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EFFECTS OF BAMBOO CELLULOSE MICRO-FIBERS ON MECHANICAL CHARACTERISTICS AND POROSITY OF CEMENT MORTAR

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This study presents the effect of utilizing cellulose microfibers obtained through extraction from bamboo as reinforcement on mortar mixtures. The mixture proportions used in this experiment are 0.5%, 1%, 1.5%, and 2% of bamboo cellulose fiber by weight of cement as additional material in mortar mixture. It was found that the optimum compressive strength of 36.4 MPa was achieved by the sample with 1.5% of bamboo cellulose fiber as additional material with water to binder ratio of 0.5. A similar trend was also found in the result of flexural strength of mortar due to bamboo cellulose fiber addition, reaching the value of 6.31 MPa on the 28th day, which is 52% higher than the flexural strength of control mortar. From the porosity results, the percentage of mortar porosity containing micro-fibers ranged from 4.6-9.1%, lower than the porosity of control mortar, indicating that the addition of fibers led to fill in the pores, resulting in a denser cement matrix. The performances of the cellulose fiber contributed to the strength development and porosity resistance of mortar even with low volume fraction, making it a potential to be used as material building construction, for instance, masonry mortar, repair mortar, rendering mortar, joint filler, waterproof mortar, decorative mortar and for precast elements in construction. The research findings also provide new perspective on the utilization of natural cellulose fibers as a sustainable construction material.

Keywords: Bamboo cellulose fiber, Compressive strength, Flexural strength, Porosity.

1 INTRODUCTION

The challenges of building materials have been prioritized in terms of creating eco-friendly and sustainable alternative building materials, which refer to the application of construction materials that can be used continuously and are widely available. A recent study has introduced cellulose fibers in concrete mixtures, which has been shown to provide positive effects. Due to the chemical composition and physical characteristics of cellulose fibers, it is a viable alternative for improving the mechanical properties of conventional concrete. Based on research conducted by Shah *et al.* (2010), cellulose fibers have unique characteristics that influence initiation crack propagation on the micro and nanostructure dimensions. The existence of natural fiber particles contributes to bridging micro-cracks that occur inside the structure of the specimens. Research by Supit and Nishiwaki (2019) provides the empirical result of cellulose fiber in comparison to control mortar, and observed cracking behavior of cement mortars containing cellulose fibers, from which it can be concluded that even a low volume fraction, i.e., 0.005 % of CNFs (cellulose nanofibers), is effective in enhancing the mechanical properties of high-performance mortar. Relatively similar inventions and discoveries by Mejdoub *et al.* (2017) in a study on cellulose fibers claimed that the age of the specimens that include cellulose fibers in mortar mixture possess better resistance than the specimen with 0% of cellulose fiber in the mortar mixture. Natural fiber leads to better toughness, elastic modulus, and crack resistance in the microstructure (Kawashima and Shah 2011). Based on the references above, it is interesting to investigate more on the effect of the cellulose fiber derived from bamboo, particularly on the characteristics of Portland Composite Cement Mortar for potential use as material in building construction. In this paper, the method of preparing the bamboo cellulose fiber is also discussed.

2 MATERIAL

The cellulose fiber used in this experiment is selected material extracted from a local bamboo plant located at Tiwoho Village, Wori, North Minahasa Regency. The primary components of bamboo are cellulose, hemicellulose, and lignin, with varying proportions of resin, tannins, wax, and mineral compounds forming the structure of the plant's texture. In this experimental work, extraction method was conducted. Prior to actual extraction, the bamboo was dried in the oven for 3 hours at 90˚C, crushed, and then samples were filtered in a sieve no. 50 multiple times to obtain the powder texture. The processing of bamboo fibers aims to obtain light fiber particles, for the fiber degradation will be easier if the fiber is in powder form. According to the results of the heat treatment, bamboo fiber comprises approximately 80% water range. The cellulose fiber extraction method isolates the cellulose fibers from the other substances and was obtained through a chemical process that includes alkalization with a sodium hydroxide solution compound (NaOH) concentration of 20% at a temperature of 100°C for 4 hours, then the maceration process with a Hydrogen Chloride (HCL) solution concentration of 2-5% at a temperature 100℃ in an isolated glass was performed. This study analyzed the mortar samples containing different dosages of 0.5%, 1%, 1.5%, and 2% bamboo cellulose fibers by wt. of cement as additional material with water/binder ratio of 0.5 and 1% superplasticizer.

3 EXPERIMENTAL METHODS

3.1 Compressive Strength

The compressive test was carried out following the ASTM C 109 (ASTM 2021) Standard on "Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2in. or 50mm Cube Specimens)" using a square mold with dimensions of 50mm x 50mm x 50mm (see Figure 1). Testing was performed at the 7^{th} and 28^{th} day after the water curing process. The values of the compressive strength test were determined by taking the average of six mortar samples and calculating the overall result.

3.2 Flexural Strength

The flexural strength test was conducted according to the ASTM C 293-02 (ASTM 2002) standard on "Flexural Strength of Concrete (using a simple beam with center-point loading)" with sample specimens of 40mm x 40mm x 160mm. In the testing machine, the center-point loading device was adjusted so that its bearing edge was exactly at right angles to the length and horizontal to the surface of the prism so that it was accurately placed.

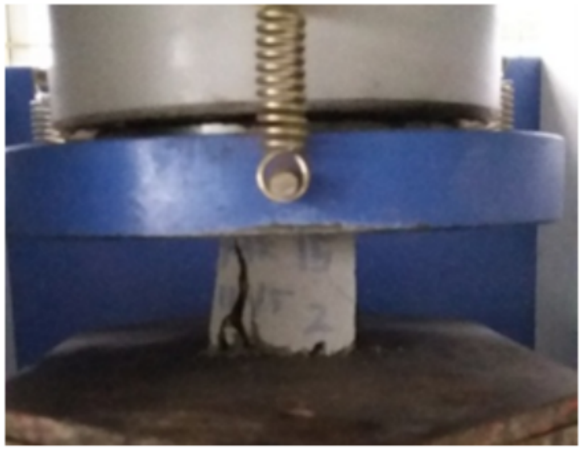

Figure 1. Compressive strength test set-up.

3.3 Porosity

Porosity test was conducted based on the ASTM C 642 (ASTM 2013) standard, "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete". The square mold with dimensions of 50mm x 50mm x 50mm was used for this experiment. Testing was performed at the 7^{th} and 28^{th} day after the curing process. It was then weighed accurately in an oven at a temperature of 110 degrees Celsius for 24 hours after being taken from the water. Considering different weights of the material being evaluated explicitly refers to specific porosity values.

4 RESULT AND DISCUSSION

4.1 Compressive Strength

The compressive strength of mortar was tested at day 7 and 28 day after curing in water. Figure 2 shows the compressive strength result of mortar with various bamboo cellulose fiber dosages. The highest compressive test is represented by the presence of cellulose fibers at 1.5% of the four different types of variations. In the mortar sample, 1.5% achieved an initial strength of 32.8 MPa after day 7 and increased to 36.4 MPa after 28 days of curing, indicating the 54.6% increase in index strength. From the variation of 0.5% and 1% cellulose fiber, the results tended to be similar and nearly equal to control mortar samples when tested. Moreover, the strength declined at 2% concentration containing bamboo cellulose fiber when the volume fraction increased. Supit and Nishiwaki (2019) which indicated that, as the concentration of cellulose fiber in high dosage increases, the compressive strength and modulus dynamics of elasticity decrease. It was hypothesized that an increase in the volume fraction of cellulose fibers reduces the adhesion interface and enhances the concentration of tensions, which is induced by challenges with porosity, compaction, and agglomeration of fibers with a high content of hydroxyl groups. When there is a high volume of fiber in the mixture, the compressive strength decreases due to the creation of hydroxyl and carboxyl formations that react with Ca+, which can decelerate the bonding time and delay the cement hydration time, respectively.

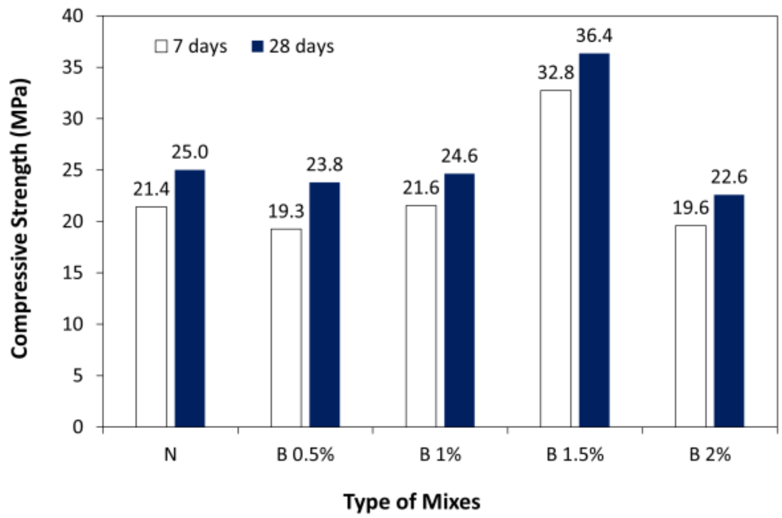

Figure 2. Compressive strength of mortar mixtures containing bamboo cellulose fibers.

Kawashima and Shah (2011) also concluded that the presence of cellulose fibers results in close proximity and strong bonds between the fibers and the cement matrix, improving density and influencing the development of compressive strength in the cement matrix. Due to inappropriate fiber dosage and fiber dispersion, the bonding between the particles in the mixture will be degraded. Researchers found that proper dispersion can optimize the advantages of combining the various fibers into a mixture by reducing free areas in the mixture and improving the durability attributes of samples by preventing cracking induced by load pressure or other causes that result in shrinkage. The dispersion of cellulose fibers in this condition tends to be a problem depending on the characteristics of the fiber, the quality of the fiber, and also the mixing technique used to integrate the material components.

4.2 Flexural Strength

As seen in Figure 3, the flexural strength of mortar containing bamboo cellulose fiber was evaluated against the control mortal. Mortar samples containing 1.5% of bamboo cellulose fiber increased the flexural strength of test objects by 4.54 MPa after day 7 and by 6.31 MPa after the 28th day, with performance index increases of 52.5% and 23.4%, respectively, when compared to mortar control. Based on the evaluated effects of post-test inspections specimens, it was identified that the addition of cellulose fibers in the mortar could delay the period carried to fracture when the load was at maximum pressure. This is also related to Jiao *et al.* (2016) who reported the ability of cellulose fibers to reinforce the bonds among microstructures. However, it was also claimed that, at a certain percentage of cellulose, the agglomeration can be expected and affects the deficient adhesion interface. Based on Mejdoub *et al.* (2017), the cellulose fiber cement composites exhibited toughness, persistence, flexural capacity, and crack resistance compared to cement-based materials that are not reinforced by fibers. The primary advantage of fiber reinforcement is the composite behavior after the crack initiation. The fiber contributes to bridging the micro crack and transmits the load.

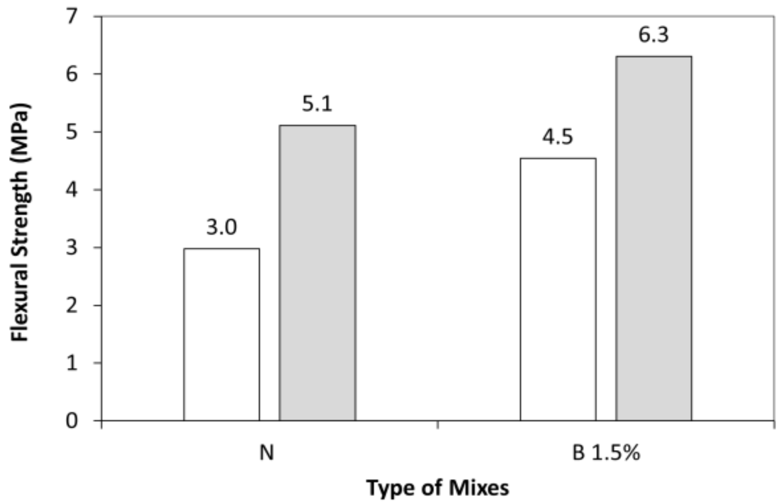

Figure 3. Flexural strength of normal mortar and mortar with 1.5% bamboo cellulose fiber.

4.3 Porosity

From the test results, the presence of cellulose fiber in the mortar mixture can maximize the deficiency that naturally occurs in Portland Composite Cement mixtures. The porosity value of cellulose mortar tested at on day 7 and 28 is shown in Figure 4.

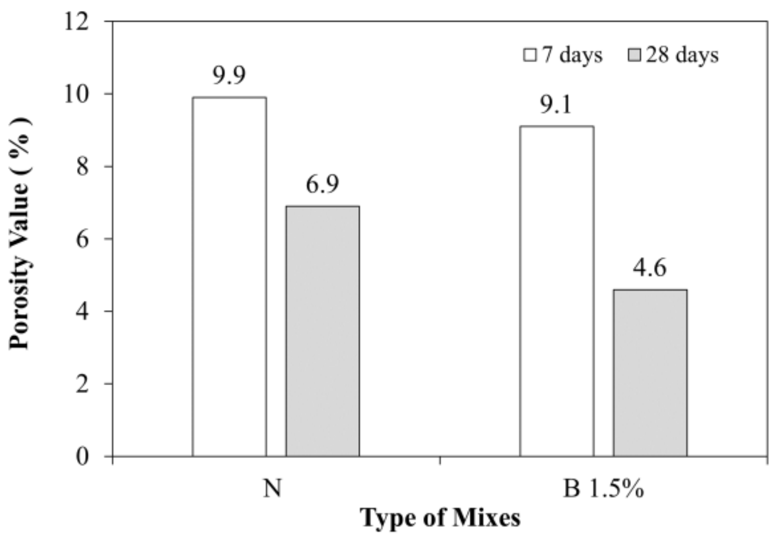

Figure 4. Porosity values of normal mortar and mortar with 1.5% bamboo cellulose fiber.

The significant distinction in porosity values in control mortar and mortar containing 1.5% of bamboo cellulose fiber by weight of cement is given in the bar chart, and it can be seen that the dosage of bamboo cellulose fiber added to the cement mixture showed a better porosity resistance, with a level of porosity of 9.1% at day 7. Pore size decreased at the 28th day, which is 4.6%. The porosity value is directly related to the number of pores or free areas spread throughout the mortar. The presence of cellulose fibers contributes to minimizing pores in the microstructure; these pores are generated because of retained air and improper compaction, and the cellulose fibers fill the space and lessen the pores by lowering the interfacial tension.

5 CONCLUSIONS

Based on the experimental results, the use of cellulose fiber at the proper dose, as determined by the optimum fiber addition dose at a fiber concentration of 1.5% of cement weight, has the potential to substantially improve mechanical strength, i.e., compressive and flexural strength of Portland Composite Cement mortar. The addition of cellulose fibers enhances the mechanical properties of mortar, preventing it from cracking under pressure and dynamic control. In addition, the presence of bamboo cellulose fiber induces the porosity value of mortar to have a smaller pore size than the control mortar. This indicates that the presence of cellulose fibers in the microstructure fills up empty spots, increasing the density of the structure and reducing pores, making it potential to be used as material building construction, for instance, masonry mortar, repair mortar, rendering mortar, joint filler, waterproof mortar, decorative mortar and for precast elements in the construction.

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