REINFORCING EFFECT OF HIGH STRENGTH VINYLON SHORT FIBER WITH VARIOUS ELONGATIONS ON CONCRETE

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High strength vinylon fibers with various elongations were prepared to examine the reinforcing effect of their short fibers on concrete. The results indicated that the flexural strength and equivalent flexural strength of concrete reinforced with vinylon fibers with the tensile strength at break of 8% were maximum. Maybe this is because the oblique tensile strength of the fiber obtained by assuming the behavior of the fibers on the rupture cross-section of concrete increases with increasing the elongation of vinylon fiber, while the Young's modulus and the work done for pulling the fiber out of concrete decrease with increasing the elongation of vinylon fiber.

KEY WORDS : Thick Vinylon Fiber, Flexural Strength, Equivalent Flexural Strength, Oblique Tensile Strength, Pull-out Test

1. INTRODUCTION

Although many researches on the mortar reinforced with fibers including organic chemical fiber, carbon fiber and glass fiber have been reported, few papers on the short fiber-reinforced concrete have been published. This is because the breaking of the short fiber by mixing and placing concrete, the poor dispersion of short fibers and the rationalization of the performance of short fiber have not been elucidated yet. Then, the reinforcing effects of the thick vinylon fiber were investigated by preparing thick vinylon fiber samples with various Young's moduli in tension and tensile elongations so as not to break the fiber and cause the poor dispersion of them.

2. PREPARATION OF THICK VINYLON FIBERS

Thick vinylon fiber samples with the tensile elongation at break stepwise varying from 4.3 to 22.8% as listed in Table 1 were prepared by spinning an aqueous stock solution of polyvinyl alcohol into hot air through nozzles to evaporate the water of solvent and thermally stretch for developing the strength and elongating the fiber by the thermal shrinkage. Thus - prepared short fiber test specimens are called A, B, C, D, E and F in the ascending order of the elongation. The sectional areas of those six thick vinylon fiber test specimens range from 0.36 to 0.52 mm^2 and the diameters in circular cross-section equivalent are from 0.68 to 0.81 mm. The relationship in those test specimens between the tensile load at break and the elongation determined accord-ing to the test method for chemical fiber filament yarn specified in JIS L 1073 is illustrated in Fig. 1.

The value obtained by dividing the tensile load of the fiber at break by the sectional area of it and the initial rising gradient are defined as the tensile strength at break and the Young's modulus in tension of the fiber, respectively. The curve has a characteristic point of inflection at the tensile load near 50N where the hydrogen bond in the OH group in the noncrystalline polyvinyl alcohol is considered to be disconnected by the increase of stress. Since the noncrystalline part becomes further stretchable by the disconnection of the hydrogen bond, the gradient of the stress-elongation curve becomes easier. Those six vinylon fiber samples with slightly different diameters have almost the same tensile load at break as each other though the tensile elongations at break of them differ from each other.

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3. TEST METHODS

3.1 PREPARATION METHOD OF FLEXURAL TEST SPECIMEN

Test specimens as short as 30 to 40 mm long of thick vinylon fibers with various diameters were prepared by cutting the samples. As listed in Table 3, the mortar test specimens were prepared for comparing with concrete test specimens prepared according to the mix proportions listed in Table 2.

The results of the sieve analysis of coarse and fine aggregates used for the experiment are within the standard range of JAS S5. The mixing ratios of vinylon fiber with concrete and mortar for preparing the test specimens are 0.75 and 1.00% by volume, respectively. The mixing ratios were determined by a method for searching fresh concrete with the appropriate workability. The vinylon fiber is finally mixed using an Omni-mixer after mixing the ingredients other than the vinylon fiber.

Compressive strength of concrete : 42.2 MPa
Compressive strength of mortar : 54.0 MPa
Coarse aggregate : Macadam produced in Mitsu-cho, Mitsugun, Okayama Prefecture
Fine aggregate : Sea sand produced in Murokishima, Sakaide City, Kagawa Prefecture 70, Sea sand produced in Ieshima-cho, Shikamagun, Hyogo Prefecture 30

Thus-prepared concrete and mortar are molded by casting the concrete or mortar divided into two parts into a mold with the dimensions of 10x10x40 cm. The molded test specimens are released from the mold the next day and cured in water of 20° C till reaching the age of 28 days. The preparation method of the test specimen is executed in accordance with JCI-SF2 "Method of Making Test Specimens for Strength and Toughness of Fiber-Reinforced Concrete" specified by Japan Concrete Institute.

3.2 FLEXURAL TEST METHOD

The deflection of the test specimen at the middle of span is measured by applying the 300 mm span-third point loading according to JCI-SF4 "Methods of Tests for Flexural Strength and Toughness of Fiber-Reinforced Concrete" specified by Japan Concrete Institute. The equivalent flexural strength (N/mm^2) is calculated from the flexural toughness from zero to 2 mm corresponding to 1/150 as long as the span of 300 mm.

3.3 PULL-OUT TEST OF FIBER

Vinylon fibers 30 mm long were embedded in mortar to make the pull-out test of fiber according to JCI-SF8 written in the standards concerning "Method of Adhesion Test for Fiber-Reinforced Concrete" specified by Japan Concrete Institute. The vinylon fibers were, however, broken by making the test. Accordingly, the test was made according to the following method: holes with the same diameter as that of the fiber are made in two plastic plates; these two plastic plates are opposed to each other with the space of 10 mm; fibers are inserted in the holes; the space between the plates is filled with mortar; and mortar is completely filled up by vibrating it with an electric-powered brush. The water/cement ratio of the mortar is 50%. The mortar is cured at 20° C for 14 days. After releasing the plates from the mortar, the fibers on one side are cut off and ten test specimens for each type of fiber are prepared. The test specimen is held with a jig and the fibers are held at the edge of mortar to pull them out. The rate of pulling is 0.5 mm/min and the relationship between the pull-out load and the pull-out displacement is recorded.

3.4 OBLIQUE TENSILE TEST OF FIBER

Although the tensile test method of fiber is specified by JIS L 1073, the cut-off portion of fiber is a straight part not keeping contact with the measuring jib. Table 1 lists the test result. The oblique tensile test assumes the tension of fiber on the rupture cross-section. The fibers are firmly held with two steel plate chucks and a device for tilting the chuck is fabricated. In this method, the fibers keep in contact with the right angle corner of the chuck. Although it is considered that the measurements are affected by the curvature of the corner of the chuck, it is difficult to reproduce the measurement because the shape of the rupture cross-section of concrete is indeterminate. The purpose of the test is, therefore, changed to quantitatively evaluate each type of fiber under the same conditions of the chuck. The tilt angle of the chuck is equal to the angle of fiber bent. The angle is changed from 15 to 60 degrees through 30 and 45 degrees. Since the fibers are not thoroughly held with the flat chuck at zero degree in a tensile test, it is replaced by the value given in Table 1 made by the JIS method.

4. TEST RESULT AND DISCUSSION

4.1 RESULT AND DISCUSSION OF FLEXURAL TEST OF CONCRETE

The mean values of the slump values of concrete prepared by various mix proportions and of the flexural test results of the four test specimens are listed in the following tables. The test results of two types of 30 mm- and 40 mm-fiber reinforced concrete and of 30 mm-fiber reinforced mortar are listed in Tables 4, 5 and 6, respectively. The relationships in the test specimens between the flexural load and the deflection are selected as the typical diagrams from the diagrams of the four test specimens as follows: the results of concrete reinforced with the fibers 30 mm and 40 mm long and mortar reinforced with the fiber 30 mm long are illustrated in Figs. 2, 3 and 4, respectively.

Concrete reinforced with the vinylon sample B is superior in the flexural strength and equivalent flexural strength to the other types of concrete reinforced with different vinylon samples. Particularly, there is a big difference in those performances of concrete between the vinylon samples A and B. The flexural load of the vinylon A-reinforced concrete test specimen sharply decreases with increasing the deflection, while the flexural loads of the vinylon B and C-reinforced concrete test specimens do not so much decrease. And the flexural loads of the vinylon D, E and F-reinforced concrete test specimens after cracking do not increase and those test specimens have a tendency to maximize the flexural load in a range of the deflection of 2 mm or more.

The relationships of the flexural strength and equivalent flexural strength of concrete with the tensile elongation at break of the fiber are illustrated in Figs. 5 and 6, respectively. Those figures reveal that those performances are largely related to the tensile elongation at break of the fiber.

The rupture cross-sections of the test specimens after the measurement were observed. Relatively few fibers were exposed on the rupture cross section and there were conspicuously many broken fibers instead in the vinylon A-reinforced test specimens, while a lot of fibers were exposed on the rupture cross-section so that the fibers seemed to be pulled out of the matrix in the vinylon C, D, E and F-reinforced test specimens. The number of the fibers exposed on the rupture cross-section was relatively larger in the vinylon B-reinforced test specimen than in the vinylon A-reinforced one in which the broken and pulled out fibers were mixedly observed. It is considered that the breaking and pulling-out of the fiber on the rupture cross-section are classified by the oblique angle and length of the fiber embedded in concrete. The probabilities of the breaking and pulling-out of the fiber vary according to the performance of the fiber. Paying attention to these phenomena, the oblique tensile test and pull-out test of fiber were made to elucidate the reinforcement mechanism of short vinylon fiber.

4.2 RESULT AND DISCUSSION OF OBLIQUE TENSILE TEST OF FIBER

The results of the oblique tensile test of various fibers are listed in Table 7. The breaking load of fiber decreases with increasing the oblique angle, particularly the vinylon sample A. The relationships in various fibers between the oblique tensile strength at break and the oblique angle are illustrated in Fig. 7. The tensile elongations at break of fibers expressed by the oblique tensile loads at break of them at the angle of 30, 45 and 60 degrees are illustrated in Fig. 8.

Fig. 7 reveals that the oblique tensile load at break of fiber decreases with decreasing the angle. Maybe this is because since the flexure stress is applied more to the side elongated by the bending of the fiber at a corner than to the opposite side of it, the fiber is broken by lower tensile load. The flexure stress on the elongated side of the fiber increases and the tensile load of it at break further decreases with increasing the bending angle of the fiber. Fig. 8 reveals that the flexure stress on the elongated side of the fiber does not increase and the tensile load at break of it hardly decreases with increasing the elongation of the fiber.

4.3 RESULT AND DISCUSSION OF PULL-OUT TEST OF FIBER

The measurements of the pull-out test of fiber were so much scattering that one result among ten was extraordinarily small. Maybe this is because the contact of fiber with cement on the interface was bad. A typical relationship between the pull-out load and the length of fiber pulled out was selected from the measurements to illustrate in Fig. 9.

The figure reveals that the initial peak in the diagram indicates the adhesiveness of the fiber to the matrix and the pull-out load which once decreases and increases again indicates the frictional force between the fiber and the matrix. The sectional area of the fiber is so much reduced by stretching it that space is left on the interface, thereby decreasing the frictional force. A fiber with lower Young's modulus may be, therefore, able to be easily pulled out with lower load.

With reference to the method for determining work load from the load-amount of slippage curve illustrated in JCI-SF8, the average of the work done for slipping 2.5 mm the fiber expressed by the elongation of the fiber is illustrated in Fig. 10. The work done for pulling the fiber out decreases in a region of large elongation of fiber and the equivalent flexural strength determined from the flexural toughness decreases in regions of vinylon sample of C, D, E and F with large elongation. The tendency agrees with that in Fig. 6.

5. DISCUSSION OF REINFORCEMENT MECHANISM OF SHORT VINYLON FIBER

The flexural test results obtained from the knowledge mentioned above indicate as follows: since the Young's modulus in tension of vinylon sample A is high, the stress of the fiber so much increases that the flexural strength is developed in a deflection region not so low as breaking the fiber in the flexural test of short vinylon sample A-reinforced concrete, but the fiber starts breaking and the equivalent flexural strength decreases by further pulling the fiber with further increasing the deflection, because the oblique tensile load at break of it is low; in the flexural test of short vinylon sample B-reinforced concrete, the vinylon sample B is hard to be broken and hard to be pulled out even by increasing the deflection owing to large oblique tensile load at break, thereby keeping the stress of the fiber even by increasing the deflection; and in the flexural tests of short vinylon fiber samples C, D, E and F-reinforced concrete, the flexural loads at break of those four vinylon samples remarkably decrease because the Young's moduli of those four vinylon samples are low, and the fibers are pulled out because the subsequent restorations of flexural load of them are insufficient though the oblique tensile loads at break of them are high. Particularly vinylon fiber sample F is glidingly pulled out of the matrix, thereby not increasing the flexure stress.

6. CONCLUSION

The research on the reinforcement of concrete with short, thick vinylon fibers with tensile elongation at break of 4.3 to 22.8% was made and the following conclusions were obtained:

(1) The flexural strength and equivalent flexural strength of concrete reinforced with the thick vinylon sample B with the tensile elongation at break of 8% are maximum.

(2) The oblique tensile load of the fiber increases with increasing the tensile elongation at break up to 8%, while the Young's modulus in tension and work done for pulling out the fibers decrease with increasing it exceeding 8%. The equivalent flexural strength has, therefore, the maximum value.

Table 1　Property of thick vinylon fibers

specimen	A	B	C	D	E	F
decitex (dtex)	4536	5051	5280	5651	5831	6433
cross sectional area (mm^2)	0.36	0.41	0.42	0.45	0.47	0.52
mean diameter (mm)	0.68	0.72	0.73	0.76	0.77	0.81
ultimate tensile load (N)	277	304	329	307	335	325
elongation at tensile strength (%)	4.3	8.4	11.4	14.0	19.7	22.8
tensile strength (MPa)	761	751	776	678	716	636
Young's modulus in tension (GPa)	29.9	23.4	21.0	18.2	17.7	16.2

dtex : weight(gr) of 10000m length fiber　　specific gravity of A ～ F = 1.30

Table 2　Mix proportions of concrete

water cement ratio W/C %	sand percentage S/(S+G) %	quantity of material per unit volume of concrete kg/m^3					fiber volume content %
		water W	cement C	sand S	gravel G	admixture	
55	55	185	337	47	784	1.7	0.75

Table 3　Mix proportions of mortar

water cement ratio W/C %	sand percentage S/C %	quantity of material per unit volume of concrete kg/m^3				fiber volume content %
		water W	cement C	sand S	admixture	
35	20	237	677	1355	6.8	1.0

Table 4　Test result of concrete (fiber length 30mm)

specimen	A	B	C	D	E	F
slump (cm)	11.0	9.9	10.6	12.1	11.0	11.2
air content (%)	3.9	3.9	4.9	4.0	3.9	4.4
flexural strength (N/mm^2)	4.35	4.13	2.90	2.71	2.40	2.23
deflection (mm)	0.54	1.33	1.14	1.79	2.40	2.89
equivalent flexural strength (N/mm^2)	2.51	3.80	2.92	2.68	2.32	2.11

Table 5 Test result of concrete (fiber length 40mm)

specimen	A	B	C	D	E	F
slump (cm)	7.9	8.1	9.8	8.9	—	10.0
air content (%)	3.4	4.3	3.7	3.5	—	3.74
flexural strength (N/mm^2)	4.37	5.00	4.30	3.96	—	1.65
deflection (mm)	0.50	1.27	1.47	2.20	—	2.45
equivalent flexural strength (N/mm^2)	2.68	4.68	3.92	3.59	—	2.01

Table 6 Test result of mortar (fiber length 30mm)

specimen	A	B	C	D	E	F
slump (cm)	14.6	15.5	14.6	17.4	—	16.9
air content (%)	6.9	6.8	6.5	7.0	—	6.2
flexural strength (N/mm^2)	5.01	4.82	5.01	4.28	—	3.35
deflection (mm)	0.47	1.28	1.49	2.28	—	2.95

Table 7 Strength of vinylon fiber by oblique tensile test

specimen	A	B	C	D	E	F
oblique angle 0 degree	277(100)	304(100)	329(100)	307(100)	35(100)	328(100)
〃 15 〃	211(74)	—	—	—	—	—
〃 30 〃	138(50)	185(61)	207(63)	193(63)	218(65)	219(67)
〃 45 〃	58(21)	146(48)	148(45)	160(52)	164(49)	171(52)
〃 60 〃	30(11)	142(47)	154(47)	153(50)	161(48)	166(51)

unit : N (%)

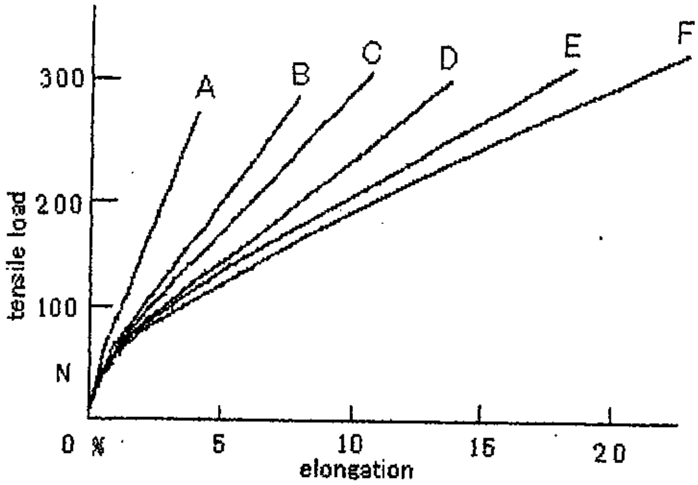

Fig. 1 Tensile load and elongation of vinylon fiber

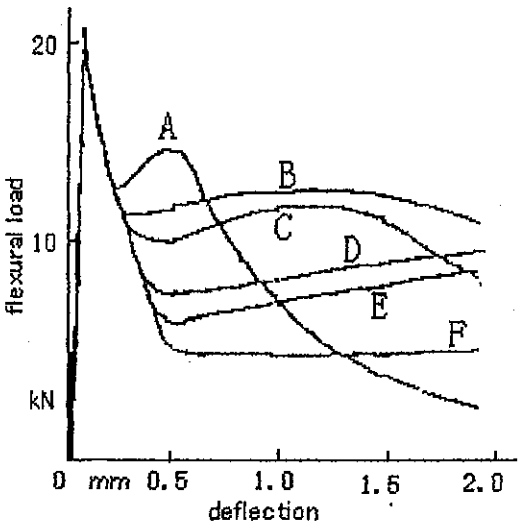

Fig. 2 Flexural load and deflection of concrete reinforced by 30 mm length fiber

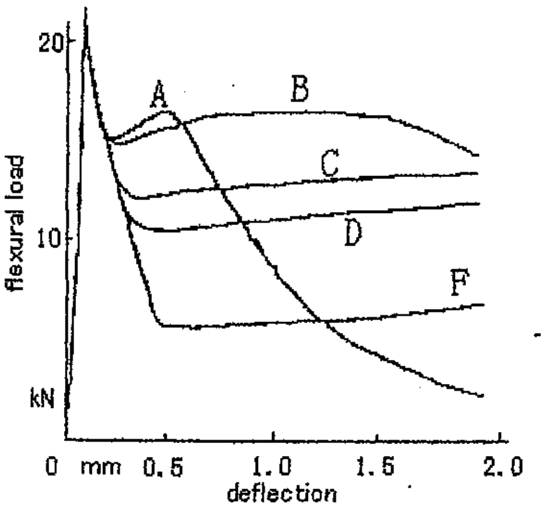

Fig. 3 Flexural load and deflection of concrete reinforced by 40 mm length fiber

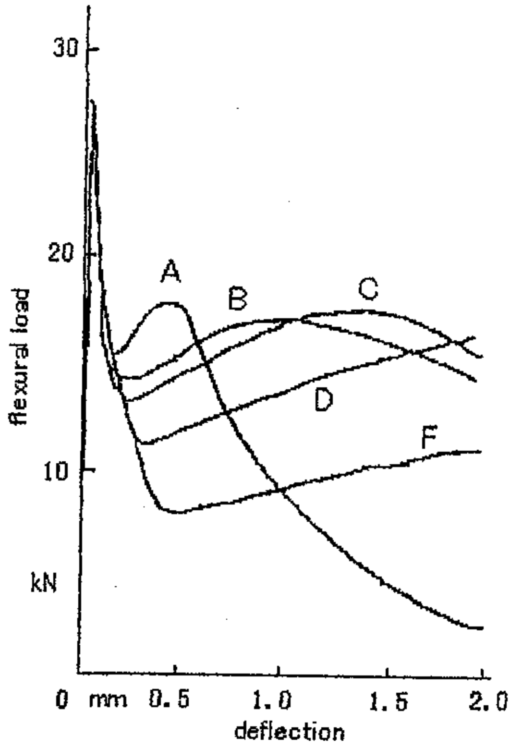

Fig. 4 Flexural load and deflection of mortar

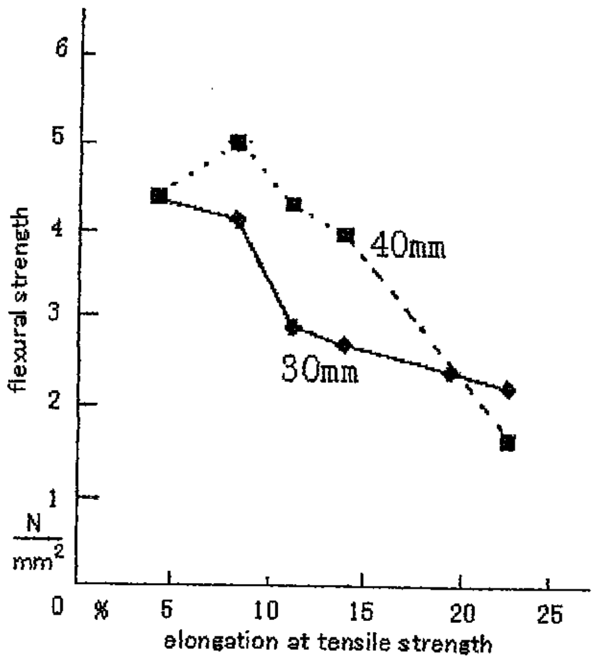

Fig. 5 Flexural strength of concrete and elongation at tensile strength of fiber

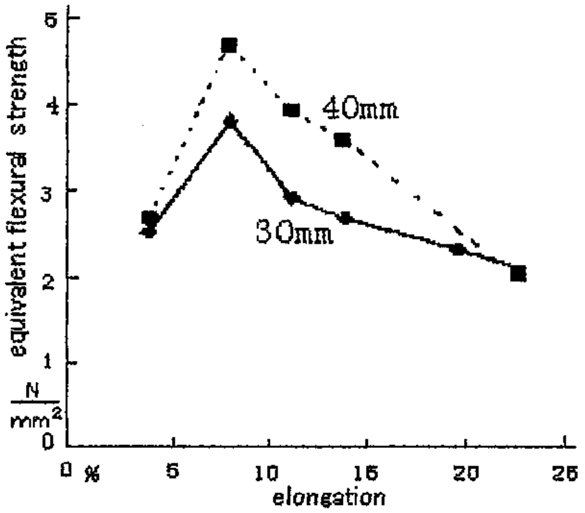

Fig. 6 Equivalent flexural strength and elongation of fiber

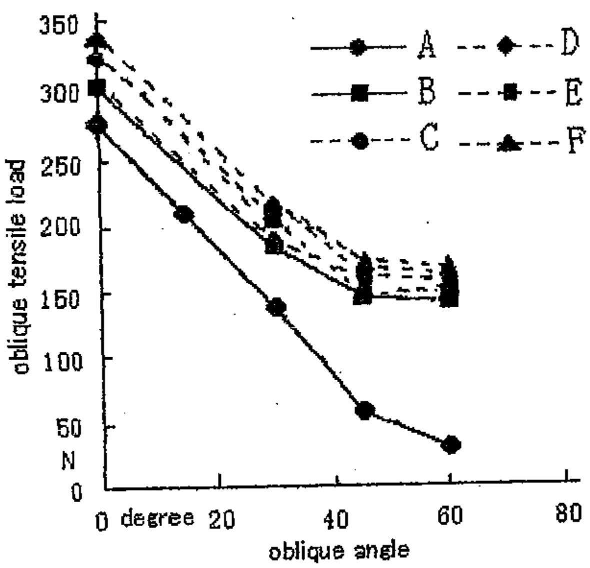

Fig. 7 Oblique tensile load and degree

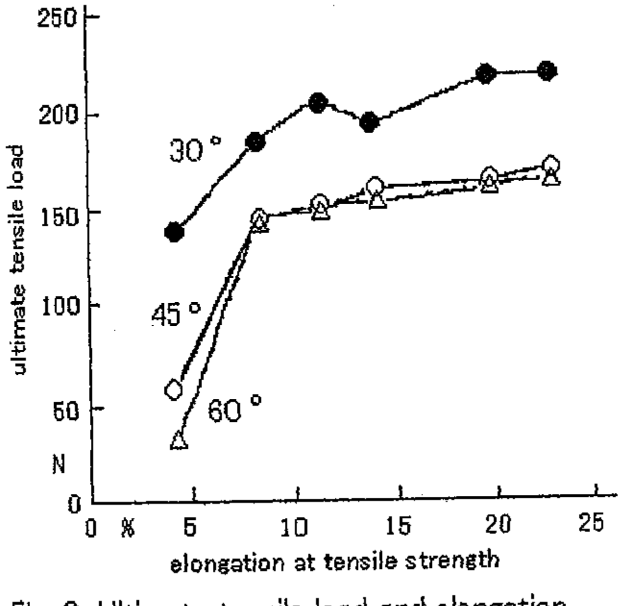

Fig. 8 Ultimate tensile load and elongation of fiber under oblique tensile load

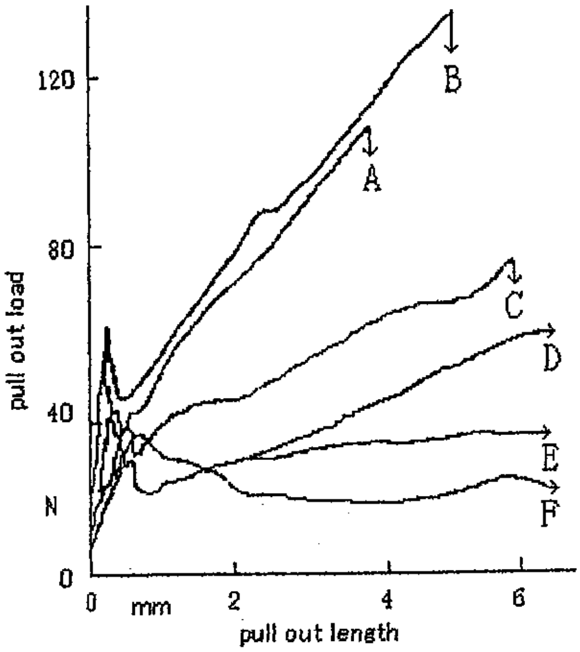

Fig. 9 Pull out load and length of fiber

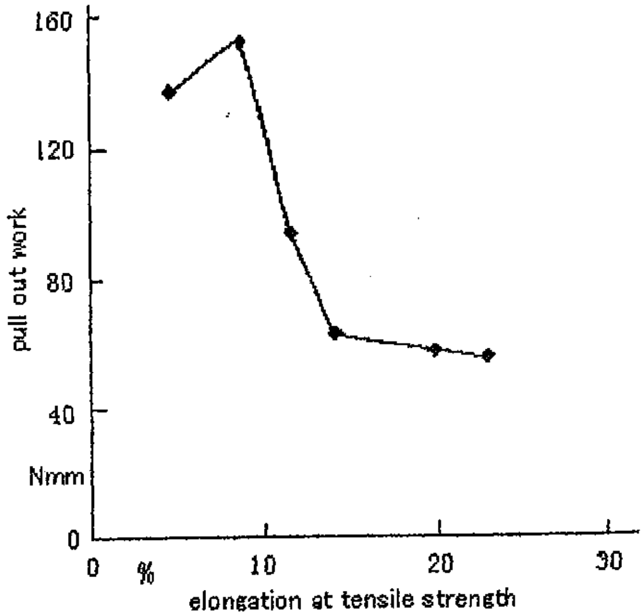

Fig. 10 Pull out work of fiber