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Experimental investigation of flexure resistance performance of bio-beams reinforced with discrete randomly distributed fiber and bamboo

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HIGHLIGHTS

- Microbial induced calcite precipitation (MICP) method applied on construction materials.
- Fiber and bamboo were proposed to improve the flexure resistance performance of bio-beams.
- Four-point bending test was conducted to evaluate the flexure behavior of reinforced bio-beams.

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ABSTRACT

Microbial induced calcite precipitation (MICP) can bond sand particles together to improve the mechanical properties of sandy soil. This environmental-friendly technique has potential applications on construction materials such as bio-bricks and bio-beams. This study is to investigate the flexure resistance performance of bio-beams by adding discrete randomly distributed fiber and bamboo materials with multiple immersing MICP treatment. Different fiber proportions (0.1%, 0.2%, 0.3% and 0.4% by weight of dry sand) were used. MICP treated bio-beams were also reinforced by five different arrangements of bamboo strips. Four-point bending tests were conducted to evaluate the flexure behavior of fiber reinforced and bamboo reinforced bio-beams. Results showed that adding fiber in the MICP treated bio-beams can increased the ductility. The optimum fiber content was around 0.3%. Addition of 0.3% fiber can significantly prevent the post peak flexure strength loss and improved the ductility of bio-beams which had 400 kPa residual strength at 15% failure strain. Bamboo reinforced bio-beam can improve the flexure strength from 890 kPa to 1750 kPa. Meanwhile, multiple immersing MICP treatment can significantly improve the flexure strength of bio-beams up to 3.0 MPa, but the ductility of fiber reinforced bio-beam reduced after multiple treatment.

1. Introduction

Microbial induced calcite precipitation (MICP) is an environmentally friendly and sustainable technique that has been widely studied in recent years. The MICP requires the existence of ureolytic bacteria, urea and calcium-rich solution to drive the biogeochemical reaction [1–3]. MICP treatment can develop cementation between soil particles to improve the mechanical properties [4–6]. MICP has been suggested to use for a variety of applications such as improvement of strength and stiffness of soil, reduced sand liquefaction, improvement and remediation of concrete, and environmental remediation [7–10]. Zhao et al. [5] used immersing method to treat Ottawa sand and achieved maximum unconfined compression strength (UCS) of 2.14 MPa with 13.45% calcite precipitation by weight of dry sand. Ramachandran et al. [11] filled the concrete cracks with Bacillus *pasteurii* (also known as *Sporosarcina pasteurii*) and sand, submerged the concrete in Urea-$CaCl_2$ medium and cured at room temperature for 28 days. The UCS results indicated that remediation was more efficient in shallow cracks (12.7 mm). The stiffness of treated beams also increased up to 100 N/mm with 3.175 mm depth of cracks. Bernardi et al. [2] developed a bio-mediated process for manufacturing of bio-bricks. The results showed the compression strength of bio-bricks could exceed 2.0 MPa which was similar to 15.8% cement treated bricks (~2.0 MPa) and better than lime treated bricks (26.7% lime, 0.98 MPa). Bu et al. [12] developed bio-beams through MICP and compared with sand-based beams made through lime modification

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and cement modification. The test results indicate that flexure strength of bio-beam was 950 kPa which is similar to flexure strength of 20–25% cement-treated sand beams, but is much higher than flexure strength of 30% lime-treated sand beams.

However, it has been found that MICP treated specimen often exhibits brittle behavior [2,5]. To improve the ductility of MICP treated sample, fiber or bamboo can be considered as reinforcement materials. Fiber reinforcement have been used to increase the shear strength, ductility and reduced post peak strength loss of soil [13–15]. Shao et al. [14] investigated the mechanical properties of sand reinforced with discrete randomly distributed fiber and found that fiber had positive effects on improving the shear strength and ductility. Li et al. [10] added 12-mm long polypropylene fiber with different mixing ratio into sand during the MICP process, and found that the unconfined compression strength, ductility and cohesion of MICP treated sample. Dixon et al. [16] studied the flexural properties of bamboo materials and recommended bamboo could be considered as one type of reinforced materials. Rahman et al. [17] found that flexure strength of bamboo-reinforced concrete beam can significantly increase. Moroz et al. [18] studied the performance of bamboo-reinforced concrete masonry shear wall, and found that bamboo reinforcement increase shear capacity and ductility.

The objective of this paper is to study the flexure resistance performance of MICP treated bio-beams. Discrete randomly distributed fiber and bamboo have been used as additives in the reinforcement. A rigid full contact mold was used in the immersing method with multiple treatments to prepare MICP-treated bio-beams. Four-point bending tests were conducted to evaluate the flexure of bio-beams.

2. Materials and testing method

2.1. Sands

Ottawa silica sand (99.7% quartz) with a median particle size of 0.46 mm was used to prepare the sand-based bio-beam. The soil was classified as poorly graded sand with USCS classification system.

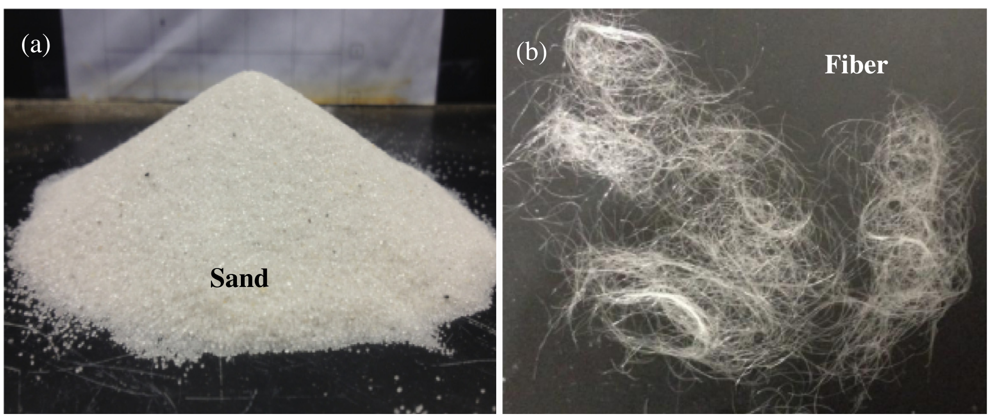

Fig. 1. Image of Ottawa sand (a) and Discrete randomly distributed fiber (b).

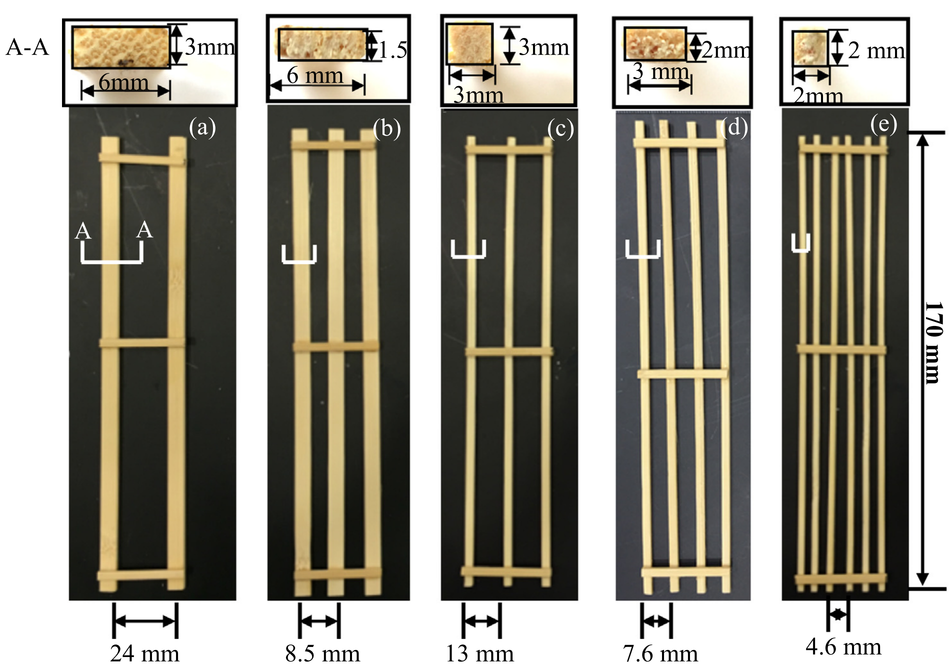

Fig. 2. Different arrangement with various cross-section sizes and numbers of bamboo strips: a) BA-1, two bamboo strips with cross section dimension of 3 mm × 6 mm (H × W); b) BA-2, three bamboo strips with cross section dimension of 1.5 mm × 6 mm (H × W); c) BA-3, three bamboo strips with cross section dimension of 3 mm × 3 mm (H × W); d) BA-4, Four bamboo strips with cross section dimension of 2 mm × 3 mm (H × W); e) BA-5, six bamboo strips with cross section dimension of 2 mm × 2 mm (H × W). The length of each bamboo strip was 170 mm.