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Properties in Strength of Raschel Netting*

Dai An KIM**

랏쉘그물감의 强度*

金　大　安**

本 研究에서는 3-course 구조와 2-course 구조의 랏쉘그물감을 선정하여 그 強度 特性을 조사하고, 이를 구성 섬유의 재료가 같은 매듭그물감 및 貫通 그물감의 強度와 비교했다. 실험으로 부터 얻어진 결과를 요약하면 다음과 같다.

1. 랏쉘그물실의 強度가 랏쉘마디에서 감소하는 원인은 장력에 의한 마디의 변형 및 마디에서의 yarn 間의 마찰력에 주로 기인한다고 간주되며, 강도 감소율은 종인에서 13%, 횡인에서 22~26% 정도이다.

2. 랏쉘마디는 3-course 구조의 것이 2-course 구조의 것보다 모든 방향의 인장에서 약간 강하고, 마디 형태의 변형도 적다.

3. 주름을 준 상태에서의 랏쉘마디의 強度 T_R는 인접하는 다리가 이루는 角을 φ라 하면

$$T_R = T_{R0} - k\varphi$$

로 주어진다. 단, T_{R0}는 φ가 0°때의 T_R의 값, k는 상수이다.

4. 랏쉘그물감의 抗張力 σ_R 및 破斷에 소요되는 일량 E_R는 引張하는 쪽의 그물코 수를 N라 하면

$$\sigma_R = KN \quad \text{또는} \quad \sigma_R = T_R N$$

및

$$E_R = AN$$

으로 표시되고, 破斷伸度는 N에 관계없이 거의 일정하다. 단, K 및 A는 상수이다.

5. 몇개의 다리가 미리 절단되어 있는 경우의 랏쉘그물감의 破斷은 미리 절단되어 있는 다리에 인접한 다리의 마디로부터 일어나며, 그때의 항장력, 破斷에 소요되는 일량 및 破斷伸度의 감소는 비록 하나의 다리가 미리 절단되어 있는 경우라 할지라도 상당히 크다.

6. 랏쉘그물감의 破裂強度는 두개의 다리를 引張한 경우의 랏쉘마디의 強度와 거의 같다.

7. 現用의 주된 세 종류의 그물감에 대해 그들을 구성하는 다리의 denier 數를 기준으로 하면, 貫通마디가 가장 強하고, 매듭의 強度는 貫通마디의 強度의 69~76% 정도이다. 랏쉘마디는 縱引時는 貫通마디 強度의 71~74%로서 매듭과 거의 같은 強度를 가지지만, 橫引時는 매듭의 強度보다 약하여 62~67%를 나타낸다.

INTRODUCTION

The Raschel netting, developed around 1951 from the Raschel technique of the textile industry, was introduced into the Korean fishery in the latter half of the 1960's. At present the netting is used partially for purse seines, fixed nets, trawl nets, etc., but it is of increasing

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** Yeosu Fisheries Technical College, 麗水水産專門學校

interest also for the other fishing nets.

The Raschel netting has no knots which are regarded in general to have many merits, and can be made at lower price than the other nettings with higher net-making efficiency. That is, the efficiency of the Raschel machines is 4 to 15 times as high as that of the others and becomes higher the smaller the mesh. Thus, the netting is often surmised to be better in strength, water resistance, cost, etc. than the traditional knotted netting. But the Raschel netting is completely different in construction from the knotted nettting and the twisted-jointed netting of which joints (mesh-apexes) can be made in a wide range of various construction. These differences in construction emphasize that the strength of Raschel netting can not be surmised so easily and the determination of the most favourable joint structure is required in order to obtain the highest possible joint strength. However, several studies on the Raschel netting [1-4] merely offered introductions and so the properties, especially in strength, of the netting are still matters of speculation.

This paper deals with the properties in strength of the Raschel netting and compares them with those of the knotted netting and the twisted-jointed netting in order to make clear the superiority or the inferiority in strength among the three kinds of nettings.

MATERIALS AND METHODS

In order to investigate the properties in strength of Raschel nettings, the tensile strength of their bars (Raschel twines), their mesh-apexes (Raschel joints), and their pieces were tested respectively. Test pieces of Raschel twines, each 10 cm long, always inclued a few joints. If the test pieces are put in tensile loads as they are, they break always at the joints or at the clamps of the testing machines and the original tensile strength of Raschel twines is not obtained. Therefore, they were coiled with fine cotton twines to be broken at the end points of the

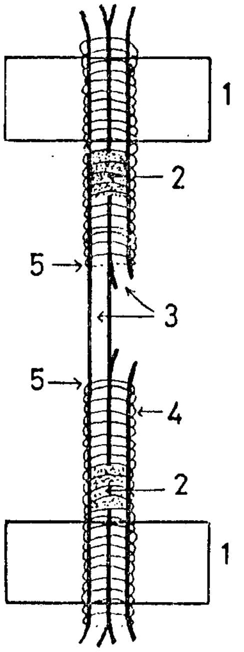
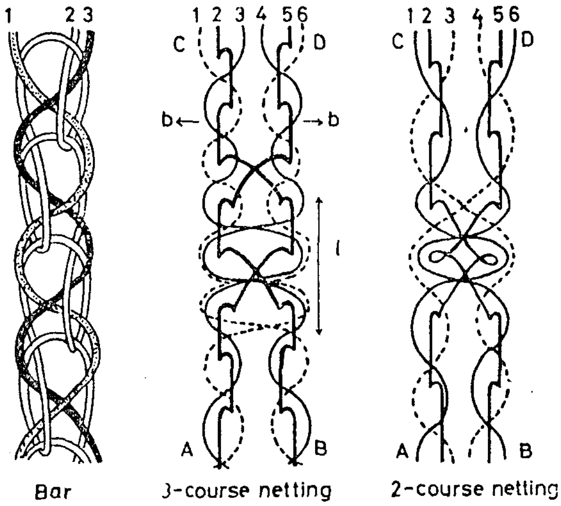


Fig. 1. Preparation of test pieces of Raschel twines. 1: Pressing clamps, 2. Raschel joints, 3: Bars(Raschel twines), 4: Cotton twines, 5: Breaking points.



Bar 3-course netting 2-course netting

Fig. 2. Construction of Raschel nettings.
Course: means the number of loops arranged breadthwise at the joints.
1, 3, 4, 6: Free yarn(Straight yarn).
2, 5: Looped yarn(Front yarn).
l: Lengthwise pull, *b*: Breadthwise pull.
A, *B*, *C*, *D*: Symbols of bars.

coils, i. e., at the bars, and were gripped to the pressing clamps used widely, as shown in Fig. 1.

The tensile strength of Raschel joints was investigated in two cases : the pull by any two bars and that by four bars. In case of four bar pull the strength was tested at twelve values of the angle between the adjacent bars, *A-B* or *C-D* in Fig. 2, by the apparatus which has been described in the previous papers.6–7)

The apparatus as shown in Fig. 3 was contributed to test the tensile strength of Raschel nettings. The meshes of the test pieces arranged between the two iron bars were constantly 7 and those hung on the iron bars varied from 1 to 15. In addition to these pieces, netting pieces with some bars cut already shown in Fig. 4 were used to investigate the influence of the cut bars on the strength. Also with nettings cut as shown in Fig. 5 the tearing strength was investigated. For measuring the above strengths, the pendulum type (0-100 *Kg*) and the autograph (0-250 *Kg*) testing machines were employed.

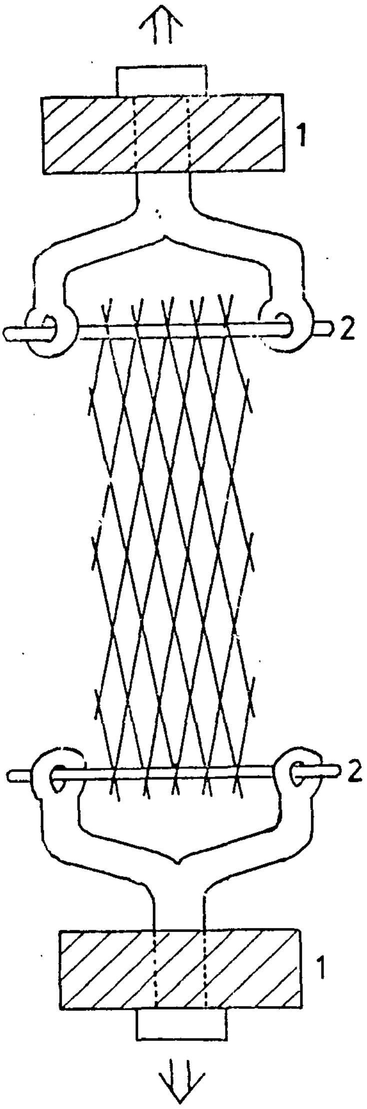


Fig. 3. Apparatus for testing netting strength.
1: Pressing clamps, 2: Iron bar.

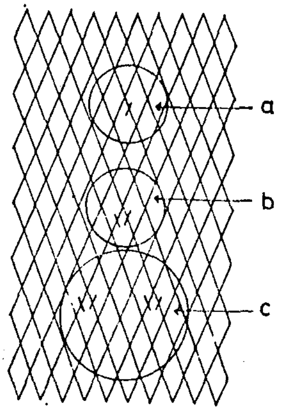


Fig. 4. Netting pieces with some bars cut already.
a: One bar cut, *b*: Two bar cut, *c*: Four bar cut.

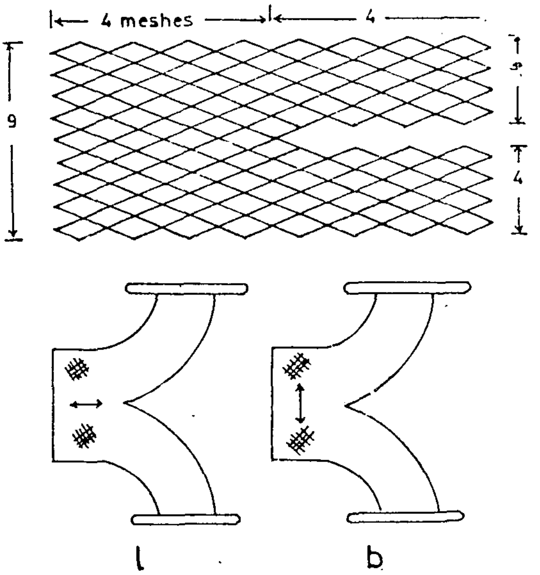


Fig. 5. Netting pieces used to test the tearing strength.
↔: Breadthwise direction of netting
l, *b*: shown in Fig. 2.

These machines both pulled the loading clamps at velocity of about 0.3 *m/min*.

Netting materials and the construction of Raschel nettings used in these experiments are given in Table 1 and Fig. 2, respectively. Reef knots and trawler knots to compare in strength with Raschel joints and twisted joints were tied with the bars of the twisted-jointed netting.

Table 1. Netting materials used in the experiment

Netting	Fiber materials	Construction of bar			Mesh size	Dyeing
		Looped yarn	Free yarn	Total		
3-course netting	Poly-ester multi-f.	420 d	420 d	2100 d (210 d ×10)	43 *mm*	black
		1260 d	1260 d	6300 d (210 d ×30)	105 *mm*	
2-course netting		(420+630) d	(420+630) d	5250 d (210 d ×25)	30 *mm*	
Twisted-jointed netting		250 d×18×2=9000 d			100 *mm*	

* Expressed by the total thickness of three looped yarns and two free yarns passing through any cross section of bars (see Fig. 2).

RESULTS AND DISCUSSION

1. The decrease in strength of Raschel twines at Raschel joints

Table 2 indicates the tensile strength of Raschel twines and that of Raschel joints pulled by any two bars and by four bars. In case of pull by two bars, the 3-course joint is arranged in order of strength as follows: *A-C(B-D)* bar pull> *A-D(B-C)* bar pull> *A-B(C-D)* bar pull, and the 2-course joint: *A-D(B-C)* bar pull> *A-C(B-D)* bar pull> *A-B(C-D)* bar pull. On the occasion pulled simultaneously by four bars, both the two types of joints show higher strength in

Table 2. Tensile strength T_0 of Raschel twines and that T_R of Raschel joints in *g/den* Value in parentheses: Rate of decrease in strength of the twines at the joints in %

Netting	T_0 in dry	T_R in two bar pull			T_R in four bar pull			
		A-C(B-D) bar pull*1	A-D(B-C) bar pull*1	A-B(C-D) bar pull*2	Dry		Wet	
					*l**3	*b**3	*l*	*b*
3-course netting (210 d×30)	3.40	1.55	1.50	1.20	2.97 (12.6)	2.67 (21.5)	3.06	2.77
2-course netting (210 d×25)	3.40	1.19	1.25	1.06	2.95 (13.2)	2.53 (25.6)	3.05	2.69

*1. This means pulling the joints lengthwise by the two bars.
*2. This means pulling the joints breadthwise by the two bars.
*3. Shown in Fig. 2.

lengthwise pull than breadthwise. Comparing the two bar pull and the four bar pull, the 2-course joint is stronger in the latter pull not only in lengthwise pull, but also in breadthwise pull. The 3-course joint stretched breadthwise is also stronger in the latter pull, but in case of lengthwise stretching the reverse takes place.

As can be seen in Fig. 2, the yarns constructing the Raschel joints are different from one another not only in passing way through the joints, but also in length, curvature, interlaced number at the joints, etc. Owing to these difference, the joints given to tensile loads are deformed from their original shape and put in a unbalanced tensile distribution. The unbalanced tensile distribution will increase the tension acting on the yarns responsible for breakage and decrease the tensile strength of the joints.

According to direct observation, the deformation of the joints seemed to be small when they were pulled to the direction in which the yarns passed mainly. This suggests that the joints will be strong when pulled to the above direction. That is, the joints pulled by two bars will be stroengest in *A-C* (*B-D*) bar pull and weakest in *A-B* (*C-D*) bar pull. Being pulled by four bars, the joints will be stronger in lengthwise pull than breadthwise. Comparing the two bar pull and the four bar pull, the higher strength will be made in the latter pull because the deformation seems to be smaller in the latter pull. But only two cases, the two bar pull of the 2-course joint and the lengthwise pull of the 3-course joint, produced results opposite to the above presumption. That is, the 2-course joint pulled by two bars showed the highest strength in *A-D* (*B-C*) bar pull and the 3-course joint stretched lengthwise made less strength in pull by four bars than by two bars. The former opositions considered to be due to the fact that the yarns running in *A-D* (*B-C*) bar direction are smaller in curvature by less interlace than the others running in *A-C* (*B-D*) and bear tension longer. The 3-course joint is originally little influenced by the deformation. Nevertheless, pulling the joint by four bars supplies tension to all of yarns and so gives higher compressive force than in case of two bar pull. This may bring about the after opposition. These results mentioned gives another information that the tensile strength of Raschel joints may be influenced mainly by their deformation and the compressive force between yarns.

As mentioned above, the deformation will put the joints into unbalanced tensile distribution and increase the tension on the yarns responsible for breakage. The compressive force will cause a frictional force on the yarns, for the yarns are compressed by anothers in course of redistribution due to tension. The frictional force will resist the redistribution as much. But the largest frictional force seems to be not made at the interior of the joints by the firmness of the joints due to much interlace of yarns or at the bars, but at the boundaries between the joints and the bars, as can be surmised from the fact that the joints are broken generally from the boundaries. Thus, the tension on the yarns responsible for breakage will increase again as mush as the frictional force increased at the boundaries. Consequently, the tensile strength of Raschel twines will decrease at the joints as much as the sum of the tension increased by the unbalanced tensile distribution and the frictional force increased at the joints. The total increment of the tension and the frictional force may be about 13 % of the tensile strength of Raschel twines in lengthwise pull and 22 to 26 % in breadthwise pull, as listed in parentheses in Table 2.

2. Comparison of strength between the 2—course joint and the 3-course joint

As mentioned above, the Raschel machines allow Raschel joints of various construction. Therefore, the determination of the joint structure having the highest tensile strength is a practical problem to be solved immediately. According to Table 2, the 3-course joint is stronger than the 2-course joint in all cases of pulls. But the difference of strength between the two types of joints is larger in pull by two bars than by four bars. These reasons are probably why the 2-course joint is easier to be deformed by less interlace of yarns than the 3-course joint, especially in two bar pull. It can be therefore seen that the Raschel joints of higher course will show less unbalanced tensile distribution and higher tensile strength. However, increasing the number of course changes the shape of meshes from rhombic into hexagonal. Therefore, the highest possible number of course is considered to be three.

The two types of joints used in this experiment both show considerably low strength when pulled breadthwise. That is, the 3-course joint pulled breadthwise has about 10% less strength than that pulled lengthwise, and the 2-course joint about 13% less strength. This emphasizes that the joint having a strength in the two pulls is to be made. As a method for settling this problem, the author considers in the joint structure that most of yarns run in diagonal lines, *A-D* (*B* -*C*) bar direction.

3. Raschel joint strength in pull by opened bars

The variation of the 3-course joint strength T_R with the angle φ between the adjacent bars *A-B* or *C-D*, is shown in Fig. 6. with increasing φ, the strength T_R decreases almost linearly, i. e.,

$$T_R = T_{RO} - K\varphi, \qquad (1)$$

where T_{RO} is the strength at $\varphi = 0^\circ$, and K is a constant decided by the kind of fiber material ($K = -0.63 \times 10^{-3}$). The decrease of the strength with increasing φ is considered to be due to the increase in deformation of the joint.

The 2-course joint strength in pull by opended bars was not tested by reason of some experimental inconveniences. But the deformaton of the joint shown in pull by hands also seemed to increase with φ. It is therefore fully expected that the 2-course joint will show the same tendency as the 3-course joint.

4. Tensile strength of Raschel netting

In testing the tensile strength of Raschel nettings, the breakage of the 3-course netting occurred always from any indefinite joint and advanced mostly to the extension line of bars or to the direction perpendicular to the pulling. However, the 2-course netting was broken mainly from the joints hung on the iron bars of the clamps or from the joints next to the iron bars and tested tensile strength seemed to show loss because of the influence of the iron bars.

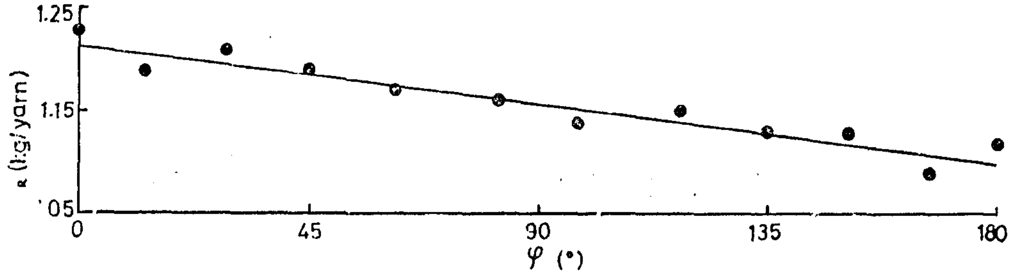


Fig. 6. Variation of Raschel joint strength T_R With φ.
Material: The 3-course netting(210×30).

Fig. 7 shows the variation of the tensile strength of the two types of Raschel nettings with the number of meshes at the pulling side. The tensile strength σ_R is proportional to the number N of meshes, i. e.,

$$\sigma_R = KN, \qquad (2)$$

where K is a constant.

Table 3 gives the value of K and the tensile strength T_R of the single Raschel joint. In case of the 3-course netting, the value of T_R is almost equal to that of K in both lengthwise and

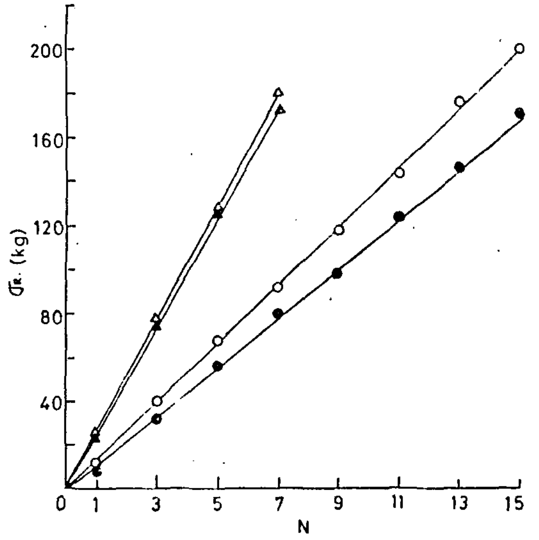


Fig. 7. Variation of the tensile strength σ_R of Raschel nettings with the number N of meshes at pulling side.
○, ●: The 3-course netting(210d×10)
△, ▲: The 2-course netting(210d×25)
○, △: Lengthwise pull.
●, ▲: Breadthwise pull.

breadthwise pulls. This means that in the 3-course netting the inequality in mesh size, thickness of yarns, tightened degree of yarns at the joints, *etc.* may be disregarded. The disregard will be within the bounds of possibility also in the 2-course netting, because the two types of nettings are made in the same condition. But the value of K of the 2-course netting is about 6 or 17% smaller than its joint strength T_R according to the pulling direction. This might be due only to the influence of the iron bars. If there exists no influence of the iron bars, the relation between K and T_R may be given by

$$K = T_R \qquad (3)$$

not only in the 3-course netting but also in the 2-course netting, and equation (2) may be rewritten as

$$\sigma_R = T_R N. \qquad (4)$$

Also substituting equation (1) in (4), σ_R in case of being given to any hanging ratio or any value of φ may be represented by

$$\sigma_R = N(T_{RO} - K\varphi)\cos\frac{\varphi}{2}. \qquad (5)$$

Table 3. Comparison between T_R and K in *kg*

Netting	*l*		*b*	
	T_R	K	T_R	K
3-course netting (210d×10)	13.5	13.3	11.2	11.4
2-course netting (210d×25)	31.0	25.7	26.6	25.0

l, *b*: Shown in Fig. 2.

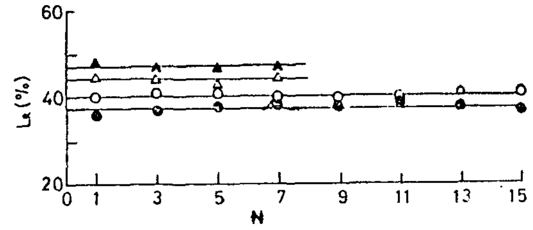


Fig. 8. Breaking elongation of Raschel nettings.
○, ●, △, ▲: Shown in Fig. 7.

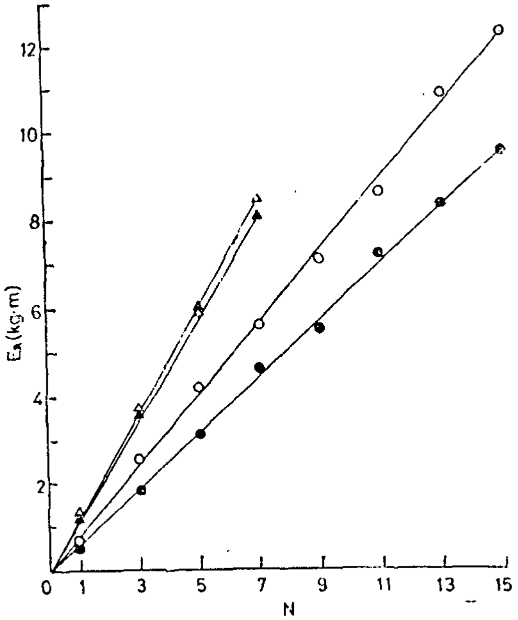


Fig. 9. Variation of the breaking energy E_R of Raschel nettings with N.
○, ●, △, ▲: Shown in Fig. 7.

Fig. 8 shows the breaking elongation of the two types of Raschel nettings. The elongation is almost constant independent of the variation of N and not so significant in difference between lengthwise and breadthwise pulls, but shows a little larger value in the 2-course netting. This is probably why the 2-course netting is made of thicker twines.

Fig. 9 indicates the variation of the breaking energy of the two types of Raschel nettings with N. The energy E_R is in proportion to N, i. e.,

$$E_R = AN \qquad (6)$$

where A is a contant (Table 4).

Table 4. Value of A in $E_R = AN$ (*kg. m*)

Netting	*l*	*b*
3-course netting (210 d×10)	0.82	0.65
2-course netting (210 d×25)	1.19	1.16

l, *b*: Shown in Fig. 2.

5. Tensile strength of Raschel netting with some bars cut already

Fishing nets during handling are frequently broken in part by a variety of troubles. When the breakage is very small, the nets can be used again without mending. But it is rather a question whether the dreakage will influence the tensile strength of the nets or not.

According to Fig. 10, the decrease in strength, breaking energy, and breaking elongation of Raschel nettings by the influence of the bar cut already becomes larger as the number of the cut bars increases, but its degree is considerably large even if in one bar cut. Moreover, direct observations exposed that the nettings are broken firstly at the joint of the bar next to the cut bar and the break spreads to another joints. These results demonstrate that the mending of nets is important not only in breakage of numerous bars but also in that of only one bar.

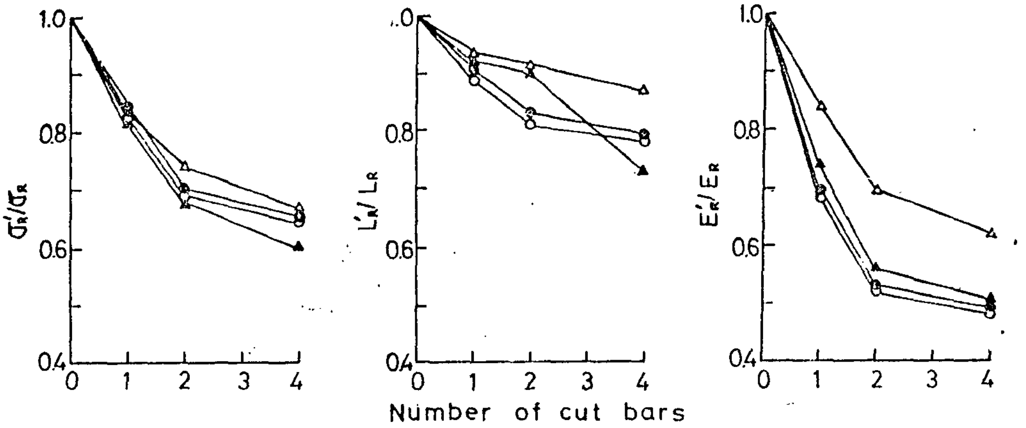


Fig. 10. Decrease in strength σ_R, breaking elongation L_R, and breaking energy E_R of Raschel nettings by the influence of the cut bars. σ_R', L'_R E'_R: indicate the strength, the breaking elongation, and the breaking energy of Raschel nettings having cut bars.

6. Tearing strength of Raschel netting

Fig. 11 gives the stress-strain diagram of Raschel nettings under tearing loads. The stress and the atrain increase together until a joint breaks and return zero at the break. This process is repeated several times because the joints are broken one by one. But there occurrs little change in the breaking load and elongation. The breaking load is almost equal to the tensile strength of single Raschel joint pulled by two bars and very small in comparison with the tensile strength of the netting tested by the method shown in Fig. 3. That is, the tearing strength is significantly low in comparison with the tensile

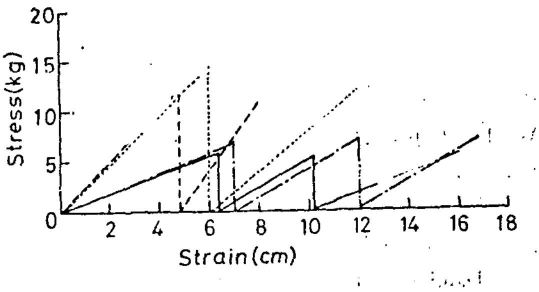


Fig. 11. Stress-strain diagram of Raschel nettings under tearing loads.
—— • —— :Lengthwise pull of the 3-course netting.
———— :Breadthwise pull of the 3-course netting.
············ :Lengthwise pull of the 2-course netting.
- - - - - - - - :Breadthwise pull of the 2-course netting.

strength. This result gives that fishing nets should be designed not to be subjected to tearing loads in actual use.

7. Comparison of Raschel joint with knot and twisted joint in strength

A comparison of the Raschel joint with the knot and the twisted joint in strength is made in fig. 12. The twisted joint is the strongest of the three kinds of joints, the knot being a poor second, and the Raschel joint being the weakest. But the difference of strength between the knot and the Raschel joint is considerably small, especially in lengthwise pull. That is, the knot strength varies between 69 and 76% of the twisted joint strength. The Raschel joint pulled lengthwise shows a strength, 71 to 74%, lying in the range of the knot strength, but that pulled breadthwise does not varying from 62 to 67%.

These results may be ascribed to the difference among the decreases in strength that netting twines show at the three kinds of joints. As made clear by the previous[5-7] and the present studies, the decreases in strength of netting twines at the three kinds of joints are all due mainly to the frictional force acting on the boundaries between the joints and the bars, although in case of the Raschel joint the unbalanced tensile distribution also influences the decrease. It can be therefore seen that the joint subjected to the smallest frictional force is most favourable and the development of new joints should be based on reducing the frictional force.

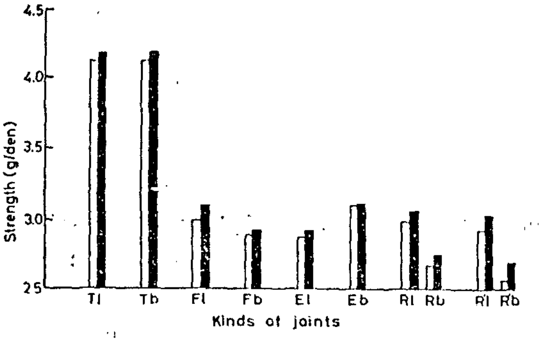


Fig. 12. Comparison of the Raschel joint with the knot and the twisted joint in strength.
Tl, *Tb*: Twisted joint.
Fl, *Fb*: Reef knot.
El, *Eb*: Trawler knot.
Rl, *Rb*: 3-course Raschel joint(210d× 30).
R'l, *R'b*: 2-course Raschel joint(210d× 25).
l, *b*: Shown in Fig. 2.
☐ : Dry, ▨ : Wet.

SUMMARY

1) The decrease in strength of Raschel twines at Raschel joints is regarded to be due mainly to the frictional force between yarns and the unbalanced tensile distribution by the deformation of the joints. The rate of the decrease is about 13% in lengthwise pull and 22 to 26% in breadthwise pull.

2) The 3-course joint is less in deformation and stronger than the 2-course joint in all cases of pulls.

3) The variation of Raschel joint strength T_R with the angle φ between the adjacent bars is expressed as

$$T_R = T_{R0} - K\varphi,$$

where T_{R0} is the strength at $\varphi = 0^0$ and K is a constant.

4) The tensile strength σ_R and the breaking energy E_R of Raschel netting are given by

$$\sigma_R = KN \quad \text{or} \quad \sigma_R = T_R N$$

and

$$E_R = AN,$$

respectively, where N is the number of meshes at the pulling side, and K and A are constants. But the breaking energy of the netting is almost constant independent of the variation of N.

5) The Raschel netting with some bars cut already breaks from the joints of the bars next to the cut bars and its tensile strength, breaking energy, and breaking elongation decrease largily even if only one bar is in already cut state.

6) The tearing strength of Raschel netting is almost equal to the tensile strength of its single joint pulled by two bars.

7) The twisted joint is much more excellent in strength than the knot or the Raschel joint. The knot strength is 69 to 76%, and the Raschel joint strength is 71 to 74% in lengthwise pull and 62 to 67% in breadthwise pull, respectively, of the twisted joint strength.

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