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Original Article

Compressive strength and ductility of short concrete columns reinforced by bamboo

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Abstract

The paper presents the structural and environmentally sustainable aspects of bamboo as a reinforcing material instead of steel reinforcement in concrete columns. Seven small-scale short columns (125 mm x 125 mm x 600 mm) with different type of reinforcements were tested under concentric loading to investigate strength capacity and ductility. The results showed that the strength capacity of short columns reinforced by bamboo without surface treatment could resist the axial load as structurally required by ACI318-05, but ductility was rather low especially the column that was reinforced by 1.6 percent of reinforcing bamboo which showed brittle behavior similar to that of plain concrete column. This was thought to be an effect of water absorption and a loss of bonding strength between concrete and bamboo. On the other hand, columns reinforced by bamboo treated with water-repellent substance, Sikadur-31CFN, showed higher strength and ductility than columns reinforced by untreated bamboo. The result also showed that 1.6 % of steel reinforcement, in relation to the column cross-section, could be replaced by 3.2% of treated reinforcing bamboo, for similar behavior, strength and ductility.

Keywords: concrete column, bamboo, compressive strength, ductility

1. Introduction

Housing industry is one of the most energy consuming activities on earth. Concrete, steel, wood, glass, plastic and many other materials have been used for construction. In Thailand, most housing structures have been built by using steel-reinforced concrete. Whenever the cost of steel imported from abroad is on the rise, housing prices will tend to be on the rise as well. As a result, many researchers have been trying to find out alternative materials to substitute the steel in reinforced concrete practices. Bamboo is one of the interesting renewable materials, particularly in tropical countries, that could be used as such a structural material substitution.

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Bamboo, a giant grass, is a natural perennial grass-like composite, and is the fastest growing woody plant in the world. There are about 1,000 species of bamboo that can be found in diverse climates, from temperate mountains to tropical regions (Chapman, 1997). Also, bamboo has constantly attracted the attention to scientists and engineers for use as reinforcement in cementitious composite materials. This is because it has distinguished properties, including high tensile strength to weight ratio, low cost, abundant availability and environmental-friendly characteristics.

There are many research works on bamboo in both scientific and engineering aspect. On the one hand, scientists have studied about how bamboo grows and how to improve bamboo's property for industry. On the other hand, material engineers and civil engineers have studied about how bamboo resists the bending stress caused by a wind load (Sutnaun *et al.*, 2005), how to apply bamboo as an engineering material, and how to use bamboo as a structural material. Chembi and Nimityongskul (1989) reported its use in construction of water tanks. Ghavami (1995) studied it for reinforcement of lightweight concrete beams. Kankam *et al.* (1986) used it as reinforcement of concrete slab.

When bamboo is considered as an engineering material, it has been recognized like timber. It is vulnerable to environmental degradation and is often attacked by insects. The durability of bamboo depends on the preservative treatment which can be applied by using either simple methods or sophisticated systems and equipments. Not only durability of bamboo but effect of water absorption and bonding strength are also important to consider bamboo as an engineering material. Ghavami (2005) studied many impermeability treatment substances to prevent water absorption and to improve bonding strength between concrete and bamboo. He also suggested the new water-repellent product, Sikadur 32-Gel (Sikadur-31CFN in Thailand), which increases bonding strength between treated bamboo segment and concrete up to 5.29 times comparing to untreated segments of bamboo.

This experimental research is focused on the use of bamboo as a reinforcing material instead of steel reinforcement in concrete. The study expects to investigate the differences between short columns reinforced by steel, by untreated bamboo and by treated bamboo, by comparing the strength capacity and the ductility for each type of reinforcement. The results are also compared to ACI318-05, an established American building code for structural concrete, to verify that the equation used to calculate a maximum axial load is still valid when it is employed for columns reinforced by bamboo.

2. Materials and Methods

2.1 Specimen preparation and testing procedure

The research intends to compare strength and ductility of short concrete columns reinforced by bamboo and short concrete columns reinforced by conventional steel reinforcement. Seven square short columns with different types of reinforcement (One with no reinforcement at all. A couple is steel-reinforced, a couple is reinforced with untreated bamboo and a couple with treated bamboo. Reinforced couples are each at same reinforcement ratios of 1.6% and 3.2%. Details of reinforcement and reinforcement ratio are shown in Table 1) were tested under uniaxial compression by a Tinius Olsen Universal Testing Machine with a maximum capacity of 2000 kN until failure. All specimens have the same cross-section of 125 mm. x 125 mm. and are 600 mm. in height. Details of reinforcement and reinforcement ratio are shown in Table 1.

Longitudinal reinforcements were prepared separately for steel reinforcement and bamboo. Steel reinforcement, 9 mm. in diameter, could be easily cut and bent to required length, while reinforcing bamboos obtained from the culms of Tong Bamboo (*Dendrocalamus asper Backer*) about three years of age were split with a wedged knife and shaped into round sections 9 mm. in diameter. Some reinforcing bamboos were treated with Sikadur-31CFN one day before the reinforcements were built up. Figure 1 shows two specimens of 1.6% and 3.2% of reinforcement ratio of treated bamboo (CBT1.6 and CBT3.2).

All columns have the same transverse reinforcements 6 mm in diameter made from round bar grade SR24 of 6 mm in diameter to protect stress concentration at the ends of column as shown in Figure 1. Longitudinal and transverse reinforcements were built up depending on the type and the number of longitudinal reinforcements. Three steel formworks were used to cast these concrete specimens. They were cast horizontally with an open surface on the top. Three standard concrete cylinders were cast at the same time to determine the compressive strength of the mix. After the concrete had set (the next day), formworks were taken off and allspecimens were cured for 28 days, under wet saw dust.

The specimen was set up on the Universal Testing Machine, and steel bearing plates were put at the both ends

Table 1. Details of reinforcement and reinforcement ratio

Specimen[1]	Type of reinforcement	Number of Reinforcement	Reinforcement Ratio ρ (%) [2]
C	No Reinforcement	0	0
CS1.6	Steel	4	1.6
CS3.2	Steel	8	3.2
CB1.6	Untreated Bamboo	4	1.6
CB3.2	Untreated Bamboo	8	3.2
CBT1.6	Treated Bamboo	4	1.6
CBT3.2	Treated Bamboo	8	3.2

[1] Specimen names are abbreviated along with their materials which C is concrete, S is steel, B is untreated bamboo and BT is treated bamboo. The numbers mean reinforcement ratio.

[2] Reinforcement ratio of longitudinal reinforcement ($\rho = A_s / A_c$) where A_s and A_c is the area of reinforcement and concrete respectively.

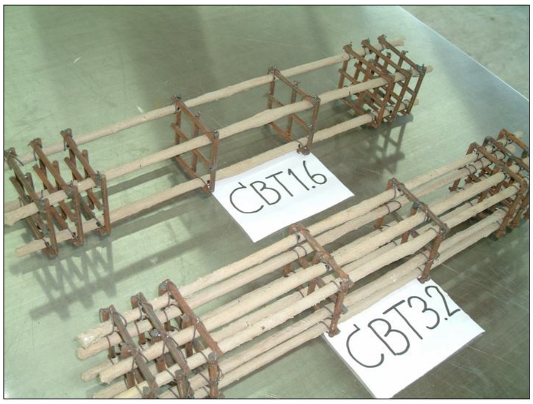

Figure 1. Two specimens of treated bamboo reinforcement (CBT1.6 and CBT3.2)

of specimen. Axial deformation of the column was collected by a dial gage attached with a magnetic base frame. After testing set up was ready, compression force was slowly applied to specimen at 0.125 mm/second of deformation rate. In the meantime, column behavior was observed at every stage during the test. Eventually, testing was automatically stopped when the column cannot resist the external load dropped more than 80% of load rate from the Universal Testing Machine.

3. Results and Discussion

3.1 Mechanical properties of materials

The target of compressive strength of concrete cylinder in this study was 24 MPa. However, the results were slightly different as evident in Table 2 because of variable parameters of material properties and mixing procedure in the laboratory. The mechanical properties of steel reinforcement and bamboo were tested and shown in Table 3 and Table 4. Additionally, reinforcing bamboos were immersed into water for one week to determine the thickness swelling comparing with oven dry stage. The result showed that reinforcing bamboos could be swelled to 21.6±4.0 percent by water absorption.

3.2 Column behavior

Column behavior could be divided into two groups by considering mode of failure. The first group consisted of two specimens, plain concrete column (C) and 1.6% of bamboo

Table 2. Compressive strength of concrete cylinder

Properties	Specimen		
	C, CS1.6 and CS3.2	CB1.6 and CB3.2	CBT1.6 and CBT3.2
Weight (N)	124.0	124.6	123.2
Diameter (cm)	15.22	15.25	15.29
Height (cm)	30.53	30.52	30.53
Unit Weight (kN/m^3)	22.3	22.4	22.0
Max. Compression Force (kN)	461.8	480.1	483.2
Average Compressive Strength (MPa)	25.4	26.3	26.3

Table 3 Mechanical properties of reinforcements

Type of Reinforcement	Yield Strength (MPa)	Ultimate Strength (MPa)	Elongation (%)	Modulus of Elasticity (MPa)
RB6	340.5	462.6	29.9	210×10^3
RB9	365.4	479.0	37.3	209×10^3

Remark: RB6 and RB9 are round bars 6 and 9 millimeter in diameter respectively

Table 4. Mechanical properties of bamboo

Mechanical Properties of Bamboo	
Ultimate Compressive Strength (MPa)	55.3
Ultimate Tensile Strength (MPa)	224.3
Modulus of Rupture (MPa)	122.9
Modulus of Elasticity (MPa)	20.8×10^3

reinforced concrete column without surface treatment (CB1.6). This group clearly showed brittle behavior in which tiny cracks occurred at the surface of the column at about 80% of maximum axial force. After reaching the maximum load, the load capacity decreased abruptly; and it finally failed in a few seconds. There was only crushing sound of concrete before failure, while there was no visible sign of spoiled concrete covering to warn before failure. So, people would be in danger if their house was constructed by these brittle columns.

The other group consisted of columns reinforced by conventional steel reinforcement (CS1.6 and CS3.2) and columns reinforced by reinforcing bamboo either with or without surface treatment (CB3.2, CBT1.6 and CBT3.2). This group showed more ductile behavior than the first group. This was because the columns were adequately reinforced by steel reinforcement or reinforcing bamboo. At first, tiny cracks visible at the surface of all columns appeared at about 80 - 90 % of the maximum axial force. After the maximum axial force, load capacity began to decrease gradually with more signs of cracks and spalling of concrete covering shown in Figure 2. Furthermore, there were sometimes loud sounds of fracture.

Figure 2. Cracks and spalling of concrete covering on column CB3.2

3.3 Comparison of theoretical and experimental results

The yield load or the maximum load of an axial load, a reinforced concrete column is the sum of yield strength of the reinforcement plus the strength of concrete. It has been found that the strength of the concrete in an axially loaded column is approximately $0.85f_c^{'}$, where $f_c^{'}$ is the compressive strength of a concrete cylinder. Thus, ACI318-05 provides equation (1) to determine the maximum load of an axially loaded column, P_0.

$$P_0 = 0.85f_c^{'}(A_g - A_{st}) + A_{st}f_y \qquad (1)$$

where A_g is the gross area of the cross section, A_{st} is the total area of longitudinal reinforcement in the column section, and f_y is the yield strength of the reinforcement. Generally, equation (1) is widely used for reinforced concrete columns with conventional steel reinforcements. In this study, however, not only columns reinforced by steel reinforcement were compared with Equation (1), but columns reinforced by reinforcing bamboo were investigated and compared as well.

In Table 5, it could be observed from the test results that all columns had the ratio of the maximum load, P_{max} to the maximum load provided by ACI318-05, P_0 more than 1.0. Therefore, equation (1) could be used to predict the maximum load of both columns reinforced by steel reinforcement and columns reinforced by reinforcing bamboo.

3.4 Comparison between plain concrete column and columns reinforced by bamboo

As mention earlier, plain concrete specimen C clearly showed brittle behavior because there was no any reinforcement in concrete. After reaching maximum axial force, load capacity immediately decreased with crushing sound and failed in a few seconds. Specimen C had ductility of 1.07 which was quite low comparing to other reinforced specimens in this study shown in Table 5.

Like specimen C, the column reinforced by 1.6% of reinforcing bamboo without surface treatment, CB1.6, had the same brittle behavior and had ductility of 1.08. This might

Table 5. Comparison of maximum load with ACI 318-05

Specimen	Axial Load		P_o	P_{max}/P_o	Axial Deformation		Ductility
	Max.Load P_{max} (kN)	Ult.Load P_u (kN)	ACI318-05 (kN)		At Max. Load (mm)	At Ult. Load (mm)	
C	355	292	337	1.05	177	190	1.07
CS1.6	423	342	415	1.02	181	233	1.29
CS3.2	502	422	493	1.02	134	158	1.18
CB1.6	370	330	357	1.04	192	207	1.08
CB3.2	409	361	365	1.12	182	209	1.15
CBT1.6	396	335	357	1.11	190	234	1.23
CBT3.2	432	368	365	1.18	151	194	1.28

be a problem of water absorption and bonding strength between bamboo and concrete during the casting and curing of concrete. At the stage of curing, reinforcing bamboo absorbed water and could be swelled up to 21.6%. The swelling in bamboo pushed concrete, and inner cracks in concrete might be occurred. After the end of curing period, 28 days, the reinforcing bamboo lost moisture and shrink back to its original size. As a result of this, voids occurred around bamboo and eliminated bonding strength between concrete and bamboo.

The other columns reinforced by bamboo had ductility more than specimen C and CB1.6, especially specimen CBT1.6 and CBT3.2 had ductility up to 1.23 and 1.28 respectively. In addition, by comparing with the P_{max}/P_0 ratio shown in Table 5 and the relationship between axial force and axial deformation in Figure 3, column CBT1.6 and CBT3.2 had strength capacity higher than plain concrete column as well as ductility.

3.5 Comparison between columns reinforced either by conventional steel reinforcement or by reinforcing bamboo

The primary objective of this study is the use of bamboo as reinforcing material in concrete by comparing the strength capacity and the ductility of columns reinforced by bamboo with those of columns reinforced by conventional steel reinforcement. So, all columns were divided into two groups by considering the reinforcement ratio (r) which is the volumetric ratio of longitudinal reinforcement to concrete.

The first group, which had the reinforcement ratio of 1.6, consisted of specimen CS1.6, CB1.6 and CBT1.6. The results in Table 5 showed that the columns in this group had the same trend of strength development in which P_{max}/P_0 ratios were slightly different in each column. Also, all columns could against an axial force capacity provided by ACI318-05. However, it was not clear to conclude that reinforcing bamboo could be used as reinforcing material instead of conventional steel reinforcement. This was because specimen CB1.6 had ductility rather low when it was compared with CS1.6, and it also showed brittle behavior like plain concrete column. This might be an effect of water absorption and loss of bonding strength between bamboo and concrete mentioned earlier. On the other hand, the column reinforced by 1.6% of treated reinforcing bamboo, CBT1.6, showed similar behavior as observed in the column reinforced by 1.6% of conventional steel reinforcement, CS1.6. In addition, the results demonstrated that specimen CS1.6 and CBT1.6 had ductility of 1.29 and 1.23 respectively which were not much different.

Like the first group, the second group consisted of CS3.2, CB3.2 and CBT3.2 which had 3.2% of reinforcement ratio, showed the same trend of the efficiency of using reinforcing bamboo as reinforcement in concrete comparing with steel reinforcement shown in Figure 5. The column reinforced by 3.2% of reinforcing bamboo without surface treatment, CB3.2, had the lowest ductility. On the other side, the strength

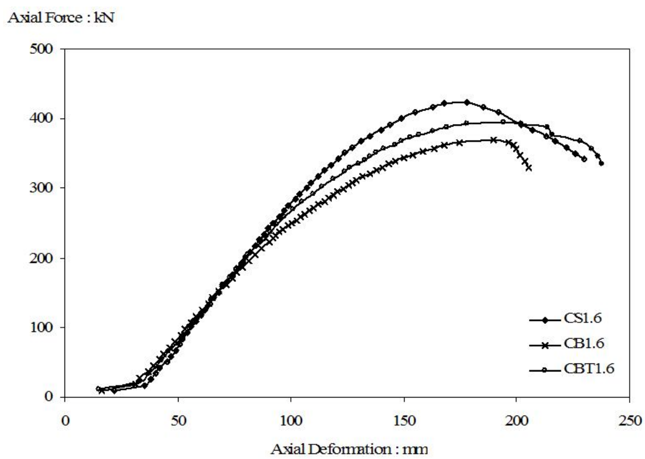

Figure 4. Comparison of columns reinforced by 1.6% reinforcement ratio

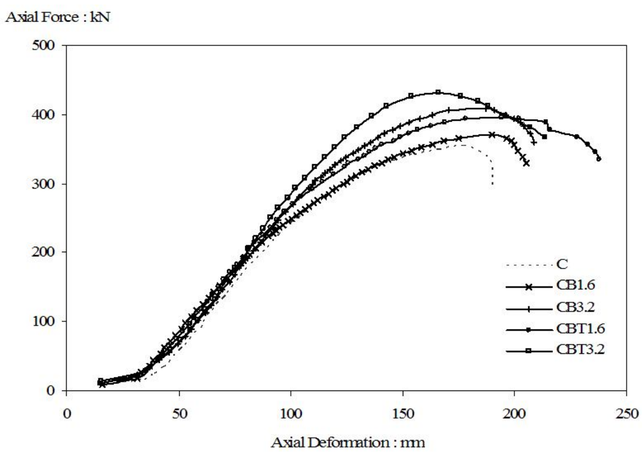

Figure 3. Comparison between the plain concrete column and the columns reinforced by bamboo

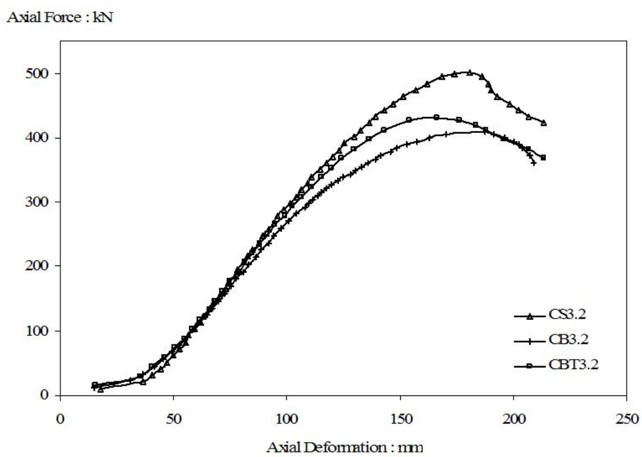

Figure 5. Comparison of columns reinforced by 3.2% reinforcement ratio

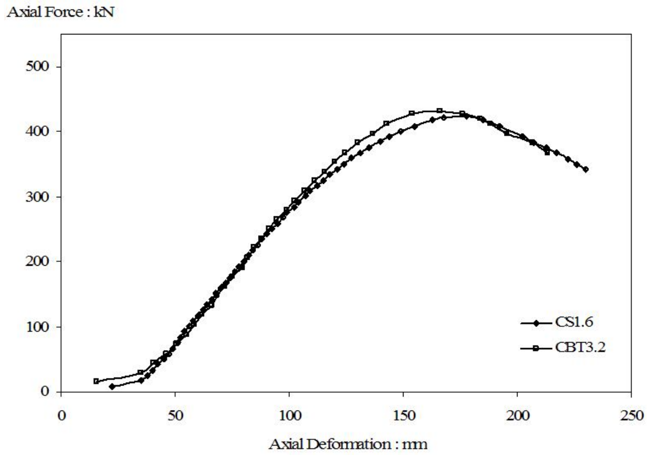

Figure 6. Comparison between CS1.6 and CBT3.2 shows the comparable strength and ductility

and ductility would be increased when the surface of reinforcing bamboo was coated by Sikadur-31CFN to improve bonding strength and to prevent water absorption. CBT3.2, a good example of the column reinforced by treated reinforcing bamboo, showed maximum ratio of P_{max}/P_0 and ductility in this group. Therefore, surface treatment had more effect on increasing strength and ductility of concrete column reinforced by reinforcing bamboo.

Furthermore, the results in Table 5 and the relationship between axial force and axial deformation in Figure 6 clearly showed that column CBT3.2 had P_{max}/P_0 ratio of 1.18 more than that of CS1.2 which was 1.02, while their ductility were almost equal. Consequently, it could be concluded that column with 1.6 percent of steel reinforcement could be replaced by using 3.2 percent of reinforcing bamboo treated by using Sikadur-31CFN as a surface coating material before concrete casting.

4. Conclusions

At the time of energy crisis, many researchers both scientists and engineers are looking for a natural material to replace the use of steel in construction industry. Bamboo is one of the most interesting materials which have distinct properties such as fast growth, high tensile strength to weight ratio, and easily found in tropical region of the globe. The results of this study showed that for the column reinforced by reinforcing bamboo without surface treatment, strength capacity was sufficient to withstand the maximum axial force provided by ACI318-05, while ductility was rather low, especially the column reinforced by 1.6% of bamboo without surface treatment, CB1.6. It showed brittle behavior like plain concrete column. This was because of the effect of water absorption and loss of bonding strength between concrete and bamboo. On the other hand, the columns reinforced by reinforcing bamboo treated with the water-repellent substance, Sikadur-31CFN, before concrete casting showed more strength and ductility than the columns reinforced by untreated reinforcing bamboo. It was also found that the 1.6% of steel reinforcement, in relation to the concrete section, could be replaced by the 3.2% of treated reinforcing bamboo which had the same behavior, strength and ductility.

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