Breaking Strength of a Knot of Fishing Net as Affected by the Angle between Legs of Mesh.

Shunpei KAKUDA

Department of Fisheries, Faculty of Fisheries and Animal Husbandry, Hiroshima University, Fukuyama, Japan

(Pls. 1–2; Text-figs. 1–7; Tables 1–6)

INTRODUCTION

It is generally known that a netting is more breakable at knots than at any other part when a overload is applied to it.

The breaking strength of knotted netting cords has been studied by TAUTI,[1) HONDA[2) 3), SHIMOZAKI[4) and others. TAUTI analyzed theoretically the tendency that a netting cord loses part of its breaking strength when knotted, and ascribed its cause to the fact that the cord is bent at the knot. He also showed experimentally that breaking strength of a cotton cord becomes smaller when it is made into a loop of a certain diameter by itself or tied into a trawler or flat knot with another piece of cord than when it is straight. Breaking strength of netting cords of various materials tied into a trawler or flat knot was investigated by HONDA,[2)3) SHIMOZAKI [4) and others. In their experiments the four legs of a knot were oriented as in a mesh that is fully stretched either longitudinally* or transversely*, and static loads were applied to them in the direction of the legs. KONDO[5) investigated the breaking strength of non-shortened nets.

When a properly designed fishing net is used in water, its meshes are spread open to the extent that has been planned in designing. Hence, it seems desirable that breaking strength of a netting should be investigated with its mesh spread open to various extents. Such a study, however, has not been published.

In the present study the breaking strength of a netting cord tied into a trawler or flat knot was investigated by varying the angle between the neighboring legs of the knot in order to clarify how the breaking strength of a netting is affected by the spreading of the mesh.

MATERIAL AND METHODS

The specifications of the netting cords used in the present study are indicated in Table 1. While cotton is a vegetable fiber, cremona is a synthetic fiber (poly-

---

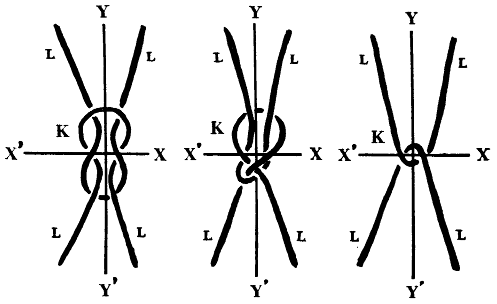
* Respectively corresponds to the case of $\alpha=0°$ and $\alpha=180°$ in Table 2 of this paper.

vinyl alcohol fiber). Cotton 1 and 2, as well as Cremona 1 and 2, are made with the same yarn and fiber and differ from one another only in the number of twists per unit length. The netting cord is cut into pieces about 35 cm long. Two such pieces of the same cord are tied into a flat or trawler knot in the middle, and are called a test piece. A test piece therefore consists of a knot and its four legs. In the case of "Plain link", a test piece consists also of two 35 cm pieces of the same cord, but one piece is simply hung over the other in the middle (Fig. 1).

Table 1. Specifications of netting cords used in the experiment.

Cord	Material	Count	Ply/No. of yarn	No. of twist per* 10 cm. of length		Diameter* (mm.)	Weight* per 100cm. of length (mg.)	Breaking* strength (kg.)	Breaking* elongation (%)
				Upper twist	Lower twist				
Cotton 1	Cotton	No. 20	3/3	32±0.9	95±5.3	0.78±0.02	329±11.4	5.38±0.409	32.2±1.56
Cotton 2	Cotton	No. 20	3/3	19±0.7	51±3.4	0.85±0.02	300± 7.8	5.66±0.182	24.6±0.98
Cremona 1	Cremona	No. 20	3/3	21±0.8	57±1.7	0.82±0.02	301± 6.4	7.61±0.402	27.8±0.62
Cremona 2	Cremona	No. 20	3/3	17±0.7	49±2.8	0.85±0.02	295± 3.0	8.16±0.327	22.6±0.44

* The mean and standard deviation based on the measurements of 15 test pieces are shown.



A. Flat knot B. Trawler knot C. Plain link

Fig. 1. Sketch of the test pieces. K, knot or crossing poin; L, leg; XX′ transversal axis; YY′, longitudinal axis.

The testing machine used is a Schopper-type tensile strength tester, the upper and the lower chuck of which are replaced respectively with a horizontal bar having two horizontally movable chucks on it. The pair of testing bars are set parallel to one another on a vertical plain. A test piece is fixed to the testing bars in the manner indicated in Fig. 2.

The chucks **A**, **B**, **C** and **D** are set at an equal distance $d/2$ from the longitudinal axis of the shaft, and the length of each leg (from the chuck to the knot or crossing point K) is made to 10 cm*. (*i.e.*, $l=10$ cm.). Consequently the four legs are arranged symmetrically with regards to both the longitudinal and transverse axes passing K(YY' and XX'). Legs are fastened to chucks in such a way that no

---

* See the foot notes * and ** of Table 2 for the exceptional cases.

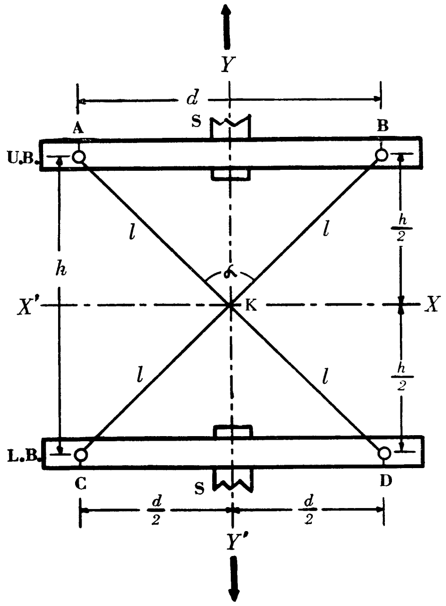


Fig. 2. A test piece fixed to the testing bars.

A, **B**, **C**, **D**, chucks; *d*, distance between the neighboring chucks; *h*, distance between upper and lower bars; K, knot or crossing point; **L. B.**, lower bar; *l*, length of a leg; S, shaft; **U. B.**, upper bar; *α*, angle between neighboring legs; *XX′*, transversal axis; *YY′*, longitudinal axis.

twisting occurs at the knot or crossing point. A pair of legs represented by a single cord are fastened to the chucks of the same bar. The angle between a pair of legs represented by the single cord, α, is varied so as to reproduce a fully spread mesh of the nettings shortened to approximately 10–80%, by varying the distance d.

When a test piece has been fixed to the testing bars, static loads are applied to it by moving the lower bar forcibly downwards (i.e., in the direction of Y') at the constant rate of 30 cm per minute, until the test piece is broken. As the load is increased, legs of the test piece are elongated by tension, while the distance d remains unchanged; as a result, the angle between a pair of legs fastened to the same bar decreases and finally reached α' (the "critical angle") when the test piece is broken. The amount of the static load, the length of the legs and the distance between the upper and lower bars at the moment the test piece is broken are respectively denoted by Fc (the "critical static load"), l' and $h+\Delta h$ (Fig. 3).

Test pieces are broken almost always at the knot or crossing point. In such cases the values of Fc and Δh are recorded. The experiments were carried out at room temperature of 20 ± 3°C using wet test pieces which had been immersed in fresh water for 24 hours at temperatures of 20 ± 2°C.

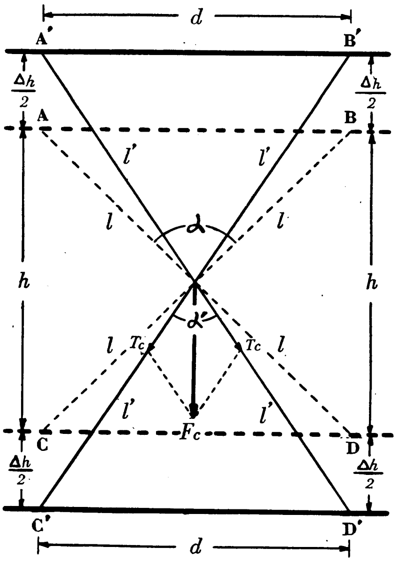


Fig. 3. Schematic representation of a test piece before stretching and at the time of its break. The broken line represents the bars and the test piece before stretching. The solid line represents those at the time of the break. *Fc*, critical static load; *Tc*, tension of a leg by *Fc*; α', critical angle.

RESULTS AND DISCUSSION

The results obtained by the method described above are shown in Table 2.

Let the tension caused on a leg of the test piece by the critical load *Fc* be denoted by *Tc*. Then

$$Tc = \frac{Fc}{2} \cdot \sec\frac{\alpha'}{2} \quad . \qquad (1)$$

Since $\cos\frac{\alpha'}{2} = \frac{h/2+\varDelta h/2}{l'}$ and $l' = \frac{\sqrt{(h+\varDelta h)^2+d^2}}{2}$, we can write (1)

$$Tc = \frac{Fc\sqrt{(h+\varDelta h)^2+d^2}}{2(h+\varDelta h)} \quad . \qquad (2)$$

As values of *Fc*, *d* and $h+\varDelta h$ are known, *Tc* can be calculated from this formula.

The breaking strength of a test piece, *BS*, in case of α' is put to $2Tc$.

$$BS = 2Tc$$

1) *Breaking strength in the "plain link".*

In the test piece of the "plain link" (Fig. 1C), the netting cord is broken at the crossing point in the majority of the cases, when the static load is increased gradually. The breaking strengths of the Cotton 2 and Cremona 2 cords for such cases are calculated from the data of Table 2A by means of formula (2) and plotted against the angle α in Fig. 4.

TAUTI[1] has shown theoretically and experimentally that when a straight cord is bent along a circle, its breaking strength decreases and the breakage tends to occur at the bending, and also that the decrease in the breaking strength is the function of the radius of curvature of the cennter line of the bent cord.

Table 2. Means and standard deviations of Fc and Δh based on 20 test pieces.

A. Plain link

α			23°	35°	47°	60°	74°	89°	106°	128°
Shortening (%)			80	70	60	50	40	30	20	10
Cotton 2	Fc (kg.)	Mean	9.40	9.18	9.16	9.03	8.84	8.78	8.53	7.96
		s	0.522	0.531	0.386	0.358	0.615	0.671	0.503	0.383
	Δh (cm.)	Mean	5.1	5.2	5.4	5.7	6.1	6.7	7.7	9.2
		s	0.23	0.19	0.13	0.20	0.22	0.23	0.20	0.16
Cremona 2	Fc (kg.)	Mean	8.55	8.87	8.57	8.88	8.41	8.45	8.32	7.76
		s	0.828	0.748	0.861	0.871	0.578	0.718	0.595	0.564
	Δh (cm.)	Mean	4.2	4.5	4.7	5.1	5.4	6.2	7.4	9.1
		s	0.34	0.14	0.21	0.62	0.18	0.21	0.22	0.13

B. Trawler knot.

α			0°*	23°	35°	47°	60°	74°	89°	106°	128°	180°**
Shortening (%)			100	80	70	60	50	40	30	20	10	0
Cotton 1	Fc (kg.)	Mean	8.64	8.69	8.44	8.38	8.23	7.96	7.44	7.22	6.71	9.45
		s	0.521	0.819	0.579	0.674	0.640	0.445	0.443	0.604	0.525	0.833
	Δh (cm.)	Mean	15.7	7.0	7.1	7.4	7.8	8.3	8.7	10.1	11.7	16.1
		s	0.33	0.22	0.21	0.21	0.22	0.18	0.20	0.21	0.19	0.43
Cotton 2	Fc (kg.)	Mean	9.72	9.56	9.44	9.33	9.08	8.63	8.20	7.71	7.14	9.95
		s	0.690	0.660	0.652	0.714	0.434	0.439	0.493	0.567	0.379	0.750
	Δh (cm.)	Mean	12.3	5.4	5.5	6.0	6.3	6.5	7.2	8.0	9.7	12.2
		s	0.30	0.25	0.16	0.17	0.27	0.16	0.28	0.26	0.17	0.37
Cremona 1	Fc (kg.)	Mean	7.77	7.81	7.33	7.24	7.22	6.62	6.37	5.67	5.15	7.98
		s	0.620	0.668	0.598	0.496	0.476	0.434	0.482	0.613	0.525	1.034
	Δh (cm.)	Mean	11.6	4.8	4.8	5.0	5.3	5.5	6.0	6.7	8.1	12.5
		s	0.12	0.16	0.18	0.18	0.18	0.17	0.17	0.17	0.18	0.17
Cremona 2	Fc (kg.)	Mean	8.34	7.92	7.91	7.76	7.38	7.07	6.56	6.25	5.50	8.48
		s	0.584	0.581	0.617	0.508	0.577	0.540	0.399	0.426	0.479	0.667
	Δh (cm.)	Mean	10.8	4.2	4.5	4.7	4.8	5.2	5.4	6.5	7.7	11.2
		s	0.23	0.15	0.17	0.10	0.17	0.19	0.22	0.02	0.14	0.22

C. Flat knot.

α			0°*	23°	35°	41°	47°	53°	60°	67°	74°	81°	89°	97°	106°	128°	180°**
Shortening (%)			100	80	70	65	60	55	50	45	40	35	30	25	20	10	0
Cotton 1	*Fc* (kg.)	Mean	8.95	8.56	8.48	—	8.38	—	7.98	—	7.72	—	7.39	—	7.22	7.00	8.45
		s	0.572	0.551	0.488	—	0.695	—	0.651	—	0.578	—	0.756	—	0.533	0.614	0.536
	Δh (cm.)	Mean	15.9	6.9	7.1	—	7.3	—	7.4	—	7.8	—	8.5	—	9.8	12.0	15.7
		s	0.32	0.18	0.19	—	0.22	—	0.21	—	0.16	—	0.21	—	0.21	0.22	0.35
Cotton 2	*Fc* (kg.)	Mean	9.65	9.30	9.35	—	8.95	—	8.42	—	8.07	—	7.92	—	7.60	7.06	9.06
		s	0.703	0.535	0.586	—	0.521	—	0.499	—	0.429	—	0.583	—	0.361	0.413	0.544
	Δh (cm.)	Mean	12.0	5.1	5.4	—	5.4	—	5.4	—	5.6	—	6.5	—	7.6	9.4	10.5
		s	0.48	0.18	0.18	—	0.18	—	0.23	—	0.23	—	0.23	—	0.23	0.14	0.42
Cremona 1	*Fc* (kg.)	Mean	8.44	7.97	7.70	7.62	7.28	8.07	8.48	8.91	8.93	8.68	8.44	8.00	7.20	5.99	7.73
		s	0.668	0.533	0.544	0.579	0.386	0.489	0.569	0.498	0.540	0.515	0.583	0.679	0.701	0.601	0.992
	Δh (cm.)	Mean	12.1	4.7	4.8	4.9	4.9	5.2	5.4	5.7	5.9	6.1	6.5	6.6	7.0	8.3	11.5
		s	0.14	0.19	0.16	0.20	0.11	0.15	0.14	0.10	0.17	0.14	0.17	0.15	0.19	0.17	0.15
Cremona 2	*Fc* (kg.)	Mean	8.59	7.90	7.57	—	7.34	—	8.16	8.89	8.77	8.48	8.31	—	6.79	5.51	8.21
		s	0.515	0.321	0.590	—	0.476	—	0.540	0.493	0.599	0.775	0.684	—	0.575	0.774	0.942
	Δh (cm.)	Mean	10.4	4.1	4.2	—	4.3	—	4.7	5.0	5.2	5.4	5.6	—	6.2	7.2	9.8
		s	0.19	0.16	0.17	—	0.14	—	0.14	0.16	0.12	0.26	0.13	—	0.02	0.26	0.21

s : Standard deviation.

* In both the upper and the lower bar, one of the chucks is set in the middle of the bar ($d=0$ cm.), to which a pair of legs represented by a single cord are fastened. Length of each leg l is 25 cm. instead of 10 cm.. Hence, $h=50$ cm..

** The chucks are set as above, and two legs representing different cords are fastened to the chuk. $l=25$ cm. and $h=50$ cm..

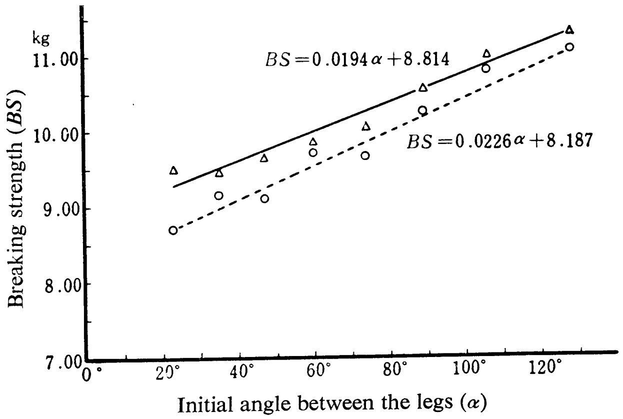


Fig. 4. Relationship between the breaking strength of netting cord and the angle α in the "plain link": Cotton 2 (triangle); Cremona 2 (circle).

It is shown in Fig. 4 that the breaking strengths of the Cotton 2 and Cremona 2 cords decrease in proportion to the decrease in the initial angle between the two legs representing the same piece of cord. It may be said that this result is in accordance with those of TAUTI.

As Table 1 shows, the Cremona 2 cord has greater breaking strength than Cotton 2 cord when both cords are straight. When linked by a "plain link", however, the breaking strength of the former is smaller for the some value of α, and is more susceptive of the change of α, than that of the latter, as is indicated in Fig. 4.

2) *Breaking strength in the trawler knot.*

The breaking strengths of the four kinds of netting cords tied into the trawler knot are calculated from the data of Table 2B and plotted against the angle α in Fig. 5.

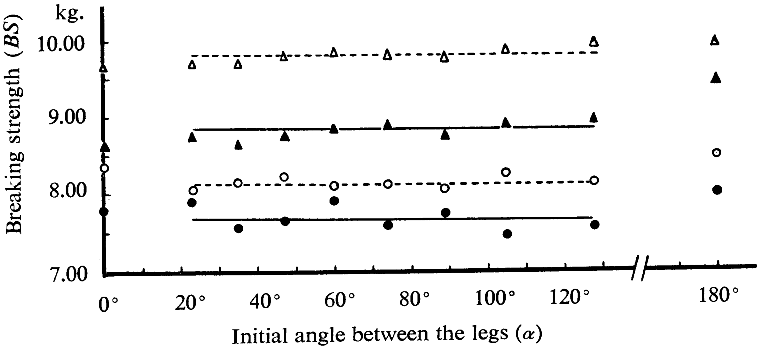


Fig. 5. Relationship between the breaking strength of trawler knot and the angle α: Cotton 1 (solid triangle); Cotton 2 (open triangle); Cremona 1 (solid circle); Cremona 2 (open circle).

This figure shows that the breaking strength of each netting cord is nearly independent of α within the range of α from 23° to 128°. In each kind of cord, the mean breaking strength for the range of α from 23° to 128° is defined as BS_α and indicated by a horizontal line in Fig. 5. The breaking strengths for $\alpha=0°$ and $\alpha=180°$ are denoted by $BS_{0°}$ and $BS_{180°}$ respectively. The values of BS_α, $BS_{0°}$ and $BS_{180°}$ for the four kinds of netting cord are shown in Table 3. It is seen from this table that in every netting cord BS_α is closer to $BS_{0°}$ than to $BS_{180°}$.

Table 3. Breaking strengths of four kinds of netting cord tied into the trawler knot.

	$BS_{0°}$ (kg.)	BS_α (kg.)	$BS_{180°}$ (kg.)
Cotton 1	8.64	8.82	9.45
Cotton 2	9.72	9.81	9.95
Cremona 1	7.77	7.67	7.98
Cremona 2	8.34	8.14	8.48

3) *Breaking strength in the flat knot.*

The breaking strengths of cotton and cremona cords tied into the flat knot are plotted against the value of α in Fig. 6. It is seen from this figure that the breaking strengths of cotton cords tied into the flat knot are nearly constant for the values of α from 23° to about 90°, but increase linearly as α increases from about 90° upto 128°. The nearly constant breaking strength of each cotton cord concurrent with the values of α from 23° to about 90° falls between the values of $BS_{0°}$ and $BS_{180°}$ of the respective cord as shown in Table 4. $BS_{0°}$ and $BS_{180°}$ of each kind of cord tied into the flat knot are defined in the same manner as in the trawler knot, and their values are obtained from Table 2C.

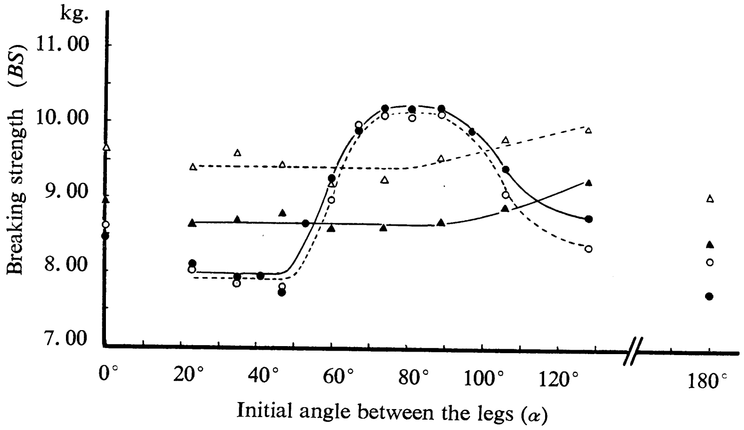


Fig. 6. Relationship between the breaking strength of flat knot and the angle α: Cotton 1 (solid triangle); Cotton 2 (open triangle); Cremona 1 (solid circle) Cremona 2 (open circle).

Table 4. Breaking strengths of four kinds of netting cord tied into the flat knot.

		$BS_{0°}$ (kg.)	BS_{α} (kg.)	$BS_{180°}$ (kg.)
Cotton	1	8.95	8.67	8.45
Cotton	2	9.65	9.41	9.06
Cremona	1	8.44	10.18	7.73
Cremona	2	8.59	10.09	8.21

As is clearly seen in Fig. 6, the breaking strength of each cremona cord tied into the flat knot changes in relation to the angle α in a rather complex manner; it remains nearly constant for the smaller values of α (23°–47°), increases in the range of α from ca. 50° to ca. 70°, shows the maximum throughout the range of α between ca. 70° and ca. 90° and decreases as α increases from ca. 90° to 128°. The maximum value is greater than either $BS_{0°}$ or $BS_{180°}$ of the respective cord as shown in Table 4. In this table, BS_{α} is the mean breaking strength for the range of α from 23° to 89° in cotton cords and from 74° to 89° in cremona cords.

The reason why the breaking strength of a netting cord, either of cotton or of cremona, tied into a flat knot changes in a peculiar manner in relation to α as compared with that of a cord tied into a trawler knot or connected by plain link can be explained from the fact that a flat knot is deformed in different ways according to the direction in which its legs are pulled (Fig. 7).

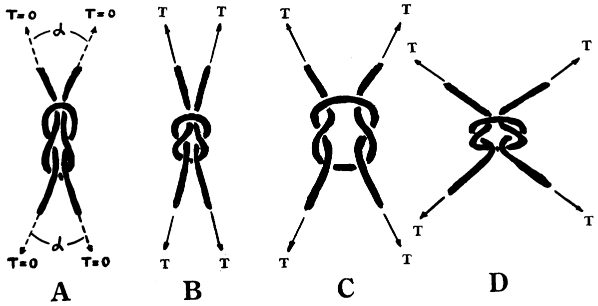


Fig. 7. Deformation of a fiat knot due to the static load applied to its legs. A, Initial shape; B, Tightening that occurs when the angle α is small; C, Loosening that occurs when the angle α is large; D, Flattening that occurs after loosening where α is ca. 105°–128°.

If a pair of legs of a flat knot that represent a single cord contain a small angle between them and are pulled gradually by a strong force, the knot becomes tightened and its size is reduced (Fig. 7B), until one of the leg is broken at the knot. It is easy to see that the radius of curvature of the cord is reduced when the knot is tightened in this way. The flat knot made of the Cotton 1 or 2 cord undergoes this type of deformation when α is between 23° and ca. 75°, and the one made of the Cremona 1 or 2 cord does so when α is between 23° and ca. 50°. It is exactly within these ranges of α that the breaking strength of the flat knot made of the respective cord remains nearly constant (Fig. 6). When α is between 60° and ca. 75°, however, the flat knot made of cotton cords is once loosened in the manner shown in Fig. 7**C** in most cases and then tightened as shown in Fig. 7**B** before breakage, while it is directly tightened in the other cases.

On the other hand, if a pair of legs representing a single cord are pulled containing a large angle between them (ca. 75°–128° in the case of Cotton 1 and 2, and ca. 50°–ca. 105° in the case of Cremona 1 and 2), the knot is loosened in the manner shown in Fig. 7**C** and a leg is broken at the knot. When α is as large as 106° or 128°, the knot is once loosened as in Fig. 7**C** and flattened later in the manner indicated in Fig. 7**D** and then one of the legs is broken at the knot. It may be said that the radius of curvature of the netting cord increases when a flat knot is loosened. When the angle α increases beyond 90° (in cotton cords) or 5o° (in Cremona cords), the breaking strength of the flat knot shows either a gradual increase (in the case of Cotton 1 and 2) or an increase followed by a leveling and a consecutive decrease (in the case of Cremona 1 and 2).

When a pair of legs of a trawler knot are pulled gradually by a strong force, the knot is always tightened in a manner similar to Fig. 7**B** and never undergoes the deformation indicated in Fig. 7**C** or **D** irrespective of the direction of the pull. This is probably the reason why the breaking strength of netting cord tied into a trawler knot is not affected by the value of α.

SUMMARY

In order to clarify the effect of the spreading of the mesh to the breaking strength of the netting cord, two pieces of the cotton or cremona netting cord were linked by a "plain link" or tied into a flat knot or a trawler knot, and the breaking strength of the cord was investigated by changing the angle between the neighboring legs of the knot and applying static loads to the legs. The cord was broken almost always at the knot or crossing point, and only the breaking strengths of such cases were treated with. Following results were obtained:

1) In the plain link, the breaking strength of the netting cord is affected by the angle between the neighboring cords. The relation between the breaking strength and this angle is linear; the breaking strength increases as the angle α (i.e., the angle between a pair of legs representing a single piece of cord) increases. The effect of this angle to the breaking strength is greater in the cremona cords than in the cotton cords.

2) The breakinng strength of the netting cord tied into the trawler knot is hardly affected by the angle α throughout the range of α from 23° to 128°, and the value is closer to the breaking strength of the mesh stretched longitudinally (i.e., in the ordinary direction) than to that of the mesh stretched transversely (laterally). This holds in cotton cords as well as in cremona cords.

3) The breaking strength of the cotton cord tied into the flat knot is almost constant when the angle α is between 23° and about 90° and this value falls between

the breaking strength of the mesh stretched longitudinally and that of the mesh stretched transversely.

4) The breaking strength of the cremona cord tied into the flat knot varies with the angle α. When this angle is between ca. 70° and ca. 90°, the breaking strength is at the maximum and is greater than in the mesh fully stretched either longitudinally or transversely. When the angle is between 23° and about 5o°, the breaking strength is comparatively small and nearly constant, and falls between the breaking strength of the mesh stretched longitudinally and that of the mesh stretched transversely.

Acknowledgement:

The author wishes to express his hearty thanks to Prof. Isao TAKESITA, under whose constant encouragement this study was carried out. The author is also grateful to Nippon Seimo Co., Ltd. for the donation of netting cords used in this study.

REFERENCES

1) TAUTI, M. 1930. J. Imp. Fish. Inst., **26**, 1: 41–51.
2) HONDA, K. 1952. "Sen'i Geppo" (Fibres Monthly), **9**, 2.
3) _______ 1952. Jap. Chem. Fibres Month., **5**, 7.
4) SHIMOZAKI, Y. 1957. "Suisan Gijutsu Sensho" (Technical Guidance for Fisheries), III. "Gosei-sen'i Gyomoko" (Fishing Nets and Cords of Synthetic Fibres): 77–79.
5) KONDO, Y. 1960. Bull. Jap. Soc. Sci. Fish., **26**: 554–558.

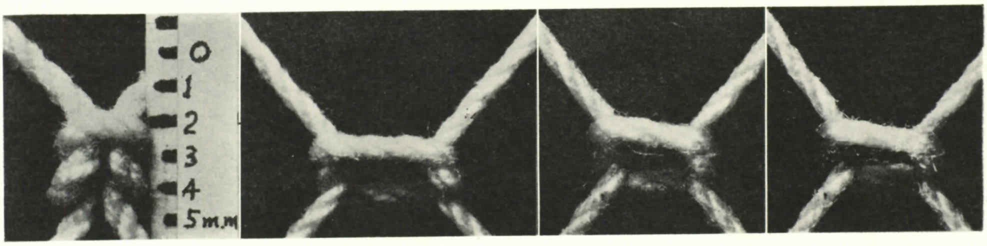
EXPLANATION OF PLATES

Plates I and II. Successive stages of deformation of the flat knots when static load (F) is applied to the legs as shown in the following table.

Plate	Fig.	Cord	α	A		B		C		D	
				F (kg.)	T (kg.)	F (kg.)	T (kg.)	F (kg.)	T (kg.)	F (kg.)	T (kg.)
I	1	Cotton 1	89°	0	0	1.5	0.9	3.0	1.8	4.9	2.9
	2	Cremona 1	89°	0	0	3.2	2.0	7.1	4.2	—	—
	3	Cotton 1	74°	0	0	2.2	1.3	4.8	2.7	7.6	4.3
	4	Cremona 1	74°	0	0	2.2	1.3	4.4	2.5	6.3	3.6
II	5	Cotton 1	60°	0	0	4.0	2.1	6.5	3.5	—	—
	6	Cremona 1	60°	0	0	3.0	1.6	6.0	3.3	7.8	4.2
	7	Cotton 1	47°	0	0	2.9	1.5	4.8	2.5	6.1	3.2
	8	Cremona 1	47°	0	0	4.0	2.1	5.9	3.1	7.9	4.1

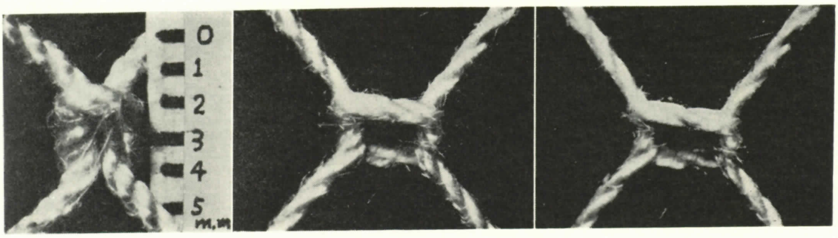
F : Static load.
T : Tension of the leg.
α : Initial angle between the legs.

Fig. 1



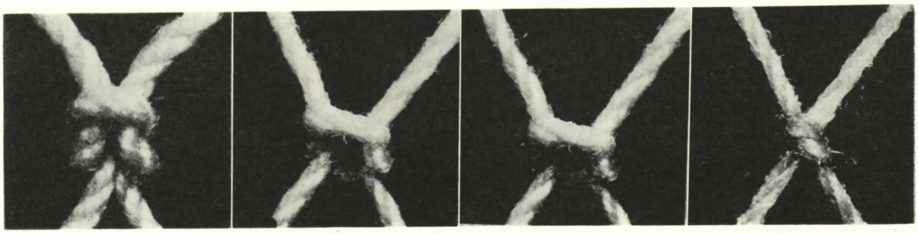
A B C D

Fig. 2



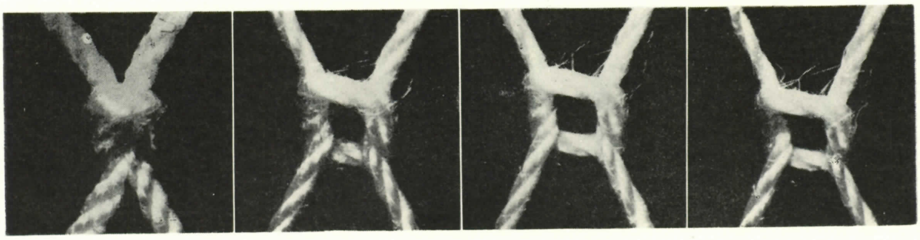
A B C

Fig. 3



A B C D

Fig. 4



A B C D

KAKUDA : Breaking Strength of a Knot of Fishing Net

Fig. 5

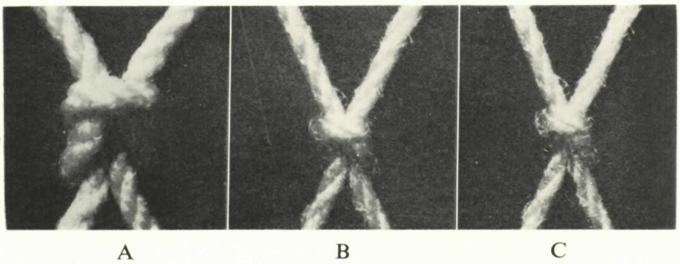


Fig. 6

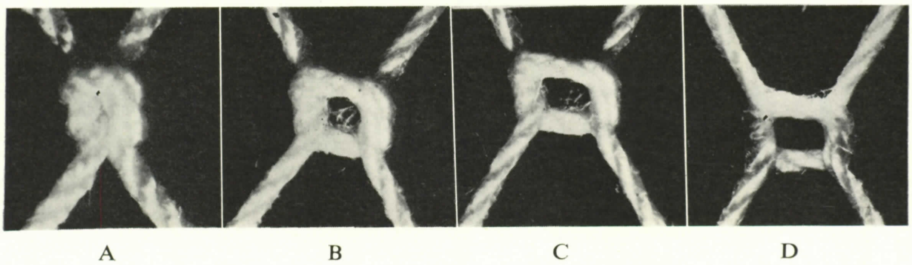


Fig. 7

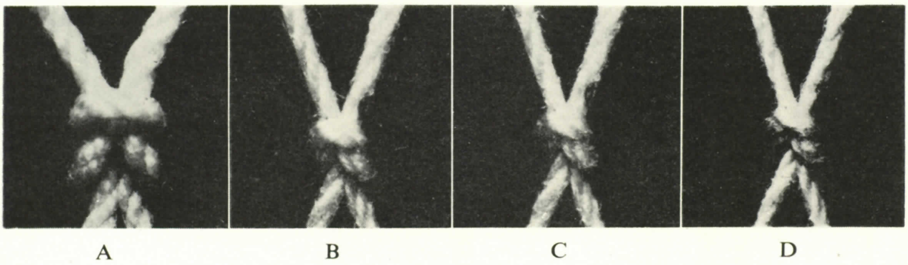
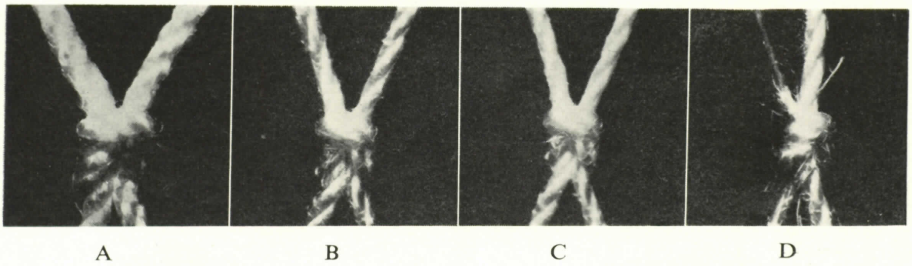


Fig. 8



KAKUDA : Breaking Strength of a Knot of Fishing Net