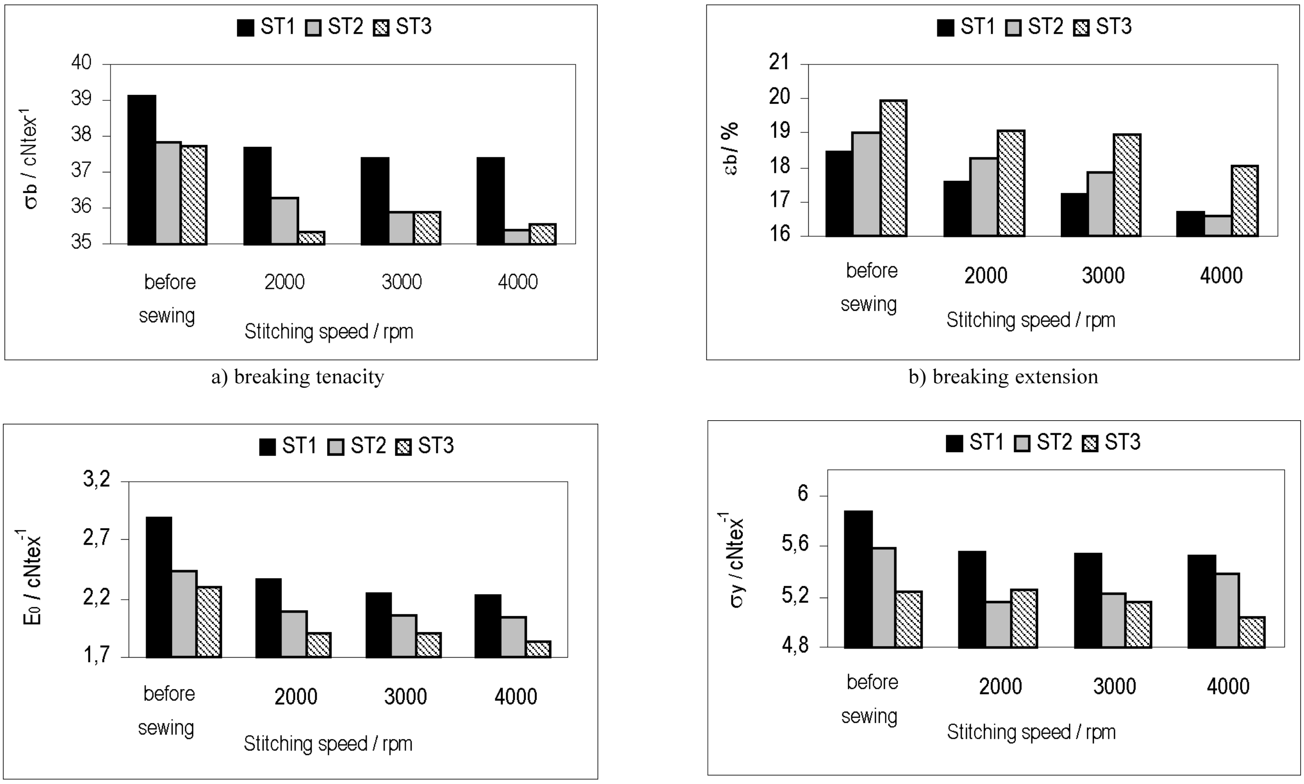
thread designated ST1, which has a lower nominal number of twists (800 tm^{-1}), still has, after sewing at the highest stitching speed of 4000 rpm, highest breaking tenacity value, tension at the yield point and modulus E_0 and E_2, Fig.1. Similar dependence is also shown for the galette lubricated thread designated ST4, where tension value at the yield point is a little bit lower.

The analysis of the results obtained for the mechanical properties of the fibres separated from the threads after sewing show the influence of twist intensity on the changes in mechanical properties. The fibres separated from threads designated ST1 and ST4, after sewing at the stitching speed of 4000 rpm exhibit highest breaking tenacity and elasticity modulus, Tab.3 and Fig.2. This means that the threads, in spite of having the highest dynamic tension during sewing, still keep the highest values of mechanical properties after loading, which is essential for further application of the thread in the forming stitches.

Investigation of the influence of twist intensity shows that higher twist intensity offers better smoothness of the thread and thus lower

Tab.3 Mechanical properties of the fibres separated from the galette lubricated threads before and after sewing

Analysed properties of the fibres		Thread type											
		ST4				ST5				ST6			
		Before sewing	Stitching speed rpm			Before sewing	Stitching speed rpm			Before sewing	Stitching speed rpm		
			2000	3000	4000		2000	3000	4000		2000	3000	4000
Breaking tenacity σ_b (cNtex^{-1})	σ_b	64.0	64.7	63.8	64.2	63.6	62.7	62.0	58.1	61.8	57.0	60.0	59.7
	S	3.1	2.4	2.3	3.4	2.7	3.7	3.2	8.2	2.3	6.6	4.5	3.1
	CV	4.9	3.7	3.6	5.3	4.2	5.9	5.1	14.1	3.7	11.6	7.5	5.3
Breaking extension ε_b (%)	ε_b	20.4	19.0	19.6	16.8	20.6	20.4	18.5	17.2	21.9	18.9	19.0	18.5
	S	1.8	1.7	1.9	1.6	1.4	2.0	1.8	2.8	1.7	2.5	2.1	1.6
	CV	8.8	8.7	9.4	9.7	6.9	9.9	9.9	16.3	7.5	13.1	11.1	8.6
Elasticity modulus (at 1%) E_0 (cNtex^{-1})	E_0	130	211	179	302	88	112	163	141	74	93	95	95
	S	21	57	37	86	17	14	39	24	6	17	15	9
	CV	15.9	27.1	20.7	22.6	19.7	12.7	23.8	16.7	8.2	18.7	15.7	9.1



a) breaking tenacity

b) breaking extension

c) elasticity modulus

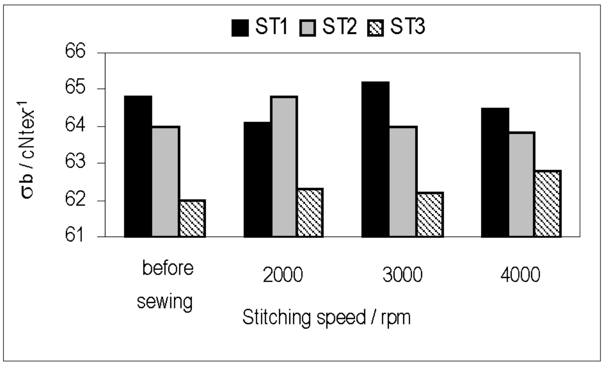
d) tension at the yield point

Fig.1 The influence of stitching speed and twist intensity on mechanical properties of the apparatus lubricated threads

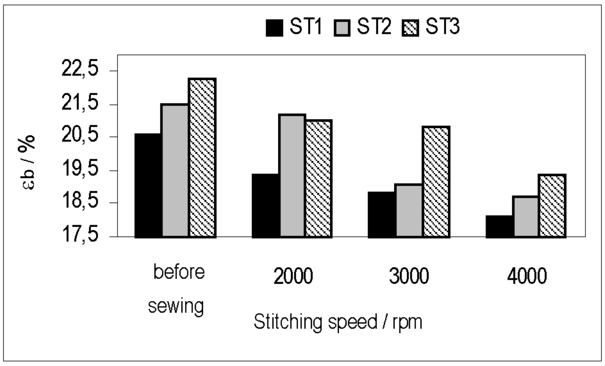
Tab.4 The changes in mechanical properties of the threads and separated fibres after loading in sewing (minus sign signifies increase of a particular mechanical property)

Thread type	Stitching speed (rpm)	Breaking tenacity change $\Delta\sigma_b$ (%)		Breaking extension change $\Delta\varepsilon_b$ (%)		Elasticity modulus change ΔE_0 (%)		Tension at yield point change $\Delta\sigma_y$ (%)
		Thread	Fibre	Thread	Fibre	Thread	Fibre	Thread
ST1	2000	3.62	1.08	4.68	5.83	18.15	-73.77	5.33
	3000	4.36	-0.62	6.49	8.74	22.13	-62.30	5.76
	4000	4.31	0.46	9.21	12.14	22.75	-151.64	6.03
ST2	2000	4.14	-1.25	3.80	1.40	13.64	-66.67	7.54
	3000	5.11	0.00	6.04	11.16	15.08	-40.48	6.43
	4000	6.46	0.31	12.70	13.02	15.90	-61.90	3.51
ST3	2000	6.39	-0.48	4.48	5.83	16.59	-11.84	-0.27
	3000	4.95	-0.32	5.07	6.73	16.68	-19.74	1.49
	4000	5.79	-1.29	9.81	13.00	19.78	-48.68	3.82
ST4	2000	7.33	-1.09	4.60	6.86	20.92	-62.31	6.11
	3000	7.59	0.31	4.94	3.92	22.41	-37.69	6.71
	4000	8.41	-0.31	10.83	17.65	25.77	-132.31	4.11
ST5	2000	8.19	1.42	3.06	0.97	18.55	-27.27	4.05
	3000	10.88	2.52	7.92	10.19	21.70	-85.23	1.05
	4000	11.42	8.65	12.57	16.50	21.48	-60.23	0.10
ST6	2000	3.29	7.77	1.87	13.70	21.11	-25.68	-2.24
	3000	4.32	2.91	5.21	13.24	20.98	-28.38	0.69
	4000	6.86	2.40	7.28	15.53	22.14	-28.38	0.18

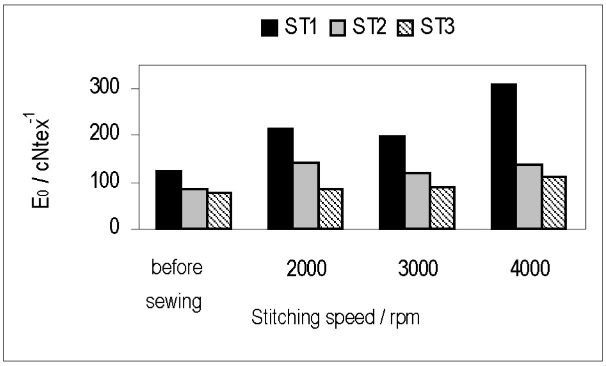
tensile force when sewing. We suppose that simultaneously the lower friction forces in rubbing of the thread arise because of greater number of the smaller contact areas with the guiding elements and working mechanisms of the sewing machine. On this account after the sewing process the smaller chan-



a) breaking tenacity



b) breaking extension



c) elasticity modulus

Fig.2 The influence of stitching speed and the number of thread turns on mechanical properties of the fibres separated from the apparatus lubricated threads

ges of the breaking tenacity and breaking extension originate for the threads, which were twisted with smaller number of turns. This is significant for all stitching speeds. This means that thread's mechanical properties have greater influence on its resistance to dynamic load compared with its surface characteristics.

The analysis of the results for tension at the yield point σ_y and threads dynamic tension σ_D at the moment of stitch tightening, Tab.1 and 2 and Fig.1, shows, that dynamic tension does not exceed the tension value at the yield point. This is also reflected in the small change in tension at the yield point for all the analysed threads after sewing. The fact is that the thread dynamic tension during sewing exceeds the value of elasticity modulus, which is reflected in the changes, i.e. decrease in breaking tenacity and extension for all the analysed threads, as well as for the fibres twisted into threads.

Additionally, the analysis of the results shows the importance of lubrication method and its impact on the thread and separated fibres mechanical properties, after sewing. Considerable change in breaking tenacity is recorded for galette-lubricated threads, which, after sewing at the stitching speed of 4000 rpm, exhibit the values from 8.86% to 11.42%, Tab.4. The apparatus-lubricated threads, however, exhibit breaking tenacity changes of only 6.46% maximum. Separated fibres from galette-lubricated threads also show greater breaking tenacity changes, i.e. up to 8.65 %, whilst the apparatus-lubricated threads change for only 1.29%. The change in breaking extension for the separated fibres moves from 12.14 to 13.02% at the stitching speed of 4000 rpm for the apparatus-lubricated threads and from 15.53 to 17.65% for galette-lubricated ones, which also confirms the importance of the lubrication method applied. Elasticity modulus changes from 15.90 to 22.75% for the apparatus-lubricated threads at the highest stitching speed, whilst the change is more noticeable for the galette lubricated threads, from 21.14 to 25.77%. The individual fibres exhibit more significant changes in elasticity modulus, which is on average somewhat higher for the apparatus-lubricated threads, Tab.4. Having this in mind, it can be concluded that the galette-lubricated threads are less resistant to dynamic loads than the apparatus-lubricated ones.

It can be concluded that the changes in thread mechanical properties are due to dynamic loading of the fibres twisted into threads, and the reason is a structural damage caused to the threads and fibres, shown to be much more intensive at higher stitching speeds. It can be seen that more noticeable changes are caused because of the dynamic load, especially significant for the decrease in elasticity modulus, which is also reflected in the decrease of breaking tenacity and breaking extension for the threads, as well as for the fibres twisted into them. A comparison of the threads analysed shows that the threads designated ST1 and ST4, having the lowest twist (779.68 tm^{-1} and 752.96 tm^{-1} respectively), in spite of the highest dynamic tension during sewing at all the stitching speeds used, still exhibit the highest breaking tenacity values, elasticity modulus and tension at the yield point. The same holds for the fibres separated from these threads. It can reasonably be expected that the threads that offer the highest, and for the sewing necessary, resistance at lower loads, will also offer good resistance against further loads in the finished article of clothing.

5. Conclusions

On the basis of the analysis of the investigation results it can be concluded:

- Dynamic loads of the threads depend on the stitching speed, number of the thread turns and method of the surface treatment; with increasing stitching speed the tensile force of the threads increases. Lower tensile force is characteristic for the threads twisted with higher number of turns and for the apparatus lubricated threads, which is attributed to greater smoothness of those threads.
- Resistance of the threads on dynamic loads depend on the stitching speed and threads' twist intensity, which have influence on changes of the threads' mechanical properties, as well as on changes of the threads' twisted fibres after the sewing process. With increasing stitching speed increases the tensile and friction load of the threads, and consequently, an increase in changes of the threads' and fibres' mechanical properties arises. Threads with lowest number of thread turns, which are achieved during the sewing process higher tensile force, preserve after the sewing process superior mechanical properties. This means that on resistance of the researched thread on loads during the sewing process have greater influence its mechanical properties in comparison with its surface characteristics. This is confirmed by analysis of changes of the threads mechanical properties after the sewing process at different stitching speeds.

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