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Tensile Properties of Knotted Line Flax Spun Yarns

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Abstract
The various tensile properties of knotted line flax spun yarns have been studied by applying a tensile test for four different structures of knots, namely the square knot, overhand knot, weaver's knot, and fisherman's knot. Four types, i.e. 50 tex (A – bleached, B – grey) and 68 tex (C – bleached, D – grey) samples, each spun from line flax, were used for experiment. In this study, the values of breaking force, tenacity, elongation at break, work of break, and specific work of break of the knotted yarns are presented. In addition, the coefficients of retention for the breaking force, elongation at break and work of break are discussed. According to this study, the tensile behaviour of knotted yarns is highly affected by the knot structure. Meanwhile the bleached knotted yarns and the grey knotted yarns exhibited rather similar tensile properties or only small differences were established.

Key words: *knot, knotted yarn, line flax spun yarn, tensile test.*

Introduction

The linking of two ends of yarn by making knots is a rather widespread operation of winding, warping, tying or weaving processes after yarn break or package end. Other methods of producing a yarn joint (e.g., splicing, gluing, wrapping, and welding) are rarely used and are also not suitable for all possible cases to replace the linking by means of knots. For instance, during winding, when a detected fault is cut from a yarn, the resulting yarn ends are pieced together by knotting or splicing. The splicing technique of the ends is a very promising way for the winding operation of some types of spun yarns, such as worsted or cotton yarns, but for some other textile yarns and manufacturing operations, such as the elimination of warp break on a weaving machine, this technique is impossible. Other possible ways of knotting application deal with the use of knots for connecting the ends of rope structures, performing surgical operations, etc.

Literature survey on tensile performance studies of various knotted structures

Various factors such as knot structure and yarn type, among others, are the basic reasons why knotted structures differ from initial yarns with respect to their tensile properties. Yarn geometry, as an important factor of the mechanical properties of yarn, is the subject matter of many scientific discussions [1]. Knots are especially important for many users - textile workers, surgeons, climbers, etc. The mechanical properties of knotted materials may be identified as critical to usability. For instance, suitable tensile behaviour for textile yarns is a basic requirement for good processability, i.e. weaveability and knittability. Therefore study of the influence of knot structure on strength and other tensile properties of various kinds of yarns such as filament yarns, spun yarns, ropes, etc., has been attempted by various researches over the years [2 - 12]. Slippage, untying, and breaking are important phenomena for the performance of knotted yarns. The tensile forces exerted on a tied yarn are converted into shear forces by the configuration of the knot and finally rupture the yarn. This influence is very complex and diverse in the individual knot structures and types of yarns. Another problem concerns the localization of breakage points. This localization results from joint contributions of loading, bending and friction forces into a complex process of knot breakage [13].

To evaluate the knot strength, a breaking force is applied as a rule. However, a coefficient of strength retention was applied by Cheng & Lam [14, 15] and also by Lewandowski & Drobina [16] in investigations of spliced joints of wool, cotton and polyester (PES)/cotton spun yarns. In addition, similar coefficients of retention may be applied for other mechanical indices, where the different tensile behaviour of knotted yarns is compared with original specimens. Lewandowski & Drobina [16] used an analogous coefficient for values of elongation at break.

The tensile behaviour of knotted textiles is highly affected by the knot type and other factors of knot making. Handbooks on knots and manuals on ropes give information on appropriate knots to use [2, 10, 17, 18]. Different names, categories and information about the typical use of knots have been reported. Rock climbers and anglers know that a simple overhand knot tied on a mountaineering rope or a fishing line weakens it substantially [10]. Friction, pressure, adverse angles and sharp turns weaken ropes with knots [2]. Sharp bends in knots result in some fibres being loaded much more than others – a stress concentration occurs. Thus knots with more gradual bends, causing less stress concentration, must be used. Tensile tests of some rope structures showed that the percent of breaking strength rated ranges from 80 - 90% for an anchor bend to 43 - 47% for a square (reef) knot [2, 3]. Pieranski et al. [13] performed studies demonstrating that the main reason for the weakening of a knotted string is the curvature thereof.

Some data on knot structures and tensile behaviour for textile knotted yarns are presented in works [4, 9, 11, 19 - 22]. In the opinion of Lawrence [4], the fisherman's knot is suitable for most yarns. The high durability of the fisherman's knot was also noted by Matukonis et al. [19]. Meanwhile, the weaver's knot is

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more appropriate for short-staple yarns as it is smaller, but it slips more easily when under tension [4]. As an additional geometrical feature, a length of knot tails can be mentioned. For instance, Busova & Minenko [20] noted that the maximum possible length of knot ends for linen spun yarns is 1 cm. Some automatic tying machines [21] can knot extremely short tails of yarns (5 mm). Hlavata & Pokorna [11] studied cotton yarn structures with the weaver's knot and fisherman's knot with tails of 11 mm and 7 mm, respectively. Adanur [21] noted that improper knotting can become critical to good weaving performance. Kovačević et al. [22] investigated various mechanical and geometrical properties of three types of textile knots, namely the weaver's knot, overhand knot, and square knot. Based on the mechanical yarn properties and knot dimensions, it was concluded which knot type is for which yarn most suitable. In this study, cotton, wool spun yarns as well as PES filament yarns before knotting and after knotting were compared. In this paper, the weaver's knot showed the highest breaking force for each type of yarn. Cybovskij & Milasius [9] reported on an investigation of knots of various technical yarns and their strength. In this report, the weaver's knot, which is often used in textiles, is not the most powerful knot. The strength for this knot is only 14 - 40% of the original yarn strength. The fisherman's and shoemaker's knots have been recommended for usage in high strength yarns, such as paraaramid, blended para- and metaaramid, high-strength PES and polyamidimid.

One more series of investigations [5 - 8, 23] focused on the properties of knots for medical application. Such knots as the previously mentioned square knot, fisherman's knot and also other modifications of knotted structures may be suitable examples for this area of use. Hockenberger & Karaca [5] studied the knot performance of monofilament and braided polyamide (PA) sutures. In this study, the square and granny knots were chosen for comparison. The effect of knot geometry on the strength of laparoscopic slip knots was also discussed in a work published by Sharp et al. [6]. As evident from this study, the 4S knot and fisherman's knot showed the highest strength. The influence of the surgeons tying technique on knot security was studied by Batra et al. [23]. Using an Instron (R) tensile tester and a portable tensiometer, knot security was tested for monofilament and multifilament PA sutures using four-throw square knots. A study of the knot performance of four different sutures – silk, PES, PA, and polypropylene (PP) – by applying square knots with two and three throws was presented by Bayraktar & Hockenberger [7]. In this paper, the results are given as stress-elongation graphic, knot slippage, and knot break values. Some studies of the tensile performance of non-sterile suture monofilaments affected by test conditions are also given by Heward et al. [8]. This study showed that the highest mean ultimate strain of each knotted monofilament type at all gauge lengths and crosshead speeds was exhibited by the granny knot. The results for this knot differed from all other samples, such as the square knot, surgeon's square knot, and surgeon's granny knot.

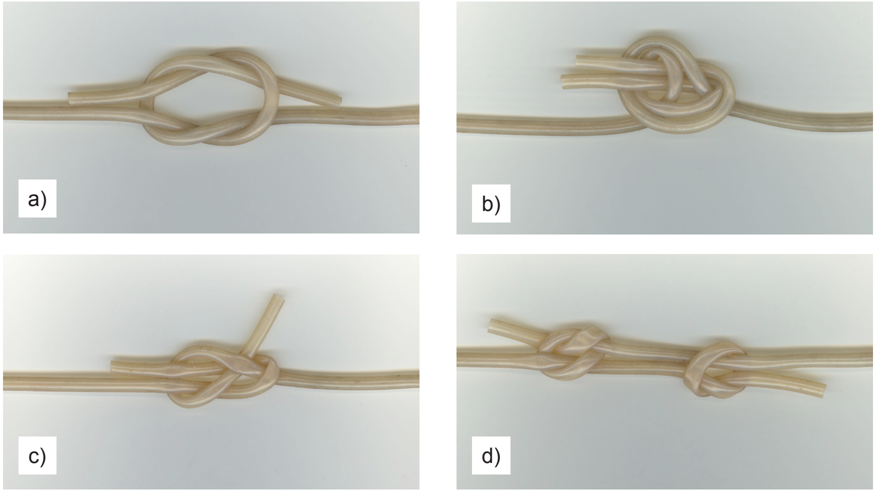

Figure 1. *Models of knotted structures: a - square, b – overhand, c – weaver's, d – fisherman's.*

Table 1. *Variants of knotted samples.*

Type of spun yarn	Variants of knotted samples			
	a – square knot	b – overhand knot	c – weaver's knot	d – fisherman's knot
A – 50 tex bleached spun yarn	Aa	Ab	Ac	Ad
B – 50 tex grey spun yarn	Ba	Bb	Bc	Bd
C – 68 tex bleached spun yarn	Ca	Cb	Cc	Cd
D – 68 tex grey spun yarn	Da	Db	Dc	Dd

The current survey on various studies of knotted structures showed that the type of knot as well as the yarn structure affect the tensile behaviour in a rather complex way. However, there is limited experimental data to understand the tensile properties of knotted linen spun yarns. Since the mechanical properties of linen spun yarns are not suitable for very good performance during weaving or in other processes of textile materials manufacturing, the tensile properties of these yarns, especially with defects such as knots, is a matter of great importance. Here we present some experiments on knotted yarns made from line flax and examine various tensile features of knot performance for some types of structures.

Experimental

Samples

The current study deals with the investigation of four different structures of knots: the square (reef) knot, overhand knot, weaver's knot, and fisherman's knot, as these types are usually used for textile yarns [4, 9, 19]. The types of knotted structures (models) are shown in ***Figures 1.a, 1.b, 1.c, and 1.d***, respectively. The square knot (***Figure 1.a***) is a simple binding knot with visually appealing symmetry. The overhand knot (***Figure 1.b***) is an easily tied asymmetric structure. Contrary to the square knot with parallel tails, the weaver's knot (***Figure 1.c***) has crossed tails. In this structure, both free ends are arranged on the same side of the knot. In the fisherman's knot (***Figure 1.d***), each line is tied in an overhand knot around the other line.

In our experimental research, sixteen variants of knotted samples comprising

Table 2. *Breaking force of knotted samples.*

Type of spun yarn	Values of breaking force, cN			
	for knot a	for knot b	for knot c	for knot d
A	475.5	724.6	596.4	792.2
B	473.1	708.6	432.4	728.2
C	681.2	1069.5	699.4	1105.3
D	665.7	1056.2	743.8	1210.0

Table 3. *Breaking tenacity of knotted samples.*

Type of spun yarn	Values of breaking tenacity, cN/tex			
	for knot a	for knot b	for knot c	for knot d
A	9.1	13.8	11.4	15.1
B	9.5	14.3	8.7	14.7
C	9.9	15.5	10.1	16.0
D	9.3	14.7	10.4	16.9

Table 4. *Elongation at break of knotted samples.*

Type of spun yarn	Values of elongation at break, %			
	for knot a	for knot b	for knot c	for knot d
A	1.1	1.7	1.6	2.0
B	1.5	2.2	1.6	2.3
C	1.7	2.0	1.5	2.3
D	1.8	2.5	2.1	2.5

Table 5. *Work of break of knotted samples.*

Type of spun yarn	Values of work of break, J			
	for knot a	for knot b	for knot c	for knot d
A	0.0162	0.0310	0.0250	0.0380
B	0.0213	0.0369	0.0192	0.0409
C	0.0346	0.0499	0.0298	0.0598
D	0.0367	0.0589	0.0420	0.0742

Table 6. *Specific work of break of knotted samples.*

Type of spun yarn	Values of specific work of break, J/tex			
	for knot a	for knot b	for knot c	for knot d
A	0.00031	0.00059	0.00047	0.00073
B	0.00043	0.00074	0.00038	0.00082
C	0.00050	0.00072	0.00043	0.00087
D	0.00051	0.00082	0.00059	0.00103

four types of commercially available line flax spun yarns of different linear density, as well as bleached or grey (natural) samples, i.e. *A*, *B*, *C*, and *D,* as shown in ***Table 1*** (see page 49), were used. The specimens with four types of different knots were tied for the test, namely *a* – the square knot, *b* - the overhand knot, *c* - the weaver's knot, and *d* - the fisherman's knot. Knot ends with a length of 7 mm were prepared for each specimen. Knots *a* and *c* were tied manually, and the samples with knots *b* and *d* were prepared by means of a hand knotter.

Test conditions methodology

A Zwick (Germany) tensile tester was used to test the tensile properties of all the original and knotted yarns. The specimen length was set at 500 mm, and a standard pretension was applied [24]. The number of measurements, from which the results were obtained, was 60 for each combination. A constant rate of specimen extension of 100% per minute [24] was used. For the knot strength test, the specimens were mounted in the clamps in such a way that a knot of the yarn was exactly in the middle of the clamp distance in the tensile tester. While performing the tests of properties of knotted structures we took into account only those measurements in which the rupture of yarn was situated exactly at the place of the knot. During the test, the slippage of specimens was checked as described in [24], and the conventional atmospheres for testing were as specified in [25].

We determined the following quantities of original and knotted yarns: breaking force cN, tenacity cN/tex, elongation at break %, work of break J, and specific work of break J/tex. Force-elongation curves were also recorded. If calculation of tenacity or specific work of break was required, the actual linear density of each sample was determined in a conventional way [29]. To observe the remainder of the tensile properties of the yarns after knotting, the coefficients of retention (%) for the following indices: breaking force, elongation at break and work of break were studied.

The results obtained were compared according to the Student's test value t [27, 28]. The t value calculated was compared with that of the Student's test t_α, where α is the confidence level. The values t_α for $\alpha = 0.95$ and $\alpha = 0.99$ were applied in the current study. If $t < t_{95}$, the difference between the results is not significant. A case of $t > t_{99}$ was treated as an indication of a significant difference. If $t_{95} \le t \le t_{99}$, the difference between the data discussed is not proved.

Results and discussion

Different variants of knotted samples showed rather dissimilar behaviour with respect to the quantities of the tensile test. The properties are listed in ***Tables 2 - 6***. The main trends for the results listed are in line with the geometry of the above-mentioned types of knotted structures from ***Figure 1***, where the tails of knots *a* and *c* interact to a smaller degree compared with those of knots *b* and *d*.

It is evident from ***Table 2*** that among the various kinds of knots, square knot *a* is generally the weakest knot with respect to the breaking force. The average values of the breaking force for other knots are greater on a different scale compared with the above-mentioned variants. For instance, the average breaking force for the weaver's knot *c* differs from the weakest one by 7% only. In this case, we have $t < t_{95}$. Meanwhile, the breaking force of the overhand knot *b* was observed to be greater than 55%, and Student's test value is $t > t_{99}$. In this study, the fisherman's knot *d* is the most powerful. The values of the breaking force differ from those of the weakest knot by approximately

67%. Thus a significant difference was observed.

Variants of knotted samples with less linear density (***Table 2***): *A* and *B*, exhibited a smaller degree of breaking force, whereas other variants with a greater linear density: *C* and *D*, showed higher strength, i.e. these values are in strong dependence on the linear density. Comparing the results of knotted samples for bleached spun yarns *A* and *C* with those for grey spun yarns *B* and *D*, we can see that mostly the breaking force for bleached samples only slightly exceeds that for grey variants. As a rule, the breaking force of the samples tested differed in the margins of errors, i.e. the bleached samples have a breaking force of the order of the grey samples ($t < t_{95}$).

As might be expected, ***Table 3*** shows that the same above-mentioned trends for different types of knots as well as for bleached and grey samples were also observed for tenacity. However, contrary to the previous results for the breaking force, tenacity is very similar for all types of yarns, i.e. *A*, *B*, *C*, and *D*. Evidently, for the most part this trend is conditioned by the same type of line flax.

Table 4 demonstrates how knot geometry contributes to the elongation at break. From the data presented it is evident that the elongation is lowest for samples with a square knot *a* and weaver's knot *c*. As $t < t_{95}$, insignificant differences were observed. This property may be conditioned by the minimum quantity of yarn length necessary for making knots *a* and *c*. Meanwhile the elongation at break for other knots such as the overhand knot *b* and, especially, the fisherman's knot *d* tends upwards significantly ($t > t_{99}$). This unique trend is related to the additional elongation of knotted specimens during the tensile test. Obviously the actual length of a yarn in the specimen with a fisherman's knot is greater when compared with that for other types of knots. Besides this, additional frictional resistance acts on the tensile process. We can also expect that because of the shortest length of a yarn for the square knot, this specimen has the lowermost elongation at break. One more reason for the hastened breakage of the knotted specimen may be stress concentration at the place of the knot.

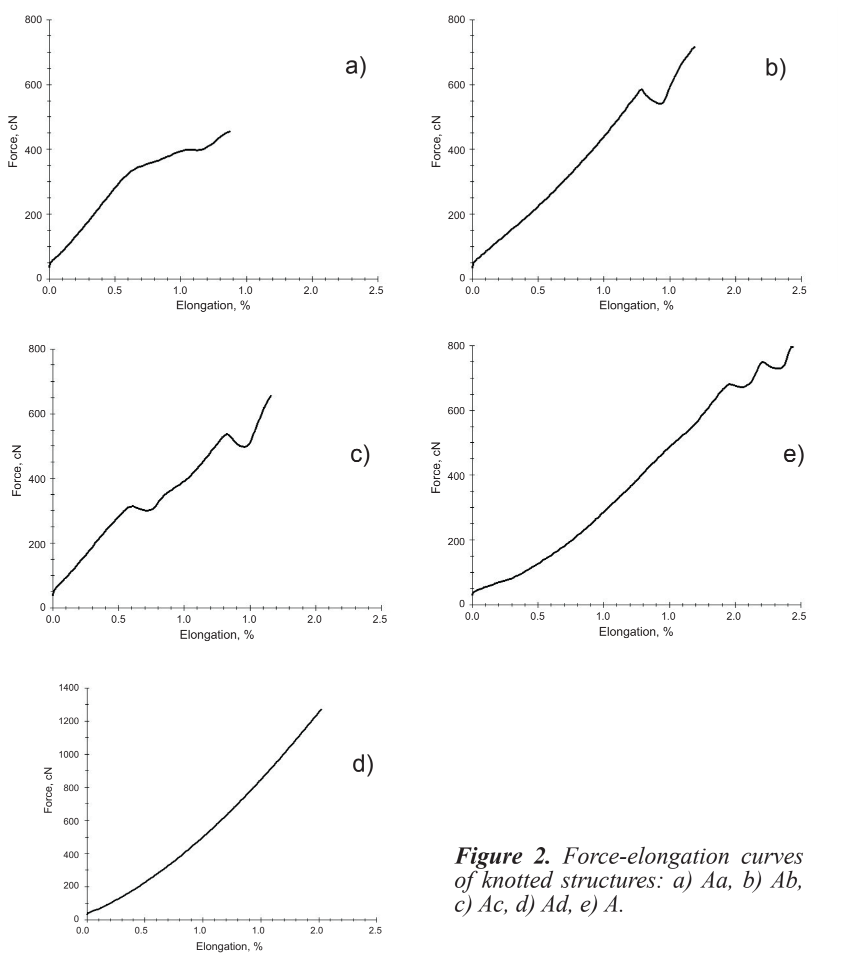

Figure 2. *Force-elongation curves of knotted structures: a) Aa, b) Ab, c) Ac, d) Ad, e) A.*

We also observed different elongation at break of bleached and grey knotted yarns. Despite the very similar elongation at break of the original spun yarns, the grey knotted samples' had a tendency to break at greater elongation as compared to the bleached knotted samples. Perhaps the phenomena of friction with different knot slippage are connected with these results. In other words, bleached yarn has higher surface evenness than that of grey yarn. As seen from ***Table 4***, the elongation at break for yarns *C* and *D* is greater if compared with yarns *A* and *B*. This peculiarity may be conditioned by the different actual length of thin and thick yarns used for tying the knots.

In ***Table 5*** (see page 50), results of the work of break of the knotted samples are given. With respect to this index, it is evident that the samples with a square knot *a*, i.e. *Aa*, *Ba*, *Ca*, and *Da* have the smallest values. The values for samples with a weaver's knot *c* have a rather small deviation (7%) from samples for knot *a*, as confirmed by the Student's test. Meanwhile other knots such as the overhand knot *b* and fisherman's knot *d* exhibited considerably greater values of work of break, i.e. $t > t_{99}$. These knots show a difference of about 63% and 95%, respectively, when compared with the square knot *a*. Results of the work of break for samples of different linear density differ in a larger scale than the linear density. This fact is visible from ***Table 6,*** where values of the specific work of the knotted samples are given. ***Tables 5*** and ***6*** also show that in many cases the grey knotted yarns (*B* and *D*) have, to some extent, greater values of work of break as well as quantities of specific work of break compared with those for the bleached spun yarns (*A* and *C*). Obviously this trend is connected with the above-mentioned different slippage of these samples.

The tensile properties of the knotted yarns discussed above are also visible from the graphs (***Figure 2.a, 2.b, 2.c, and 2.d***), where typical force-elongation curves for samples *Aa*, *Ab*, *Ac*, and *Ad* are shown. These curves have evident quantitative and qualitative differences if compared with that for knotless variant *A* (***Figure 2.e***). For instance, in the graphs

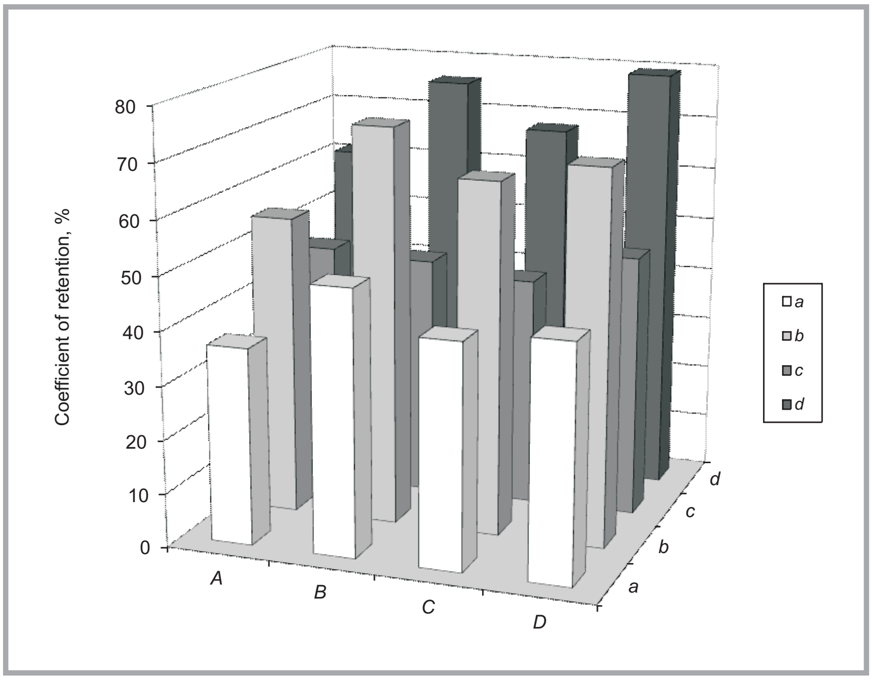

Figure 4. Coefficients of retention for the breaking force of different knotted samples: A, B, C, D – types of spun yarns; a, b, c, d – types of knots.

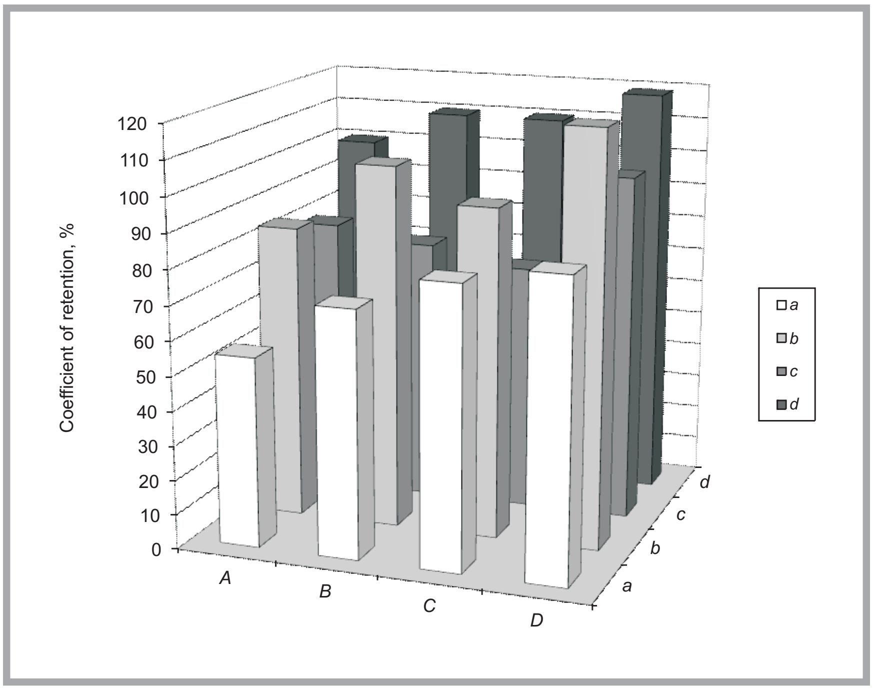

Figure 5. Coefficients of retention for elongation at break of different knotted samples: A, B, C, D – types of spun yarns; a, b, c, d – types of knots.

of knotted variants, rather visible fluctuations of the force were observed.

The values of coefficients of retention for the breaking force, elongation at break and work of break of different knotted samples are shown in ***Figures 3 - 5***, respectively. In the current stage of the study, values for the knotless samples, i.e. the initial parameters have been assumed at a level of 100%.

Figure 3 shows that the percentage of the initial breaking force ranges from 37 - 49% for a square knot *a* to 61 - 80% for a fisherman's knot *d*. Hence the square knot for line flax spun yarns exhibited a coefficient of retention close to the rope structures mentioned earlier [2 - 4]. The strength of the weaver's knot *c* (***Figure 3***) is 43 - 49%; this index for the overhand knot *b* fluctuated between 56% and 74% of the original yarn strength. Examination of the weaver's knot for the breaking force also shows (see ***Figure 3***) that the line flax spun yarns have higher retention than the various technical yarns previously mentioned [9].

It is evident from ***Figure 4*** that the values of coefficients of retention for elongation at break are greater compared with those for the breaking force (see ***Figure 3***). This trend was observed for all samples tested. The samples with a weaver's knot *c* have a tendency to break at an elongation smaller than that of the original yarns. In this case, the values of coefficients of retention were 80 - 88%. Other knotted samples, such as with a square knot *a*, overhand knot *b* and fisherman's knot *d*, sometimes have values of elongation higher than the initial values. In our opinion, additional elongation may be influenced by the slippage of knot ends during stretching.

Earlier analysis of ***Figures 3*** and ***4*** had shown that the knot type could have a strong influence on the values of coefficients of retention for the breaking force and elongation at break. ***Figure 5*** shows that all these trends, to a certain extent, have been revealed in the values of the coefficient of retention for the work of break of the knotted samples tested. As a prevailing trend for the knotted samples, a reduction in the work of break was observed. However, because of additional elongation of some knotted samples (for instance, knot *d*), this reduction was not so markedly displayed as it had been for the breaking force.

It is also evident from ***Figures 3 - 5*** that mostly the bleached knotted samples have fewer smaller coefficients of retention compared with those for the grey knotted samples. In our opinion, these differences may be connected with the frictional behaviour of the yarns tested.

Conclusions

According to this study of line flax spun yarns, the tensile behaviour of knotted yarns is greatly affected by the knot structure. The fisherman's knot shows the best tensile properties for line flax spun yarns, while other knots, such as the overhand knot, weaver's knot and, especially, the square knot, exhibited considerably worse properties than the fisherman's knot.

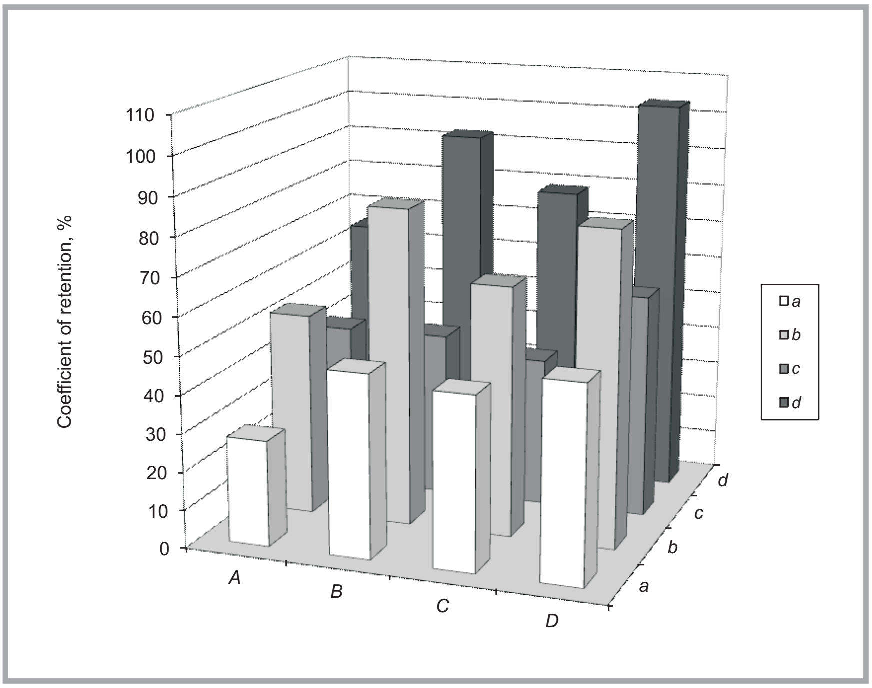

***Figure 6.** Coefficients of retention for work of break of different knotted samples: A, B, C, D – types of spun yarns; a, b, c, d – types of knots.*

Analysis had shown that the tensile properties of all the knotted line flax spun yarns tested essentially differ from the original (without knots) spun yarns. However, the values of coefficients of retention are different for the tensile indices tested. For instance, the coefficient of retention for the breaking force ranges between 37% and 80%. The values of coefficients of retention for the elongation at break are greater compared with those for the breaking force. For instance, for a weaver's knot these values were 80 - 88%. Moreover because of the additional slippage of tails in the knot structure, some types of the knotted samples tend to break at higher elongation compared with that of the original samples. As a prevailing trend for the knotted samples, a reduction in the work of break was observed.

The bleached knotted yarns exhibited a breaking force similar to that of the grey knotted yarns. In many cases, the grey knotted structures have, to some extent, greater values of work of break, specific work of break and elongation at break compared with those of the bleached knotted structures.

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References

1. Petrulis D. *Models of Fibres and Yarns Geometry*. Scientific monograph. Technologija, 2009.
2. McKenna HA, Hearle JWS, O'Hear N. *Handbook of Fibre Rope Technology.* Woodhead Publishing Limited, 2004.
3. Columbian Rope Company. Efficiencies of Common Rope Splices, Knots, Bends and Hitches. Product Information Bulletin, Columbian Rope Company, Guntown, Mississipi, 1986.
4. Lawrence CA. *Fundamentals of Spun Yarn Technology*. CRC Press, 2003.
5. Hockenberger AS, Karaca E. Effect of Suture Structure on Knot Performance of Polyamide Sutures. *Indian Journal of Fibre & Textile Research* 2004; 29: 271-277.
6. Sharp HT, Dorsey JH, Chovan JD, Holtz PM. The Effect of Knot Geometry on the Strength of Laparoscopic Slip Knots. *Obstetrics and Gynaecology* 1996; 88: 408-411.
7. Bayraktar EK, Hockenberger AS. Investigating the Knot Performance of Silk, Polyamide, Polyester, and Polypropylene Sutures. *Textile Research Journal* 2001; 71: 435-440.
8. Heward AG, Laing RM, Carr DJ, Niven BE. Tensile Performance of Nonsterile Suture Monofilaments Affected by Test Conditions. *Textile Research Journal* 2004; 74: 83-90.
9. Cybovskij A, Milašius R. Mazgo sandaros įtaka techninių siūlų stiprumui, „Gaminių technologijos ir dizainas". In: *Konferencijos pranešimų medžiaga*, Kaunas, 2005, pp. 3-7.
10. Ashley CW. *The Ashley Book of Knots*. Doubleday, 1993.
11. Hlavata H, Pokorna M. Vliv různých způsobů spojeni příze na výskyt chyb a zpracovatelnost. *Tekstil* 1989; 44: 244-250.
12. Gries T, Daumas A. Fadenverbindungen: Methoden und Anwendungsbereiche. *Melliand Textilberichte* 2003; 7-8: 608-615.
13. Pieranski P, Kasa S, Dietler G, Dubochet J, Stasiak A. Localization of Breakage Points in Knotted Strings. *New Journal of Physics* 2001; 10: 1-13.
14. Cheng KPS, Lam HL. Strength of Pneumatic Spliced Polyester / Cotton Ring Spun Yarns. *Textile Research Journal* 2000; 70: 243-246.
15. Cheng KPS, Lam HL. Physical Properties of Pneumatically Spliced Cotton Ring Spun Yarns. *Textile Research Journal* 2000; 70: 1053-1057.
16. Lewandowski S, Drobina R. Strength and Geometrical Sizes of Pneumatically Spliced Combed Wool Ring Spun Yarns. *Fibres & Textiles in Eastern Europe* 2004; 12, 2(46): 31-37.
17. Jarman C. *The Essential Knot Book*. International Marine, 1986.
18. Smith B, Padgett A. *On Rope*. National Speleological Society, 1996.
19. Matukonis A, Milasius V, Katunskis J. *Audimas*. Mokslas, 1983.
20. Busova NA, Minenko NG. *Weaving of Linen Fabrics* (in Russian). Legkaja industrija, 1978.
21. Adanur S. *Handbook of Weaving*. Technomic Publishing Co., 2001.
22. Kovačević S, Schwarz I, Brnada S. Tekstilni uzlovi. *Tekstil* 2006; 55 (7): 327-333.
23. Batra EK, Franz DA, Towler MA, Rodeheaver GT, Thacker JG, Zimmer CA, Edlich RF. Influence of Surgeons Tying Technique on Knot Security. *Journal of Applied Biomaterials* 1993; 4: 241-247.
24. International Standard ISO 2062.
25. International Standard ISO 139.
26. International Standard ISO 2060.
27. Matukonis A, Palaima J, Vitkauskas A. Tekstilės medžiagotyra. Mokslas, 1976.
28. Hoel PG. *Introduction to Mathematical Statistics*. John Wiley & Sons, 1984.

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