Research and Development on Bamboo Reinforced Concrete Structure

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ABSTRUCT:
Recently, in the attention in response to global warming issues and sustainable society, the manufacturing using natural materials has become actively. Bamboo, low cost, fast growing, and broad distribution of growth, is expected to contribute significantly to earthquake-resistant construction and seismic retrofit technology in the developing countries. The authors also have been studied for understanding the mechanical behavior of bamboo reinforced concrete member and clarifying the differences of structural properties from steel reinforced concrete and bamboo reinforced concrete (TERAI, 2011a, b, c and d). This paper investigates the mechanical properties of bamboo reinforced concrete structure. It compares these experimental results of bamboo reinforced concrete members with the experimental ones of reinforced concrete members, and the mechanical property of the bamboo reinforced concrete members is studied. From these experimental works, the possibility of effective using of ‘Bamboo' is discussed.

Keywords: Bamboo Reinforced Concrete, Bamboo, Corrosion, Pull-out test, Flexural strength

1. INTRODUCTION

In recent years, steel prices have soared. For developing countries, steel is difficult to obtain because of expensive prices, and for the construction industry, usage of steel is currently limited heavily. The production of steel has high consumption of fossil fuels, so, the steel discharge in the construction of structures has been presented, showing the possibility of drastic reduction by research institutes. Meanwhile, for developing countries, it is important to make the development of buildings construction; low cost, no requirement of sophisticated technologies and reliable construction methods.

Environmental destruction such as pollution of air and water has been occurring in some regions by rapid development and production of materials like iron, steel, glass, cement and aluminium that use limited mineral resources. On the other hand, plants and fibers are annually reproducible clean resources. Bamboo is a unique group of gigantic grasses the culm of which originates in underground rhizomes. It grows naturally in many parts around the world country but some species are artificially planted. Bamboo forests are found across tropic and sub-tropic zones between latitudes of about 40° south, i.e. areas with mean annual temperatures of from 20°C to 30°C. Bamboo suitable for water pipes grows at altitudes from 20 to 3,000meters. The plant is fully mature at an age of three to four years.

In recent years, many researches around the world are begun to explore the use of low-cost and low-energy substitute construction materials. Among the many possibilities for such substitutions, bamboo, which is one of the fastest growing plants, has got a great economic potential. Bamboo has been used in constructions of bridges and houses for thousands of years in Asia. Bamboo takes less energy to harvest and transport. Therefore, bamboo has low manufacturing costs compared with steel, bamboo is widely expected to be possible even in countries and regions that have no advanced manufacturing technology and construction techniques.

A study of the feasibility of using bamboo and non-steel as the reinforcing material in concrete members was conducted in our laboratory. This paper deals with the effect of the corrosion of bamboo, the bond properties by the surface condition of the bamboo reinforcement, and the flexural behavior of bamboo reinforced concrete slabs by the curing condition.

2. CORROSION OF BAMBOO

The volume of bamboo is expanded to absorb the water in the concrete. In addition, the volume of bamboo shrinks to lose the water according to the drying of concrete. Because the shrinkage of bamboo is so larger than that of concrete and its speed is also faster, the bamboo embedded in concrete will be exposed to expansion and contraction repeatedly. It is believed that this is one of the reasons why the bond stress has been lost. The change in tensile strength of bamboo soaking in the alkali water is known as shown in Figure 2.1. However, the experimental detail is unknown because of old data.

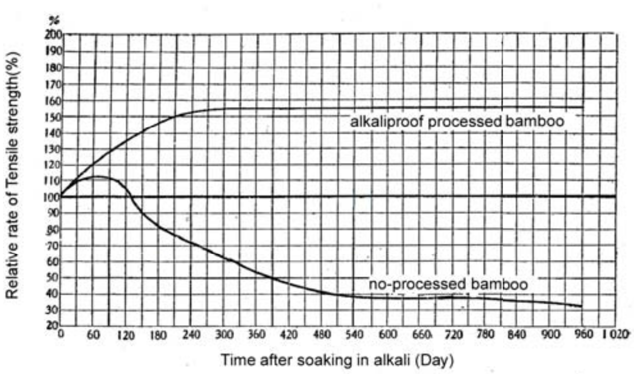


Figure 2.1. Influence of time on corrosion (Hosoda, 1942)

2.1 Outline of experiment

The test piece for tensile strength was cut out from 160mm diameter, 15mm thickness, 3years bamboo with the dimensions shown in Figure 2.2 and 2.3. Test section (60mm; centre of specimen) of the bamboo specimen was filled with cement paste cured *w/c* ratio of 80% and 100% as shown in Figure 2.4. After that, test specimens were cured by sealing the top to prevent drying. Test specimens were remoulded at 28days and placed in the laboratory. At 28, 56 and 84days, 3 bamboos were removed from the cement paste and tensile tests were carried out, as shown in Figure 2.5, after measuring the weight and the cross sectional-dimension of the specimens.

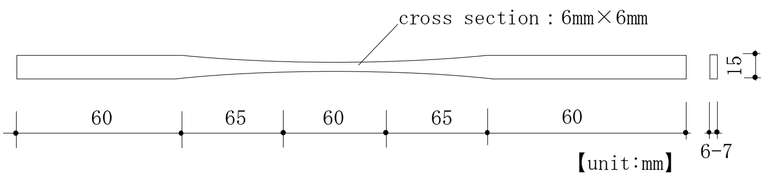


Figure 2.2. Test specimen for tensile strength

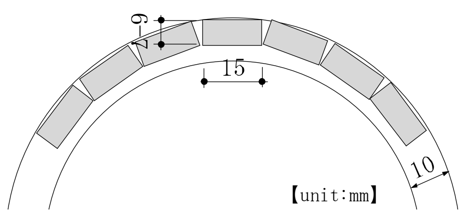


Figure 2.3. Extraction of test specimens (Cross section of Bamboo)

Figure 2.4. Specimens

Figure 2.5. Tensile test Setup

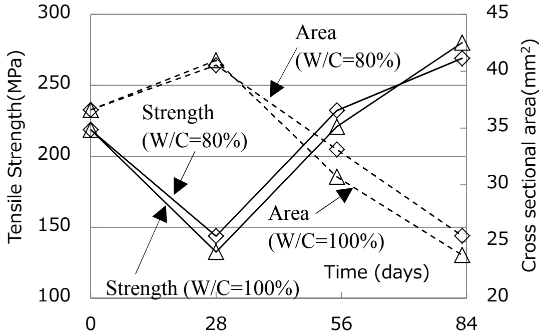


Figure 2.6. Tensile strength and Cross sectional area of Bamboo: Effect of *w/c* ratio

2.2 Test results and discussion

Figure 2.6 shows the tensile strength and cross sectional area of bamboo filled with cement paste at 28, 56 and 84days of curing. The tensile strength is calculated by dividing the cross-sectional area of the maximum tensile load. In the past research, the bamboo was soaking in the alkali water during curing, so that the inside of bamboo specimen did not dry. Therefore, since the inside of bamboo was always wetting and submerged by alkali, it is thought that the cell of bamboo was destroyed gradually.

Figure 2.7. Fracture surface tested at 56days: (left) *w/c* ratio =100%; (right) *w/c* ratio =80%

Fracture surface of bamboo at 56days of tensile test are shown in Figure 2.7. In the specimen with a high water cement ratio *w/c*=100%, it is roughly perpendicularly divided so that the fiber of bamboo may split, but in the specimen *w/c*=80%, it turns out that the fracture surface is torn to pieces. Since amount of water will increase if a water cement ratio is large, the amount of water absorption to bamboo is large, and a cement particle melts easily into the bamboo fibers. Therefore, since the cell of bamboo was invaded by alkali and broken, it is thought that the bamboo fractured so that a fiber might decompose.

3. BOND PROPERTIES OF BAMBOO BAR

The purpose of this chapter is to investigate the effect of the factors influencing the resulting of pull-out bond stress in the concrete.

3.1 Materials

The bamboo used in this investigation in Japanese Timber Bamboo, collected in Miyoshi-city, Hiroshima. Two diameter of bamboo, 30mm and 22mm, were used. The yield strength of the bamboo was 197MPa as the test data carried out in our laboratory.

Low strength concrete mix-designed were studied, in order to prepare a low strength concrete (*fc* = 10MPa at 28days; 16.2MPa tested at 62days; cement content 231kg/m^3; water/cement ratio = 0.88), the aggregate being mixed and with a maximum size of 15mm.

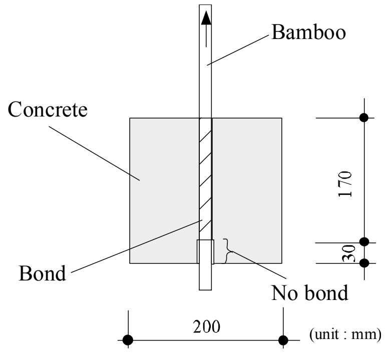


Figure 3.1. Specimen of pull-out test

3.2 Specimens

To improve the bond stress between the bamboo reinforcing bars and the surrounding concrete, pull-out tests were conducted on the specimens shown in Figure 3.1. Nine prismatic specimens were cast with a single bamboo or steel embedded longitudinally in the specimen. In order to verify the effect of the difference in the bamboo surface condition, variables considered in this study were the material coated on the embedded bamboo surface (synthetic resin and synthetic rubber) and the surface condition (groove and its space). A summary of specimens is listed in Table 3.1.

Table 3.1. Detail of specimens

Specimen	No.1	No.2	No.3	No.4	No.5	No.6
agent	Synthetic resin	Synthetic resin	Synthetic resin	Synthetic rubber	Synthetic rubber	Synthetic resin
method	Brush coating	Spraying	Spraying	Spraying	Spraying	Brush coating
Surface	-	Slot processing @25㎜	-	-	Slot processing @60㎜	Slot processing @40㎜
Treatment	Whole	Whole	Whole	Whole	Partial	Partial
Photo						

It is well known that bamboo embedded in concrete absorbs the water contained in the concrete. Therefore, bamboo repeats the relaxation and the expansion of volume, the bond between bamboo bars and the surrounding concrete is reduced. In addition, as the cause of bamboo loses its strength in concrete, it is also known that the alkaline component in the concrete decompose the fat content of bamboo. In this experiment, a synthetic resin and synthetic rubber is used for waterproofing on bamboo surface. Instead of expensive and special materials, as a readily available, a synthetic rubber shown in Figure 3.2 (c) and a synthetic resin shown in Figure 3.2 (a, b) have been challenged.

(a) Synthetic resin Brush (b) Synthetic resin Spray (c) Synthetic rubber Spray

Figure 3.2. Materials for surface treatment

Figure 3.3. Specimens

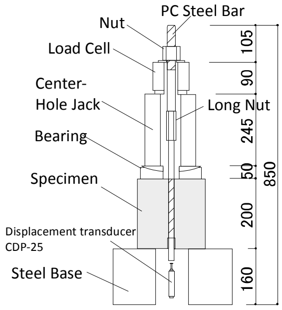
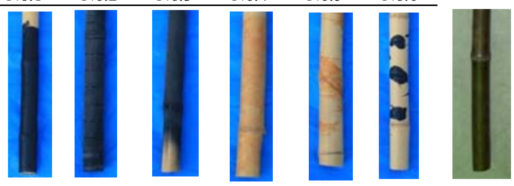


Figure 3.4. Test Apparatus

3.3 Loading and measurements

The pull-out specimen was placed above the steel base as shown in Figure 3.4. Pull-out loads were subjected to the top end of the embedded bar with the center hall jack of 500kN capacity. Slip displacement at the free end of the bar was measured with a displacement transducer instrumented at the end of the prism.

Figure 3.5. Detail of Joints between Bamboo and PC bar



Specimen	No.1	No.2	No.3	No.4	No.5	No.6		Round Bar	Deformed Bar
Diameter (mm)	31.42	28.89	23.56	25.91	31.60	30.10	16.00	φ19	D19
Load (kN)	22.50	18.17	15.67	16.33	14.33	9.67	-	-	-
Bond stress (MPa)	1.34	1.18	1.25	1.18	0.85	0.60	0.66	0.34	2.43

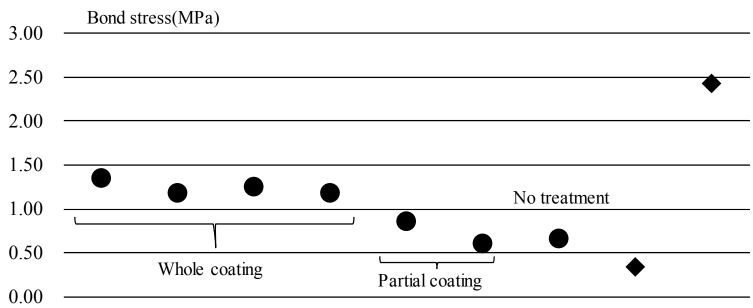


Figure 3.6. Bond stress

The strength of the joint between Bamboo bar and PC bar had to take into account the necessity of preventing joint broken before the bond slip occur. So, bamboo bar and PC bar connected with the center hole jack, was joined by adhesive force, as shown in Figure 3.5. To begin, insert the screw inside the bamboo bar, filled with a chemical reaction of epoxy resin adhesive form (left Figure 3.5). Then, covered with a steel pipe welding a nut on the outside of the bamboo, was firmly adhered to the same adhesive filling the gap on the inside of the steel pipe to the surface of the bamboo. Based on preliminary tests several times, it was confirmed that the bond length of this joint is least 200mm or more.

3.4 Test results and discussions

3.4.1. Bond stress

Figure 3.6 shows a comparison of the bond stress of the nine experiments, just before the start of a large slip deformation. Bond stress was calculated based on the measured value of the diameter of the test bars by the following equation:

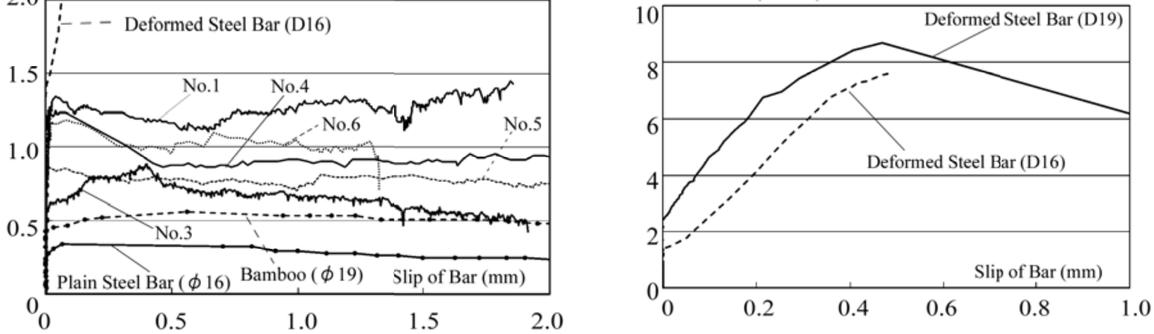
$$\tau = \frac{Q}{\ell \cdot \phi} \tag{1}$$

Where Q is the pull-out load (N), φ is the circumference of longitudinal reinforcement (mm) and ℓ is the embedded length (=170mm).

The surface of specimens No.1-4 is coated by the materials for treatment, entirely. The surface of specimens No.5 and 6 is smeared the materials on top of the groove on the bamboo surface, partly. It is considered that the bond stress of specimens No.5, 6 and non-coated bamboo is reduced, since the relaxation and expansion were repeated by the absorption of water on the surface of bamboo. Then, the bamboo began to slip in low bond stress 0.6-0.85MPa. On the other hand, the bond stress of specimens No.1-4 covering by full treatment show the high value 1.2-1.35MPa, but still is about half compared with the deformed steel bars. From the above, it is confirmed that such a simple surface treatment can be improved the bond stress between bamboo and the surrounding concrete. The difference by the materials on surface was not observed.

3.4.2. Bond-Slip

Assuming the bond stress to be uniformly distributed along the length of the bar, the average bond stresses (below: bond stress) were calculated by dividing pull-out force by bond area. The typical bond stress and slip curves are shown in Figure 3.7. The maximum bond strengths with bamboo observed up to a slip of 0.02mm. After the maximum bond strength, the bond stress gradually decreased and became constant when slip increased. These constant values were considered to be caused by the friction force between the bars and the concrete from the roughness of their surfaces. This behavior is almost the same as the plain steel bar; however, the bond strength with bamboo was higher than the one with plain steel bar.



(a) (b)

Figure 3.7. Bond Stress and Slip Curves (a) for slip < 2.0mm (b) Steel Bar

4. BAMBOO REINFORCED CONCRETE SLAB

4.1 Test specimen

The flexural failure of bamboo reinforce concrete slabs were studied. The configuration and sectional details of all specimens are shown in Figure 4.1. For the tension reinforcement, bamboo (diameter: 15.3mm, yield strength 197N/mm^2) divided in a quarter were used. Specimens were reinforced singly (tension reinforcement ratio p: 0.48%). As shown in Figure 4.1, the bamboo were reinforced in a lattice pattern and tied with the twisted rope (φ=1.8mm) made of polypropylene at the intersection of bamboo reinforcements. A total of 12 test specimens consisted of six specimens aging underground and six above the ground, tested at 1 month, 3 month, 6 month, 1 year, 3 year and 5year, respectively.

Ready mixed concrete confirming to JIS A 5308 with the proof compressive strength of 10.1 N/mm^2 and the slump value of 18cm (the measured value: 16.0cm) was used. The maximum size of coarse aggregate was 15 mm and the air content was 5.2% (measured). The mixing proportion for concrete is listed in Table 4.1. Figure 4.3 shows the scenery at the concrete casting.

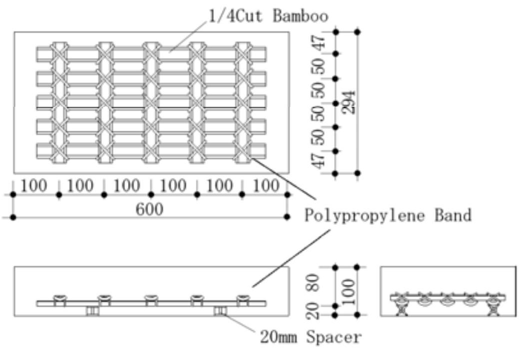


Figure 4.1. Details of specimens

Figure 4.2. Bending test setup

Table 4.1. Mixing proportion

Compressive strength level Fc (MPa)	Water Cement Ratio W/C (%)	Fine Aggregate Content S/a (%)	Unit Weight(kg/m^3)				
			Water W	Cement C	Fine aggregate S	Coarse aggregate G	Mixture agent
10.1	88	63.0	203	231	1119	683	1.85

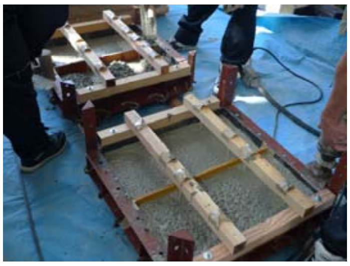


Figure 4.3. Casting of slab specimens

Figure 4.4. Curing condition (left) underground, (right) above ground

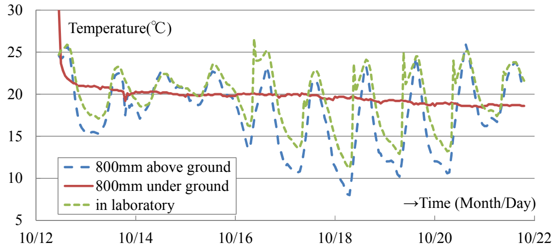


Figure 4.5. Changes of temperature at curing points

After the eights day of casting concrete, specimens were remolded, measured the dimensions and the weight. The half is placed 800mm above ground made a stand with a roof, shown in Figure 4.4 (right). The other half is buried underground digging a hole to 800mm, shown in Figure 4.4(left). For management of concrete strength, test cylinders of 100mm diameter was constructed and cured under the same conditions.

To record the change in temperature of the curing location, automatic measuring thermometer was placed in three places underground, above ground and in the laboratory. Figure 4.5 shows the measurement results of 10 days after specimens placing. The temperature above ground and in the laboratory, depending on outside temperature changes, is moving up and down every day. However, it can be confirmed that the temperature of underground is kept almost constant throughout the day.

Slab specimens were loaded concentrically with a tensile/compression tester with 5MN capacity, as shown in Figure 4.2. During the loading test, the load P was measured by load cell. Displacements δ of the specimen were externally measured by displacement transducers instrumented at the sides of the specimens.

4.2 Test results

4.2.1. Concrete Strength

The results of tests on specimens carried out at 28 and 84days are shown in Figure 4.6. The compressive strength of test cylinder cured underground changes significantly highly from the one cured in laboratory. It can be considered that while the inside of the laboratory is dried, the underground is humid at any times therefore supply of water to the concrete can be accomplished. It turns out that the tensile strength of test cylinder cured underground increased the rate of strength development of concrete.

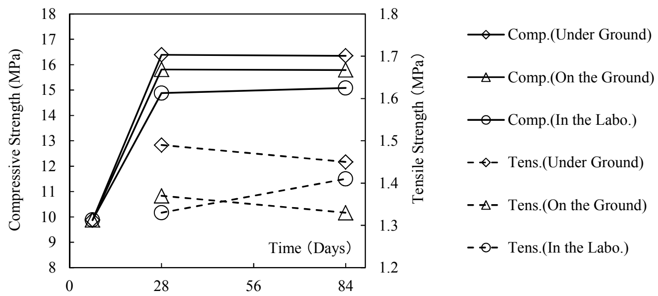
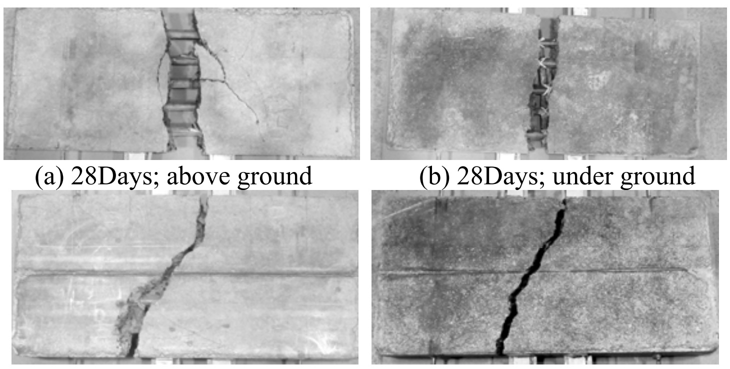


Figure 4.6. Compressive and tensile strength. (Effect of curing condition)



(a) 28Days; above ground (b) 28Days; under ground

(c) 84Days; above ground (d) 84Days; under ground

Figure 4.7. Cracking pattern after failure

4.2.2. Slab test

Figure 4.7 shows the crack patterns observed after failure in the all specimen which failed dominantly in flexural decay as expected after de-bonding of tensile bamboo reinforcement. Regardless curing time, in all specimens, a crack occurs just below the loading point. With the deformation increasing, the width of initial flexural crack is expanded. Figure 4.8 shows a comparison between the load-deflection curves of specimen tested at 28 and 84days for aging time.

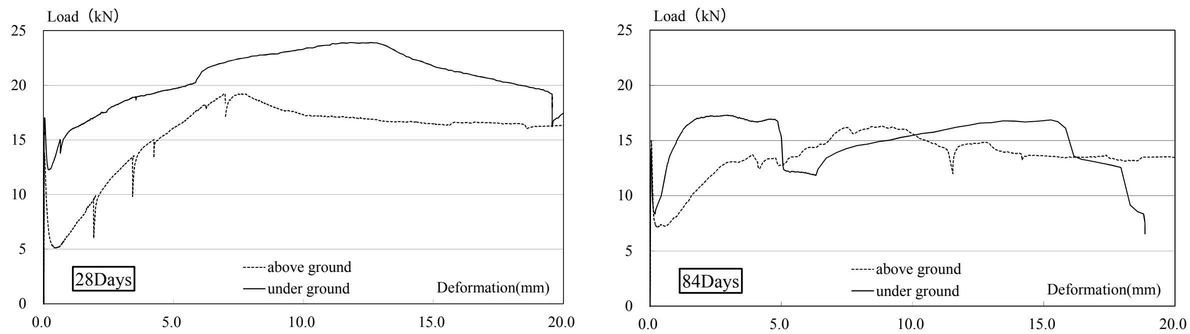


Figure 4.8. Load-deflection curves of BRC slabs (left) 28days, (right) 84days

It was observed that the curvature of specimen cured underground is larger than the one cured in the air. When fresh concrete is poured, its water will moisten the bamboo; then, during the curing time, the concrete will harden and lose water so that the bamboo will again dry out. This drying process will completely break any bond between the bamboo and the concrete. It can be considered that underground humidity is high at any times therefore supply of water to the concrete can be accomplished. It also considered that bamboo reinforcement absorbed water moderately will become difficult to split.

For analyzing of strength of bamboo reinforced concrete members, the cross-sectional size of a bamboo is not constant, therefore strength changes with places. Since bamboo is bent at the node or there is "spring" over the longitudinal length, it is very difficult to calculate the strength of bamboo reinforced concrete members. Here, in order to estimate the strength of bamboo reinforced concrete members, the form and the section of the bamboo were assumed as follows:

(1) Cross-section of the bamboo is assumed to be circular hollow. From the average measured value, the outside diameter is 15.3mm, the inner diameter is 9.5mm and the thickness of hollow is 2.9mm.
(2) Bamboo is homogeneous over the entire length.
(3) Tensile strength of bamboo is 197N/mm^2 as the strength of bamboo node. The strength of the internode was set to 118.2N/mm^2 (=0.6*197N/mm^2) as 0.5 to 0.7 times strength of the node.

Table 4.2. Test results

Time	curing condition	Test			Calculation			
		Bending crack load	Bond crack load	Ultimate load	Bending crack load	Bond crack load	Shear crack load	Ultimate load
28Days	Over the Ground	10.00	13.50	19.20	6.71	19.5	31.4	14.60
	Under the Ground	7.11	16.50	23.91	7.30	19.5	31.7	14.60
84Days	Over the Ground	12.00	14.95	16.33	6.52	19.5	31.4	14.60
	Under the Ground	10.33	13.90	17.30	7.11	19.5	31.7	14.60

【unit : kN】

Strengths of bending cracking, bond and ultimate bending were calculated on the assumptions as above. Table 4.2 shows the calculated values and the test values at the time of these events were occurred by the experiments.

Bending crack load : Bending crack load was calculated by the formula of AIJ Standard for Structural

Calculation of Reinforced Concrete Structure, the test value is higher than the calculated value in all specimens.

<u>Bond load</u> : Bond load was calculated based on the bond strength value (τ=0.40N/mm^2). Since the calculated bond strength was assumed the state of five bamboo reinforcement slip at the same time, the test value is smaller than the calculated value in all specimens.

<u>Ultimate bending load</u> : Ultimate bending load was calculated by the formula of $M=0.9a_t\sigma_y d$. Although the ultimate bending load was assumed the state of five bamboo reinforcement fracture at the same time, the longitudinal reinforcement did not break off. Therefore, the maximum load of experiment was much higher than the calculated ultimate bending load.

5. CONCLUSIONS

This paper presents the feasibility of using bamboo and non-steel as the reinforcing material in concrete members. In order to investigate the fracture behavior and the mechanical properties of Bamboo Reinforced Concrete members, 9 pull-out and 4 slab specimens were constructed and the pull-out tests and 3 point bending test were carried out. By analyzing the test results, the following conclusions were drawn in this study:

(1) The tensile strength filled with cement paste cured *w/c*=80% and 100% significantly increase with aging time.

(2) The behavior of pull-out test with bamboo is almost the same as the plain steel bar; however, the bond strength with bamboo was higher than the one with plain steel bar. It can be expected that the bond strength covering with full treatment shows the high value 1.2-1.35MPa.

(3) Bamboo reinforced concrete slab: When fresh concrete is poured, its water will moisten the bamboo; then, the concrete will harden and lose water so that the bamboo will again dry out. This drying process will completely break any bond between the bamboo and the concrete. It can be considered that underground humidity is high at any times therefore supply of water to the concrete can be accomplished.

The availability of combination bamboo and concrete structure can be confirmed. Therefore, for construction of the actual structure, it is necessary to verify some realistic methods. It can be said that this study is the first step towards the development for the future. It is important to accumulate further experimental data and to consider the practical application. For practical application of the structure with bamboo, it seems to be important to consider the following conditions: 1) Design of the structure with bamboo, 2) Combinations of materials (the concrete strength and type of bamboo), 3) Construction and Workability and 4) Durability of bamboo within mortar and concrete.

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