Research article

Bending Strength and Toughness Properties of Pavement Concrete Reinforced with Bamboo Fiber

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Abstract The problems of neglected bamboo forest have been actualized in association with the aging of the people owning bamboo forest in recent years in Japan. Then it becomes imperative to establish the methods of effective utilization of the bamboo. Some bamboo has enough tensile strength as construction material, and studies and experiments on bamboo have been increasing gradually. The purposes of authors are to make short fiber of bamboo ("BF" for short) from Moso- bamboo, one of most popular bamboo in Japan, by ourselves, and to develop the concrete for pavement which matrix are reinforced with BF. A cross-linked effect between concrete surface on crack by BF had been expected as same as other kinds of short fibers. The purpose of this paper is to confirm the reinforcement effect by BF, and cement mortar was the object in order to simplify the experiments, in which the basic properties were investigated. The experiment factors are the amount of BF, water cement ratio, fiber length and distribution method of BF. These influence on compressive strength, bending strength and bending toughness was investigated experimentally. As the results, the followings were obtained. The strength does not increase only by a cross-linked effect by BF. The coefficient of toughness can be improved greatly by BF, and this effect is shown even in little quantity of fiber. Influence of water cement ratio on the toughness improvement is small. In case of random mixing of BF, each strength become lower without depending on fiber length, toughness coefficient can be improved. In case of spreading of BF, the strength and toughness coefficient can be improved even in little quantity of fiber.

Keywords bamboo fiber, short fiber, bending toughness, strength

INTRODUCTION

In recent years, the problems of neglected bamboo forest have been actualized in association with the aging of the people owning bamboo forest in Japan. Then it becomes imperative to establish the methods of effective utilization of the bamboo. Actually, bamboo has enough tensile strength as shown in Table 1 and studies and actions about the bamboo has been increasing gradually. Authors has made short bamboo fiber (see Photo 1, BF for shot) by ourselves from Moso-bamboo, and it is the final purpose to develop the concrete for pavement which matrix is reinforced by this BF. The purpose of this study is to confirm the reinforcement effect by BF. Mortar was intended to simplify the experiments, and its basic properties were investigated. The factors of experiment were fiber

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amount, water cement ratio, fiber length and casting method of fiber, and the influence of them to compressive strength, bending strength and bending toughness was acquired experimentally.

Table 1 Tensile strength of Moso-bamboo

No.	width (mm)	thickness (mm)	cross section (mm^2)	fracture load (N)	tensile strength (N/mm^2)
1	10.2	7.80	79.6	11400	143.3
2	13.5	8.00	108.0	12700	117.6
3	11.1	8.40	93.2	10000	107.3
4	12.7	7.80	99.1	13850	139.8
5	11.9	8.13	96.7	11950	123.5
6	9.2	8.33	76.4	9600	125.7
7	9.7	8.63	83.5	8150	97.7
8	9.5	8.43	79.8	10250	128.4
9	9.6	7.57	72.9	8100	111.1
10	11.3	8.13	91.6	11350	123.9
		average		10735	121.8

Photo 1 Handmade bamboo fiber

METHODOLOGY

a) Making of Bamboo Fiber and Materiasls

As a result of trial and error, the bamboo was molded into a fiber form by the next process. (1)split by circular wedge (2)unfastened by compressor for concrete (3)struck by mallet and unfasted again (4)cut to predetermined length. The moisture state of bamboo was determined as that it had been dried in laboratory over 1 year after the felling (air-dried state).

The materials were high early strength Portland cement, JIS standard sand, BF and tap water. Size of specimen was 40×40×160mm and they were taken out of molds on the next day of the casting. After curing in water, the tests were carried out at 7 days of material age.

b) Series I

The purpose in series I was to find the appropriate mixing ratio of BF which length was 20mm (aspect ratio was 13.3). In previous experiment, W/C was 50%, mixing ratio of BF (outer percentage based on the mass of mortar) was 0, 1, 3 and 5%. As the results, the workability decreased remarkably at 5%, so it was concluded that 3% was upper limit. Then, W/C was varied with 50, 55 and 60%, and BF mixing ratio was varied with 0, 1, 2, and 3%. These mix proportions are shown in Table 2 as the mixing weight. The compressive strength and bending strength of BF mortar was obtained in accordance with "Cement Strength Test" to confirm the strength improvement effect by BF. Furthermore, the bending toughness was calculated based on the JSCE concrete standard specifications (See Figure1), expecting the toughness improvement effect by BF.

c) Series II and III

In series II, the BF length was changed to 30 and 40mm to increase adhesion. W/C was 55%, and BF mixing ratio was 0, 1, 2, and 3%. Table 3 shows the mix proportion of series II.

A method to spread BF in tensile domain was adopted in series III. Because when BF is mixed simply, the placement of BF becomes random in three-dimensionally and the two-thirds waste should occur in a direction of stress. In actual construction, it will be effective to induce a direction of BF by a container which has slits (see Photo 2). Firstly, specimens were made in the cover of 0mm, mixing ratio of 0.5%, fiber length of 30, 60 and 90mm and the strength was evaluated by bending strength. As the result, fiber length of 60mm, which had increased the bending strength most, was

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adopted, and the specimens with the cover of 5 and 10mm were made in this fiber length. Table 4 shows the mix proportion of series III.

Table 2 Mix proportion of series I

W/C (%)	BF (%)	fiber length (mm)	mixing weight (g) W	C	JIS Sand	BF
50	0	20	225	450	1350	0
	1					7.7
	2					15.5
	3					23.2
55	0		247.5	450	1350	0
	1					7.9
	2					15.9
	3					23.8
60	0		270	450	1350	0
	1					8.1
	2					16.2
	3					24.4

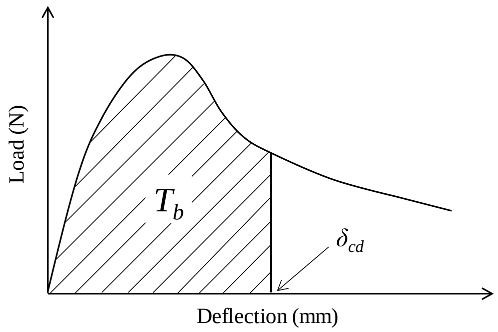

Fig. 1 Calculation of T_b

Photo 2 Casting of BF in series III

Table 3 Mix proportion of series II

W/C (%)	BF (%)	fiber length (mm)	mixing weight (g) W	C	JIS Sand	BF
55	0	–	247.5	450	1350	0
	1	30				7.9
	2					15.9
	3					23.8
55	1	40	247.5	450	1350	7.9
	2					15.9
	3					23.8

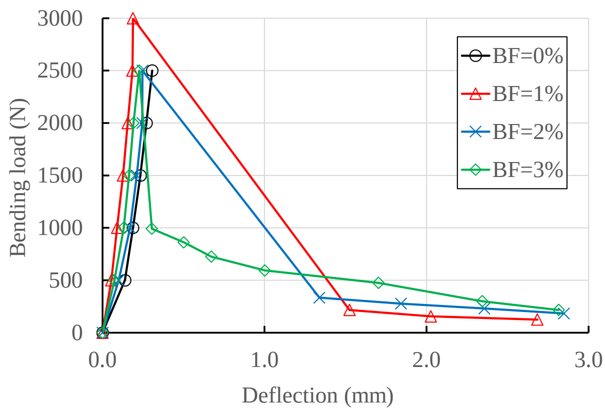

Fig.2 Load and deflection curve of series I (W/C=55%)

Table 4 Mix proportion of series III

W/C (%)	BF (%)	fiber length (mm)	mixing weight (g) W	C	JIS Sand	BF
55	0.5	30	247.5	450	1350	4.0
		60				
		90				

Calculation of Toughness

Figure 2 shows the load-deflection curve in series I (W/C=55%). Bending toughness could be evaluated by toughness coefficient, and when this is large, the toughness at destruction could be improved, which leads the restraint of disasters and accidents.

The spans of beam specimens were 45cm and loads were applied at the 2 points of 3 equal parts. In order to obtain the details of data for toughness coefficient, the loads were applied slowly until the deflection became 3mm by the confirmation of data logger. After the measurement, load-deflection curve was described in the procedure of JIS. The toughness coefficients were calculated by formula (1) using the area from 0 to 1mm of the deflection by the curves.

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$$\sigma = \frac{T_b}{\delta_{cd}} \cdot \frac{L}{bd^2} \qquad \cdots\cdots\cdots\cdots (1)$$

Here,

- σ: bending toughness (N/mm^2)
- T_b: Area to δ_{cd} (N･mm)
- δ_{cd}: deflection (=span/150; mm)
- L: span (=120mm)
- b: width of section (=40mm)
- d: height of section (=40mm)

RESULTS AND DISCUSSION

a) Series 1

Figure 3 and 4 show the relationships between BF mixing ratio and compressive strength or bending strength. Both strength decreased in comparison with non-mixing of BF. According to the observation of the fractured section of mortar, every BF slipped out without being cut, which means that the adhesion of BF and mortar was not enough and the primary tensile strength of BF was not shown.

Figure 5 shows the relationship between BF mixing ratio and toughness. Improve of toughness coefficient by BF can be confirmed. It is effective even in low BF mixing ratio, and the influence of W/C on the effect is small. It is estimated that the cross-linked effect by BF increased the toughness coefficient according to the above-mentioned observation results.

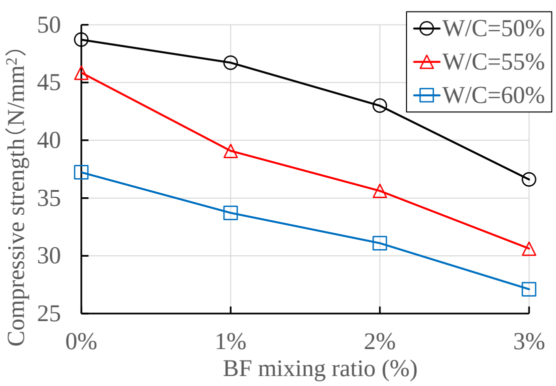

Fig. 3 Relationship between BF mixing ratio and compressive strength in series I

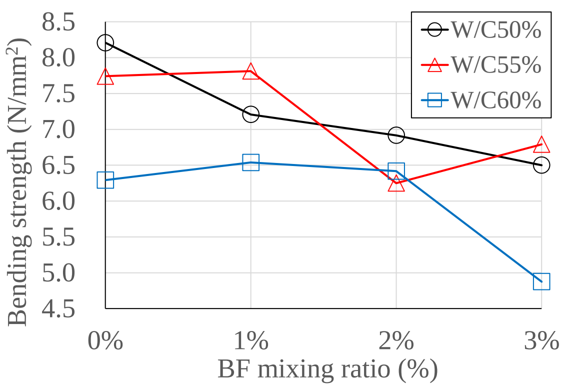

Fig. 4 Relationship between BF mixing ratio and bending strength in series I

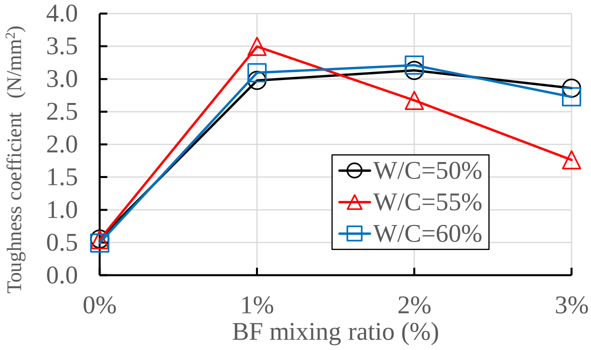

Fig. 5 Relationship between BF mixing ratio and toughness coefficient in series I

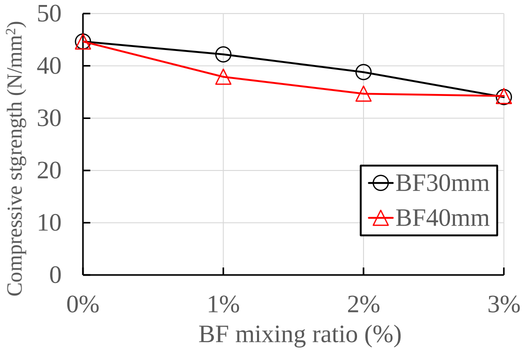

Fig. 6 Relationship between BF mixing ratio and compressive strength in series II

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b) Series II and III

Figures 6 and 7 show the relationships between BF mixing ratio and compressive strength or bending strength. Figure 8 shows the relationship between cover and bending strength in series III. Bending strength and compressive strength decreased by mixing BF. However, in the case that BF was spread with little cover and the fiber length was 60mm, the effect of BF was shown most, and the bending strength was stronger than non-mixing, nevertheless the mixing amount was only 0.5%. When BF is mixed at random, it is estimated that the effect as the fiber cannot be shown, even if fiber length and mixing amount are changed, because the adhesion between fiber and mortar are not enough.

Figure 9 shows the relationship between the mixing ratio and toughness coefficient with various fiber length. The toughness coefficient improved with the increase of mixing ratio generally in series II, however, the effect by the change of fiber length could not be confirmed. Figure 10 shows the relationship between cover and toughness coefficient in series III. The toughness coefficient of the mix proportion with the fiber length of 60mm and the cover of 5mm improved most even the mixing amount was only 0.5%.

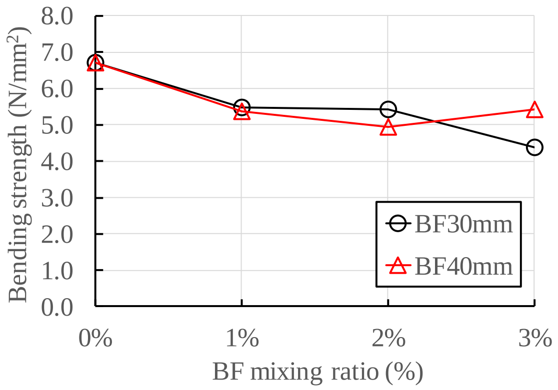

Fig. 7 Relationship between BF mixing ratio and bending strength in series II

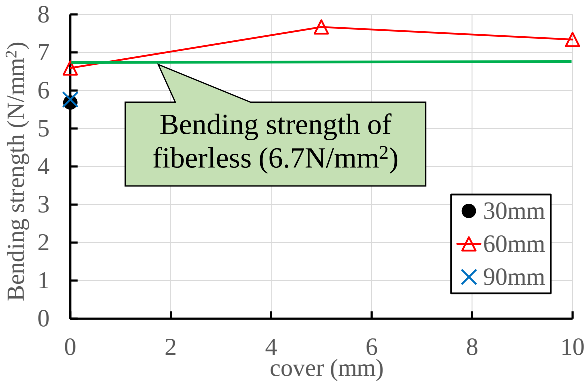

Fig. 8 Relationship between cover and bending strength in series III

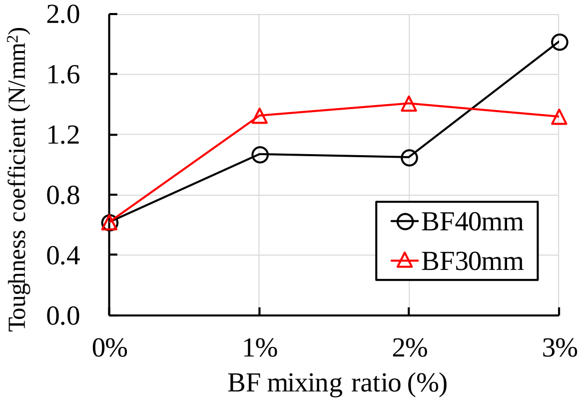

Fig. 9 Relationship between BF mixing ratio and toughness coefficient in series II

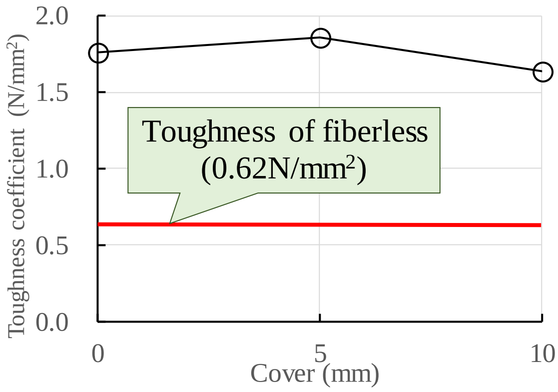

Fig. 10 Relationship between cover and toughness coefficient in series III

CONCLUSION

The summary of this study on the concrete for pavement which short bamboo fiber was mixed with is as follows:

(1) The strength does not improve only by a cross-linked effect.

(2) Toughness coefficient greatly improves, and the effect is shown even if the amount of fiber is little.

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(3) The influence of W/C on the effect of toughness improvement is small.
(4) When bamboo fiber is mixed at random, each strength decreases, and toughness coefficient increases regardless of fiber length.
(5) In case of spreading construction of bamboo fiber, both strength and toughness coefficient improves even by little amount of fiber.
(6) As a contrivance to align the same direction of bamboo fiber easily in large scale on actual road, the sieve with slit in one direction could be effective, practicable and economical.

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