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Technical Note

Mechanical Properties of Concrete with Bamboo Chips

Sung-Sik Park [1], Yao-long Hou [1], Jun-Cheol Lee [2,*] and Sueng-Won Jeong [3]

[1] Department of Civil Engineering, Kyungpook National University, 80 Daehakro, Bukgu, Daegu 41566, Korea
[2] Daegyeong Regional Infrastructure Technology Development Center, Kyungpook National University, 80 Daehakro, Bukgu, Daegu 41566, Korea
[3] Principal researcher, Korea Institute of Geoscience and Mineral Resources, Daejeon 34132, Korea
* Correspondence: darkgreen@knu.ac.kr; Tel.: +82-53-950-6335

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Abstract: Mechanical properties of concrete with bamboo chips as a potential source of aggregates have been investigated in this study.The measurement of this investigation includes slump loss, compressive strength, strain at peak compressive stress, modulus of elasticity, compressive toughness ratio, and splitting tensile strength. A 0.5-cm-thick bamboo chip was cut to a 1 cm (width) × 1 cm (height) piece and then dried, wetted, and coated to minimize water absorption.The coarse aggregates in the concrete specimen were replaced with 10%, 20%, and 30% (by volume) of each bamboo chip. The testing results showed that the compressive strength and splitting tensile strength of concrete with bamboo chips decrease with increasing bamboo chip content (BCC). It is considered that the decrease of strengths is due to the weak bond between the mortar and the bamboo chip.

Keywords: bamboo chip; strength; concrete; aggregate; water absorption

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1. Introduction

Natural aggregates used in construction are gradually being depleted due to industrialization and urbanization. Therefore, the development of sustainable construction materials (e.g., bamboo) and recyclable construction resources is necessary. Bamboo is inexpensive, grows rapidly, and is widely distributed around the world. In addition, over the last few decades, this material has beenincreasingly used in developing countries, owing to its flexibility and resistance to seismic loading. However, the compressive resistance of bamboo is relatively low, hence, the use of this material for structural members is limited to light loads. Recently, several studies have considered the use of bamboo-reinforced concrete members as an alternative to the use of steel members [1–6]. Ghavami investigated bamboo as a potential replacement for steel rebar and determined the flexural strength of bamboo-reinforced concreteand focused on bamboo as an engineering material, where durability is essential, and treated the bamboo with oil for waterproofing [7,8]. Coated bamboo splints exhibited good durability and strength in bamboo bonded with mortar. In addition, concrete bricks reinforced with bamboo fibers were arranged vertically and horizontally and subjected to repeated loads.

Bars of bamboo culm, splint, or fiber have mainly been used for structural members and reinforcement of concrete. Published studies on the use of bamboo chips for mixing concrete are rare [9,10]. Therefore, in the present study, coarse aggregates in concrete specimens were replaced with 10%, 20%, 30%, and 100% (wetted bamboo only) bamboo chips and cured for 7 and 28 days. The chips were treated dried, coated, and wetted in order to determine the effect of water absorption on strength development. The compressive and tensile strength of the bamboo were evaluated from the viewpoint of potential bamboo usage in coarse aggregates, where the bamboo inclusion ratio and treatment type are considered.

2. Experimental Program

2.1. Materials

In this study, Wangdaebamboo with average diameter and average height of 10 cm and 20 m, respectively, was used. To replace the coarse aggregate in concrete, the bamboo (compressive strength: 42.5 MPa) was cut into 10 mm × 10 mm × 5 mm chips (specific gravity: 1.27), as shown in Figure 1. The bamboo was treated in three ways, i.e., the material was coated, dried, and wetted prior to being mixed with the concrete. The bamboo chips considered in the present study were dried for 24 h in an oven at 60 °C or wetted by soaking for 24 h under water. Coated chips were obtained by immersing the dried chips for 2 hunder the general waterproof agent (3M, General waterproofMP 131) and drying them for 24 h at the room temperature.

Figure 1. Bamboo chips.

Ordinary Portland cement and tap water were used for mixing the concrete specimens. River sand(maximum size of 2 mm and specific gravities of 2.67) and natural aggregates(maximum size of20 mm and specific gravities of 2.58) equivalent ASTM C33 were used [11]. Table 1 shows the specification of aggregate used in this study.

Table 1. Specification of aggregates.

Type	Size Range (mm)	Fineness Modulus	Specific Gravity	Water Absorption (%)
Fine aggregate	10–20	6.5	2.58	1.1
Coarse aggregate	0.15–2.0	2.65	2.67	3.2
Bamboo chip	10	-	1.27	55.9

2.2. Design of Experiments

In this work, the coarse aggregates in concrete specimens were replaced with bamboo chips, which were treated in different ways that yielded three different types of chips (dried, coated, wetted). The influence of the bamboo water absorption rate on the properties of the concrete specimens could therefore be evaluated. The coarse aggregates in concrete specimens were replaced with 10%, 20%, and 30% (by volume) of bamboo chips and cured for 7 and 28 days (see Table 2 for BCC).

Table 2. Summary of concrete specimen with bamboo chips.

TEST ID	Curing Age (day)	Bamboo Chip Type	Bamboo Chip Content, BCC (%)
NB-7	7	No bamboo	0
DB10-7		Dried	10
DB20-7			20
DB30-7			30
CB10-7		Coated	10
CB20-7			20
CB30-7			30
WB10-7		Wetted	10
WB20-7			20
WB30-7			30
NB-28	28	No bamboo	0
DB10-28		Dried	10
DB20-28			20
DB30-28			30
CB10-28		Coated	10
CB20-28			20
CB30-28			30
WB10-28		Wetted	10
WB20-28			20
WB30-28			30

The mixture proportion of the plain concrete is shown in Table 3. The plain concrete was designed to achieve a 28-day compressive strength of ~28 MPa, and the concrete mixture was prepared at a water-to-cement ratio of 0.45. Furthermore, the mixture proportions of the concrete were based on satisfying an air content and a target slump-loss of 3.5±1.0% and 200±50 mm, respectively.

Table 3. Mixture proportion of plain concrete.

W/C (%)	S/a (%)	Unit Weight (kg/m^3)		
		OPC	S	G
0.45	50	467	804	777

Note: W/C = water to cement ratio, S/a = sand to coarse aggregate ratio, OPC = ordinary Portlandcement, S = sand, G = Gravel.

2.3. Specimen Preparation and Test

A pan mixer was used to mix the concrete. Regarding the fresh concrete properties, the value of the slump loss was measured after slump tests conducted in accordance with ASTM C143 [12]. For each mixture, a total of twelve 10 mm (diameter) × 20 mm (height) cylinders were cast in steel molds. These specimens were then cured in a temperature-controlled water bath at 20 ± 2 °C until the time of testing.

Compressive strength tests and splitting tensile strength tests were performed, in accordance with ASTM C39 and ASTM C496, respectively, on three 7-day- and 28-day-cured specimens. The axial deformations occurring during the compressive tests were measured using two linear variable differential transformers (LVDTs) mounted on opposite sides of the specimen (gage length: 50 mm), in accordance with JSCE-SF5 [13–15].

3. Experimental Results and Discussion

3.1. Slump Loss

Figure 2 shows the slump losses of fresh concrete with respect to the replacement ratio of each bamboo chip. A constant slump value of 19 cm was obtained for increasing BCC of the specimen with wetted bamboo chips. However, the slump value of the specimens with coated and dried bamboo decreased with increasing BCC, possibly owing to the low weight of these chips and the slip occurring between the chips and the mortar.

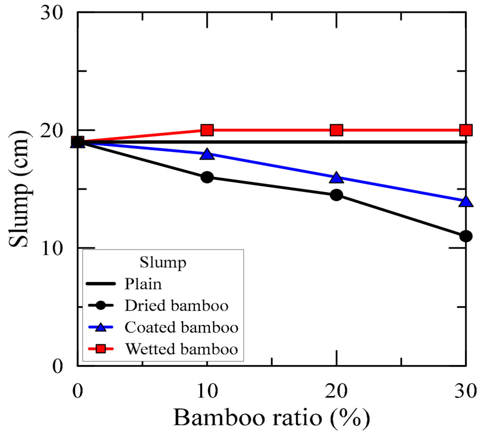


Figure 2. Results of slump tests.

3.2. Compressive Properties

Figure 3 shows the compressive stress-strain curves of the hardened concrete with different replacement ratios of each bamboo chip. Based on these stress-strain curves, several compressive properties are extracted include the compressive strength, strain at peak stress, and specific toughness ratio. Table 4 shows these properties with respect to the replacement ratio of each bamboo chip.

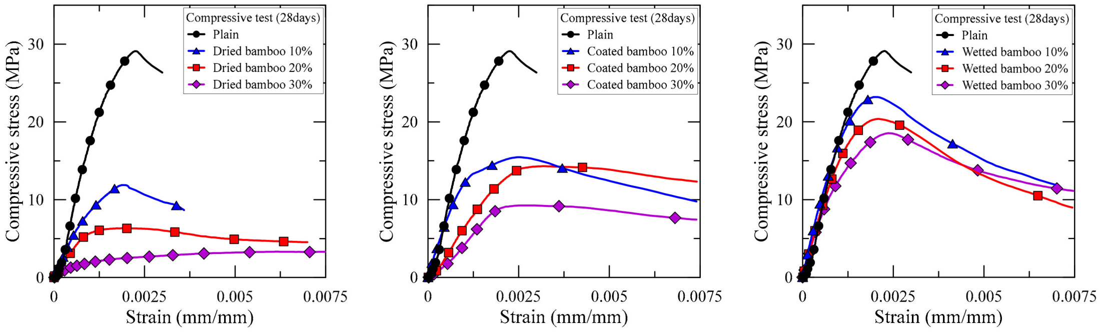


Figure 3. Compressive stress-strain curves.

Table 4. Experimental results.

TEST ID	Compressive Strength (MPa)	Strain at Peak Stress (%)	Elastic Modulus ($\times 10^4$ MPa)	Compressive Toughness Ratio (%)	Splitting Tensile Strength (MPa)
NB-7	18.00	0.22	1.87	0.26	1.89
DB10-7	9.40	0.30	0.55	0.34	1.15
DB20-7	4.28	0.33	0.38	0.68	0.82
DB30-7	2.37	0.35	0.20	0.59	0.37
CB10-7	9.84	0.28	1.26	0.45	1.39
CB20-7	7.94	0.35	0.81	0.51	1.11
CB30-7	7.33	0.33	0.29	0.44	0.74
WB10-7	12.52	0.27	1.48	0.73	1.63
WB20-7	11.26	0.30	0.97	0.71	1.52
WB30-7	9.51	0.29	0.78	0.58	1.35
NB-28	30.77	0.22	2.20	0.17	2.38
DB10-28	13.55	0.20	1.35	0.30	1.59
DB20-28	5.76	0.27	0.50	0.66	0.83
DB30-28	3.13	0.35	0.32	0.65	0.38
CB10-28	15.01	0.26	1.63	0.61	1.74
CB20-28	14.15	0.25	0.98	0.61	1.13
CB30-28	8.99	0.20	0.51	0.63	0.84
WB10-28	23.73	0.25	1.89	0.50	2.21
WB20-28	19.04	0.28	1.22	0.55	1.79
WB30-28	17.75	0.23	1.03	0.57	1.61

3.2.1. Compressive Strength

The compressive strength of the bamboo-free plain concrete specimen was 18 and 31 MPa at 7 and 28 days, respectively. As BCC increased, the strength and stiffness decreased, regardless of the bamboo-chip type. Figure 4 shows the compressive strength of 7-day- and 28-day-cured concrete with bamboo chips.

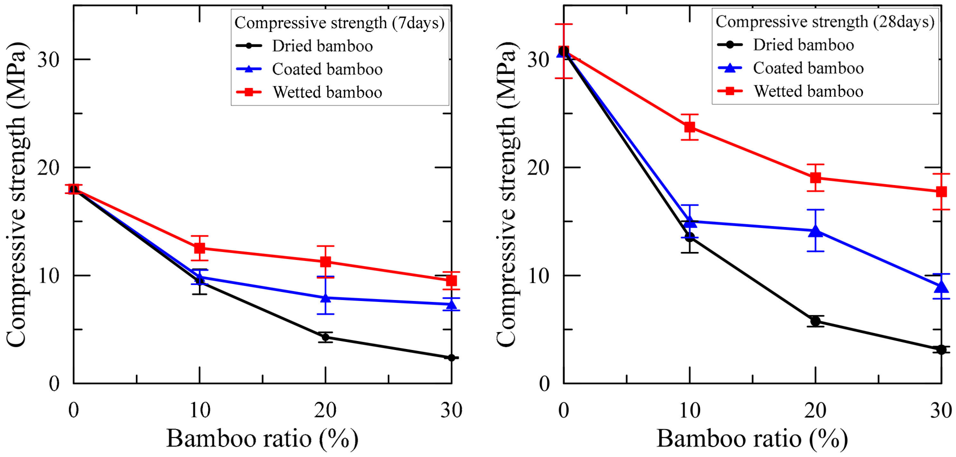
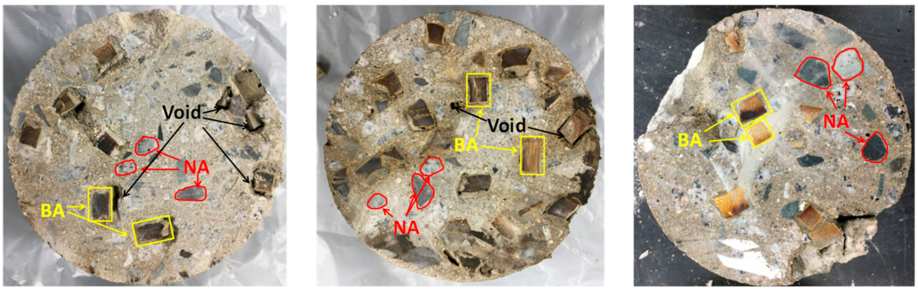


Figure 4. Comparison of the compressive strength.

At 28 days, the strength of the concretewith 30% of dried bamboo chip was about 10% of that of plain concrete. The chip became swollen after absorbing some water for hydration. This resulted in micro cracks and weak bonds between the mortar and the aggregates, leading to low strength when dried bamboo was used for the natural coarse aggregate. Figure 5 shows the cutting plane of the specimen with different bamboo chips. During cutting, some of the dried and coated bamboo chips were removed, owing to the weakness of the interface. In contrast, the natural aggregates (NA in Figure 5) and wetted bamboo chips (BA in Figure 5) were characterized by a relatively strong cemented interface between the aggregate and the mortar.



(**a**) (**b**) (**c**)

Figure 5. Cutting plane of concrete with bamboo chips: (**a**) Dried bamboo, (**b**) coated bamboo, (**c**) wetted bamboo.

As expected, the compressive strength of concrete with and without bamboo chip increased with increasing curing age. The strength of plain concrete was increased by71% when the curing age increased from 7 to 28 days. The compressive strength of the concrete with 10%, 20%, and 30% of the dried (coated and wetted) bamboo chip increased by 44% (53% and 90%), 35% (78% and 69%), and 32% (23% and 87%), respectively, when the curing age increased from 7 to 28 days. The greatest increase in strength occurred for the concrete with wetted chips. Moreover, the rate of increase induced by curing decreased with increasing BCC, and for a BCC of 30%, the treatment of the bamboo influenced the overall strength.

3.2.2. Compressive Toughness Ratio

The compressive toughness ratio is calculated by dividing the area below the stress-strain curve by the maximum compressive strength [16]. In this study, a strain of 0.75%, which was employed in JSCE-SF5 and previous studies, was taken as the reference. The area below the curve was calculated and the toughness ratio was then determined [17,18].

As shown in Figure 6, the toughness ratio increased (to some extent) with increasing BCC. This is especially true for specimens with dried bamboo chips, where a significant increase in the ratio was observed.

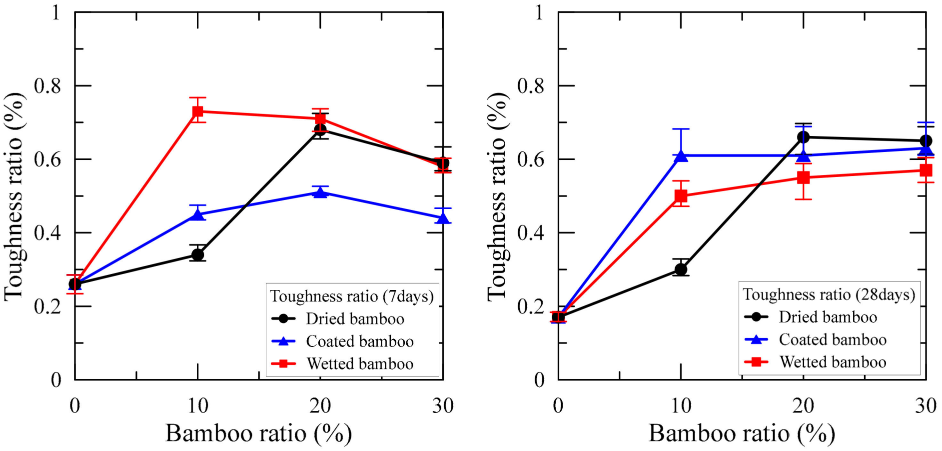


Figure 6. Toughness ratio of the specimens with different bamboo chips.

3.2.3. Modulus of Elasticity

The elastic modulus was calculated using the measurement value that is closest to 1/3 of the peak stress. The elastic modulus of the 7-day- and 28-day-cured plain concrete was 1.9×10^4 and 2.2×10^4 MPa, respectively.

As shown in Figure 7, the elastic modulus of the concrete with bamboo chip decreased with increasing BCC at the age of 7 days and 28 days. The elastic modulus of the concrete with dried bamboo chip showed the largest decrease compared to that of the concrete with wetted or coated bamboo chip.

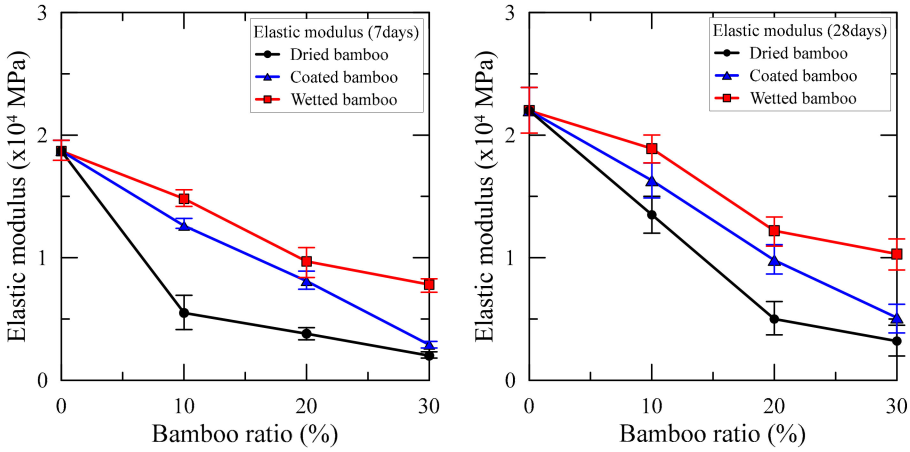


Figure 7. Elastic modulus of specimens with different bamboo chips.

3.3. Comparison of Splitting Tensile Strength

The splitting tensile strength of the 7-day- and 28-day-cured concrete was plotted as a function of BCC (see Figure 8).

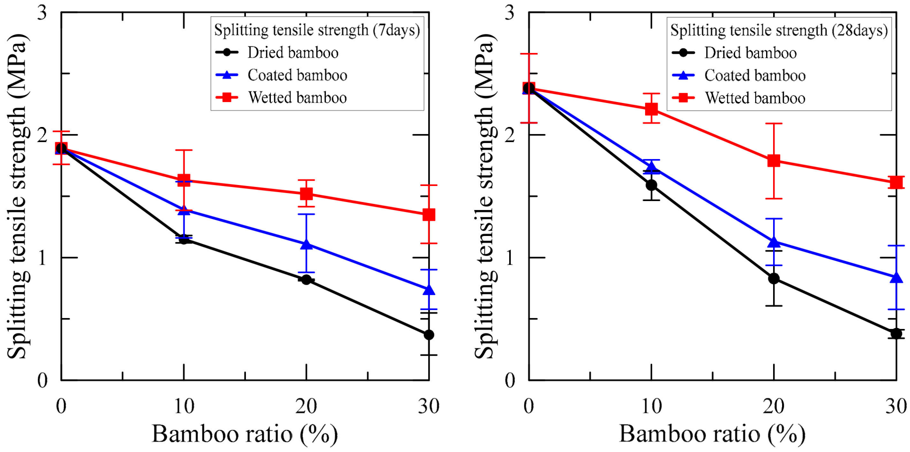


Figure 8. Results of splitting tensile strength tests.

The splitting tensile strengths of the concrete with 10%, 20%, and 30% of the dried (coated and wetted) bamboo chip decreased by 33% (26% and 7%), 65% (52% and 24%), and 84% (64% and 32%), respectively, compared to plain concrete at the age of 28 days.Therefore, the largest strength reduction occurred in the concrete with dried bamboo chip, whereas the smallest reduction occurred in the concrete with wetted bamboo chip. This is consistent with the development of a strong interface between the wetted chips and the mortar. The development of this interface results from sufficient water for hydration with negligible water absorption by the chips.

As observed from the compressive strength test, the splitting tensile strength increased with increasing curing age. However, when dried bamboo chips were mixed at a ratio of >20%, the strength increased only slightly with curing time, owing to the weak interface between the dried chips and the mortar. This weak cement interface may have resulted from the swelling of dried chips following the absorption of water. The result was shown as Table 4.

4. Conclusions

Several studies have focused on using bamboo splints to replace steel reinforcing bar or fiber. However, the use of bamboo chips to replace aggregates has rarely been investigated. In this study, 1 cm × 1 cm × 0.5 cm (thickness) bamboo chips were wetted, dried, and coated. The chips were used to replace 10, 20, and 30% of the coarse aggregates in concrete. Only wetted bamboo chips were used to completely replace the natural coarse aggregates. The chips were then cured under water for 7 and 28 days, and the corresponding compressive and splitting tensile strengths were subsequently evaluated. The major results of this study are summarized as follows:

- Regardless of the bamboo type, both compressive and splitting tensile strengths decreased with increasing BCC. The strength of the specimen with 30% dried bamboo was 87% of the strength associated with ordinary concrete without bamboo. When natural coarse aggregates were replaced entirely with wetted bamboo chips, the compressive and tensile strengths decreased to ~10% of the plain-concrete strength. This results from the fact that the bamboo chip had lower strength and a weaker interface than the natural coarse aggregate.
- The specimen with wetted bamboo exhibited the highest strength, whereas the specimen with coated and then dried bamboo exhibited the lowest strength. During the curing process, the dried bamboo absorbs water, causing the volume to expand, resulting in micro cracks in the concrete and leading to a reduction in the strength of the concrete.
- The elastic modulus decreased from 2.2×10^4 MPa to 0.32×10^4 MPa, when the BCC increased from 0 to 30%. Moreover, except for the toughness ratio of the plain concrete, the toughness ratio decreased slightly with increasing BCC.

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Conflicts of Interest: The authors declare no conflict of interest.

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