Studies on Strength of Netting (1)

The Decrease in Strength of Netting Twines by Knotting*

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그물감의 강도에 관한 연구 (1)

그물실의 강도가 매듭에서 감소하는 기구

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그물실의 강도가 매듭에서 감소하는 기구를 명백히 하기위해, 매듭에서의 그물실의 파단현상을 관찰하고 강도 감소에 영향을 끼치는 요소들을 조사하여 매듭의 강도를 나타내는 식을 유도하고, mono-filament, multi-filament, 및 spun 그물실로 구분된 11종류의 그물실에 대해 매듭의 강도를 측정하여 상기 식에 의한 계산치와 비교했다.

실험의 결과, 매듭이 파단을 일으키는 부분은 매듭의 첨단, 즉 매듭과 다리와의 경계이었으며, 강도감소의 원인은 이 첨단에 마찰력이 작용함으로 인해, 첨단에 위치한 섬유들이 자신에 걸리는 장력에 의해서 재분포하는데 마찰력만큼 저항을 받게 되기 때문이라고 간주되었다. 매듭의 강도 T는

$$T = \frac{T_o}{1 + \mu \dfrac{S}{\rho} e^{-\mu\theta}}$$

로 표시되었고, 이 식에 의한 계산치는 실험치와 거의 일치했다. 단, T_o는 그물실의 항장력, μ는 그물실간의 마찰계수, S는 매듭의 첨단과 그 첨단을 압축하는 그물실과의 접촉길이, ρ는 그 첨단을 압축하는 그물실의 곡률반경, θ는 그 첨단을 압축하는 그물실이 반대편 첨단에서 다른 그물실과 마찰되는 각도이다.

INTRODUCTION

Knotted netting in general breaks firstly at a knot, and then, knot after knot, the break spreads to every part of the netting. That is, the netting is no stronger than its weakest knot. This is of course why the netting twines forming the netting cannot keep their original strength at the knot. Hence, the analysis of the decrease in strength becomes a basis on the estimation of the netting strength.

Many studies have been made on the knot strength, [1]~[12] but merely offered its experimental data. There exists the paper of TAUTI[13] on the mechanism of the decrease. In the paper he described that the decrease was due to the elongation in centre lines of plied yarns by bending of netting twines at the knot and so the knottd netting twines decreased in strength as much as the tensile stress was exerted on the outmost layers of the plied yarns. The exertion of the tensile stress, he illustrated, was because the plied

yarns were contracted in radius by the elongaion in the centre lines and the outmost layers of the plied yarns compressed against the inner. However, netting twines seem to show no change in the length of the centre lines in spite of bending, [14]~[7] and, if bent, to be subjected to the tensile stress at their outer part. [18]~[19]

This difference of the recent view in bending effect to the Tauti's theory gives that the mechanism of the decrease is still a matter of speculation.

This paper deals with the factors influencing the decrease in strength of netting twines by knotting and the mechanism of the decrease.

MATERIALS AND METHODS

In order to investigate whether the drawing-out of netting twines from the knot by tensile loads has influence on their decrease in strength or not, the drawn-out length was measured by the apparatus shown in Fig. 1. First a tenth of the knot strength tested in advance was applied to the bars, and then the tips of the knot or of the bars, i.e., the boundaries between the knot and the bars, were marked with black ink as shown in Fig. 2. Secondly, nine tenths of the strength was applied. The lengths between the ink marks and the new tips produced by the second loading were measured by the reading microscope. For this experiment, cotton 30tex× 25×3, manila 1067tex×3, amilan 23tex×23×3, and kanebian 30tex 20×3 were used.
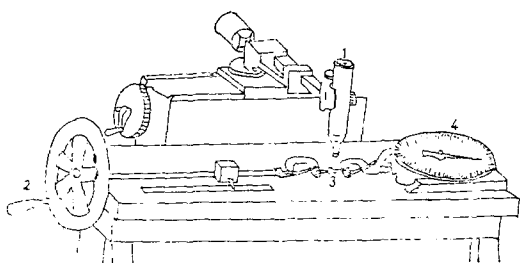

Fig. 1. Apparatus for measuring the drawn-out length.
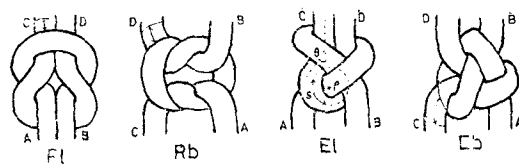1: Reading microscope,
2: Handle, 3: Knot,
4: Strength indicator.

Fig. 2. Types of knots. Rl:Reef knot stretched lengthwise, Rb:Reef knot stretched breadthwise, El:Trawler knot stretched lengthwise, Eb:Trawler knot stretched breadthwise. A,B,C,D:Symbols of bars. ←→:Drawn-out length or length between the ink mark and the tip.

Netting twines used to investigate the relataion between the calculated and experimental values of knot strength are listed in Table 1. The coefficient of friction μ between the netting twines was obtained from $W_2/W_1=e^{\mu\theta}$, where W_1 and W_2 were measured the moment of netting twine, which was hung on the pieces of the same netting twine attached to the iron cylinder by glue, started to slip under an increasing load at its one side as shown in Fig. 3.
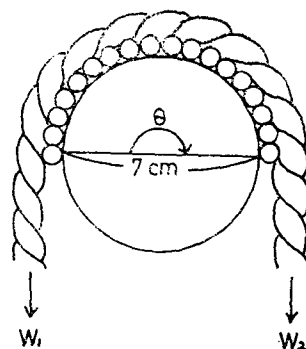

Fig. 3. Measurement of the coefficient of friction between netting twines. W_1:Initial load, W_2: Final load.

For testing the tensile strength of netting twines and knots, *Schopper* type testing machine (capacity:250 kg and 100kg, pulling velocity: 0.3 m/min) was employed.

RESULTS AND DISCUSSION

1. Factors influencing the decrease in strength of netting twines by knotting

Loading to a knot draws out netting twines to the four bars, while the space for drawing-out is gradually decreased. Netting twines, therefore, show more contraction in diameter at the knot than at the bars, and are strongly compress at the knot.

Being compressed in course of drawing-out, a netting twine will be subjected to a frictional forc, which is proportional to the size of curvature of its partner netting twine and greater in larger coefficient of friction.

Fig. 4. represents the relation between the coefficient of friction and the decreasing rate in strength of netting twines by knotting. It seems that netting twines of larger coefficient of friction show more decrease in strength.
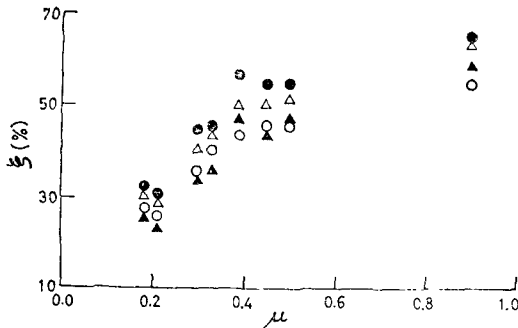

Jig. 4. Relation between the coefficient of friction (μ) and the decreasing rate in strength of netting twines by knotting (ξ). Materials and their coefficient of friction are shown in Table 1. $\bigcirc$: Rl, $\bullet$:Rb, $\triangle$:El, $\blacktriangle$:Eb.

A direct observation of knot breakage exposed that netting twines broke in general at the tip of the knot. The reef knot broke from any one of its four tips regardless of pulling direction. The trawler knot broke from the tip of bar A when pulled lengthwise, but from the tip of bar C in breadthwise pull. More strictly, the knots broke from the outer part of the tip when compressed at both parts of the tip (the tip of bar B in breadthwise pull of the trawler knot), but from the inner part of the tip when compressed mainly at the inner part(all tips of the reef knot,

the tip of bar A in lengthwise pull and the tip of bar C in breadthwise pull of the trawler knot).

The break of the reef knot from any one of four tips is probably caused by the equality in curvature among four netting twines compressing the four tips. The tip of bar A and that of bar C in the trawler knot are compressed respectively by the netting twines of the largest curvature, as shown in Fig. 2.

The break of knots mainly from the inner part indicates not only that the tensile stress exerted on the outer part by bending of netting twines is negligible, but also that the knots break from the compressed part, i. e., from the part subjected to the frictional force. These results on the coefficient of friction, the curvature and the breakage may be taken to indicate that the tip under the largest frictional force should be responsible for the knot failure, in which the breakage is oposed to the TAUTI'S theory indicating that netting twines always break at a point marking a maximum curvature in the interior of the knot. In view of the influence of the frictional force, the influence of heat by the friction can be suggested. However, the change in strength of knots in case of immersing in water has no significant difference with that of straight netting twines in the same case. It may therefore be put that the influence of heat is negligible.

Tension applied to a knot draws out netting twines from the knot to the bars and the netting twines in the knot contract in diameter. According to the investigation of the relation between the drawn-out length and the decreasing rate in strength of netting twines by knotting (Fig. 5), no relation seems to be made. It can be therefore seen that the influence of the drawn-out length on the knot strength is negligible. Hence, the knot deformation due to the drawing-out, e. g., the contraction in diameter of netting twines, may be neglected. This neglect is also substantiated by comparing the contraction in diameter (D/D_0, Table 1) with the knot strength (Fig. 7).
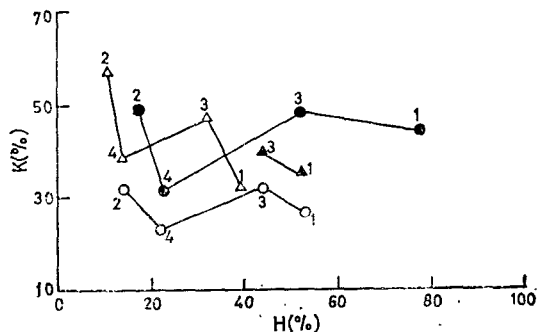
Fig. 5. Relation between the rate of decrease in strength at the knot (K) and that of drawn-out length (H) $K=\dfrac{T_o-T}{T}\times100(\%)$, $H=(L/L_o)\times100(\%)$, T_o:Unknotted strength, T:Knotted strength, L:Total drawn-out length from knot, L_o:Length of netting twines required to make a knot. ○: amilan 23tex×28×3, ●:kanebian 30tex ×20×3, △: manila 1067tex ×3, ▲:cotton 30tex×25× 3, 1:Rl, 2:Rd, 3:El, 4:Eb.

Therefore, the decrease in strength of netting twines by knotting may be concluded to be due mainly to the frictional force acting on the tip of the knot.

2. Derivation of knot strength

Based on the frictional force acting on the tip of the knot, an expression may be derived for the knot strength.

The frictional force F is given by

$$F=\mu\frac{S}{\rho}T_p, \qquad (1)$$

where μ is the coefficient of friction between two netting twines forming a knot, s the contact length between the tip and the netting twine compressing it, ρ the radius of curvature of the compressing, and T_p the tension applied to the compressing. If T is the tension in the bars or the knot strength in case of knot breakage, T_p will be of the form:

$$T_p= Te^{-\mu\theta}, \qquad (2)$$

where θ is the angle at which the compressing netting twine rubs with another one in the vicinity of the opposite tip. Substituting Equation (2) in (1), F becomes

$$F=\mu\frac{s}{\rho}\,Te^{-\mu\theta}, \qquad (3)$$

Table 1. Contraction in diameter of netting twines at the tip of the knot
D_o: Diameter at the bars, D: Diameter at the tip), and values of T_o, μ, s, ρ and θ

Materials		T_o $(kg/yarn)$		μ		D_o	D			(mm)
		Dry	wet	Dry	Wet	(mm)	Rl	Rb	El	Eb
Polyethylene[1]	29×3	1.56	1.53			2.94	2.66	2.80	2.76	2.76
	13×3	1.57	1.64	0.18	0.21	1.82	1.60	1.72	1.70	1.70
42 tex	5×3	1.65	1.75			1.14	1.02	1.08	1.08	1.08
Nylon[2]	50×3	1.01	0.88			2.34	2.12	2.30	2.24	2.24
	30×3	1.10	1.08	0.30	0.33	1.66	1.56	1.64	1.64	1.44
23 tex	5×33	1.21	1.10			0.70	0.66	0.68	0.68	0.68
Polyester[3]	52×3	0.91	0.82			2.38	2.20	2.36	2.32	2.30
	25×3	0.98	0.95	0.39	0.45	1.62	1.54	1.60	1.58	1.58
30 tex	10×3	0.99	0.96			1.02	0.94	1.00	1.00	1.00
Vinylon[4] 30 tex	20×3	0.83	0.72	0.50	0.90	1.72	1.58	1.66	1.66	1.66
	10×3	0.88	0.77			1.16	1.10	1.16	1.14	1.14

	Rl	Rb	El	Eb
s[5]	1.36D	1.82D	2.59D	2.44D
ρ[6]	0.67D	0.67D	1.00D	1.21D
θ	$\pi/3$	$\pi/6$	$\pi/4$	$\pi/4$

[1] Mono-filament, [2] Multi-filament, [3][4] Spun, [5][6] Obtained from $s=D\varphi/2\cos\alpha$ and $\rho=D/2\cos^2\alpha$, assuming that netting twines at the knot describe a helix as shown in Fig. 6
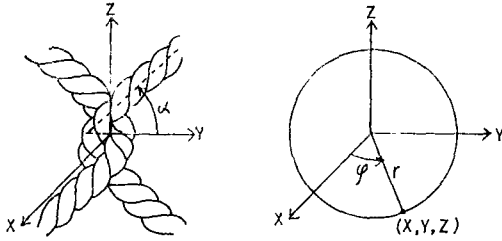
Fig. 6. Helix described by netting twines at the knot.

If the frictional force exerted on the fibres at the tip by F are defined by f_1, f_2, $f_3, \ldots$, the sum Σf_i may be almost equal to F, i. e,,

$$\Sigma f_i = F. \tag{4}$$

The frictional force f_1, f_2, f_3, $\cdots$will resist the redistribution of fibres respectively as much as the given forces, so that the tensions in the fibres will increase respectively as much as the resistances r_1, r_2, $r_3, \ldots$ on the fibres. These relation may written as follows:

$$f_1 = r_1, \quad f_2 = r_2, \quad f_3 = r_3, \ldots \cdot \tag{5}$$

The total increment of tension at the tip may be equal to Σf_i or Σr_i. Therefore the tensile

strength of netting twines at the tip, i. e., the knot strength T may be expressed as

$$T = T_o - F \tag{6}$$

or

$$T = \frac{T_o}{1 + \mu \dfrac{s}{\rho} e^{-\mu\theta}} \tag{7}$$

where T_o stands for the tensile stregth of netting twines in case of being unknotted.

3. The calculated and experimental values of knot strength

The values of T_o, μ, s, ρ, and θ in Equation (7) are summarized in Table 1, and the calculated and experimental values of knot strength in Fig. 7. A good agreement between the calculated and experimental values is demonstrated by filament twines such as polyethylene and nylon. Spun twines such as polyester and vinylon show experimental values approximating the calculated in finess, but slightly less in general. This difference seems to increase with the thickness of spun twines.
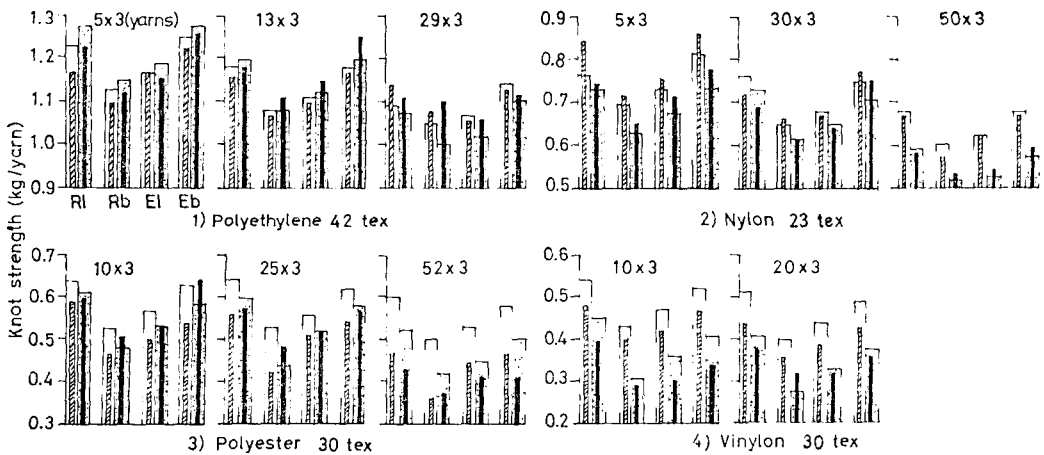

Fig. 7 Relation between the calculated and experimental values of knot strength.

☐: Calculated values in dry, ▦ : Calculated values in wet. ▨ : Experimental values in dry, ▪ : Experimental values in wet.

Under tensile loads some fibres of spun twines always slip off without breaking.[20],[21] Being bent at the knot, spun twines are exposed to the tensile stress at their outer part, and to the compressive stress at their inner part. These

two stresses may encourage the fibre slippage, probably by decreasing the contact length between fibres at the outer part, and by putting the twine lay in disorder. Owing to these effects, the fibres will slip off more guickly than when

the twines are not bent, and so a difference between the calculated and experimental values may be produced,

As netting twines were thickened, the calculated and experimental values of knot strength per yarn decreased together, but a difference between the two values was on an increase in spun twines only. This increase may be ascribed to the increase in slipping velocity of fibres with thickness of spun twines.

When knots were immersed in water, their strength became a little stronger in the case of polyethylene and polyester, and weaker in nylon, but remarkably weaker in vinylon. This variation of the experimental values almost falls into line with that of the calculated.

Knots are arranged in order of the experimen tal values as follows: the reef knot pulled lengthwise ≒ the trawler knot pulled breadthwise⟨the trawler knot pulled lengthwise⟩ the reef knot pulled breadthwise ; where the second was a little stronger than the first in netting twines of relatively small coefficient of friction, but the first was a little stronger than the second in netting twines of relatively large coefficient of friction. These tendencies also agree with those of the calculated values.

As mentioned above, the experimental values of knot strength are in general agreement with the calculated. Therefore, the mechanism of the decrease in strength of netting twines by knotting may be expressed as Equation (7).

SUMMARY

1) The decrease in strength of netting twines at the knot may be regarded to be due mainly to the frictional force acting on the tip of the knot. The knot strength T may be given by

$$T = \frac{T_o}{1 + \mu \frac{s}{\rho} e^{-\mu\theta}},$$

where T_o is the tensile strength of unknotted netting twines, μ the coefficient of friction between two netting twines forming a knot, s the

contact length between the tip and the netting twine compressing it, ρ the radius of curvature of the compressing, and θ the angle at which the compressing rubs with another one in the vicinity of the opposite tip.

2) Knots are arranged in order of strength as follows: the reef knot pulled lengthwise ≒ the trawler knot pulled breadthwise⟨the trawler knot pulled lengthwise⟩ the reef knot pulled breadthwise.

ACKNOWLEDGEMENT

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