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Bamboo Sawdust as a Partial Replacement of Cement for the Production of Sustainable Cementitious Materials

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Abstract: This paper reports on the utilization of recycled moso bamboo sawdust (BS) as a substitute in a new bio-based cementitious material. In order to improve the incompatibility between biomass and cement matrix, the study firstly investigated the effect of pretreatment methods on the BS. Cold water, hot water, and alkaline solution were used. The SEM images and mechanical results showed that alkali-treated BS presented a more favorable bonding interface in the cementitious matrix, while both compressive and flexural strength were higher than for the other two treatments. Hence, the alkaline treatment method was adopted for additional studies on the effect of BS content on the microstructural, physical, rheological, and mechanical properties of composite mortar. Cement was replaced by alkali-treated BS at 1%, 3%, 5%, and 7% by mass in the mortar mixture. An increased proportion of BS led to a delayed cement setting and a reduction in workability, but a lighter and more porous structure compared to the conventional mortar. Meanwhile, the mechanical performance of composite decreased with BS content, while the compressive and flexural strength ranged between 14.1 and 37.8 MPa and 2.4 and 4.5 MPa, respectively, but still met the minimum strength requirements of masonry construction. The cement matrix incorporated 3% and 5% BS can be classified as load-bearing lightweight concrete. This result confirms that recycled BS can be a sustainable component to produce a lightweight and structural bio-based cementitious material.

Keywords: bamboo; sawdust; pretreatment; bio-based material; mechanical property

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1. Introduction

The Paris 2024 Olympics have committed to reducing their carbon footprint, with the Olympic and Paralympic Villages being built using 100% bio-based materials. This example illustrates that the trend in the construction industry in the twenty-first century is towards sustainable and environmentally friendly building materials. To date, concrete has been the most widely used building material in the world, with ordinary Portland cement being the key ingredient in concrete. Cement production exceeds 4 billion tons per year and leads to ~8% of the world's carbon dioxide emissions [1], which is the main driver of the greenhouse effect. According to the Paris Agreement on climate change, emissions from the cement sector should decrease by at least 16% by 2030. These factors explain our passion for investigating a natural and sustainable substitute for cementitious materials.

China contains 5.4 million hectares of bamboo planting area where the environment and climate are suitable for bamboo growing [2]. Bamboo belongs to the grass family, which consists of more than 1600 species. As the fastest-growing plant in the world, bamboo can grow up to 90 cm per day and reach maturity in only 2–3 years. Mature bamboo has almost the same strength and hardness as hardwood, which take more than 50 years to mature [3]. Its rapid maturity and sustainability have made bamboo the main rival for wood in the construction industry over the past 20 years. Applications of bamboo in various fields are increasing, and include framework, cladding, posts, and furniture. The main environmental problem in the booming bamboo industry is solid waste disposal. According to a report from the Cultural and Tourism Office of Anji, China, in 2015, the city produced more than 0.16 million tons of bamboo waste per year. Most bamboo waste is generated as clean biomass energy, but limited amounts of bamboo are reused. The efficient recycling of these wastes and their reuse as an ingredient in bio-based materials was the initial objective of this research.

Many studies have been carried out on mortar or concrete that incorporates lignocellulose aggregates, including hemp [4–6], wood [7], sisal [8], jute [9], coconut [10], palm oil [11], and sugarcane bagasse [12]. Cellulose, hemicellulose, and lignin are the primary biochemical compositions of these natural fibers. Other components as impurities, such as pectin and wax substances, also exist on the fiber surface. Cellulose is the main composition of cell wall, which provides the strength of fiber. It is insoluble in water, organic solvents and alkaline solution [13]. Hemicellulose comprises the sugar component, which bridges cellulose fibers with hydrogen bonds. Lignin is a cementing material. Bamboo fibers contain 40–55% cellulose, 18–20 hemicellulose, and 15–32% lignin [14]. The high proportion of cellulose makes bamboo a potential component for building materials. However, limited literature has focused on the valorization of bamboo in cementitious materials. Fias et al. [15] studied the replacement of 10–20 wt.% cement by Brazilian bamboo leaf ash (BLA) calcined at 600 °C. The same compressive strength resulted for the control mortar and BLA blended mortar, which confirmed the use of BLA as a substitute for cement. Xie et al. [16] observed that the flexural strength and impact resistance of mortar could be improved by reinforcement with 4–16 wt.% bamboo fibers (BF). Shrinkage could be inhibited by 12% because of the BF reinforcement [17]. However, efficient incorporation of vegetable products in the cementitious matrix requires the overcoming of problems of workability, compatibility, and durability. The workability problem relates to the high water absorption of vegetable fibers [18]; the compatibility problem relates to a weak bonding between natural fibers and the cement matrix [19]; and the durability problem relates to biodeterioration and a resistance to freezing and thawing [20]. To overcome these problems, the fibers are pretreated before fabricating the composite. The pretreatment methods, such as cold water, hot water, and alkali solution, have been investigated in the literature in order to modify the structure and morphology of natural fibers and improve the matrix interface, as well as increasing the durability of fibers in the alkaline environment of the cement matrix [21–24].

Sawdust is a by-product generated during the process of manufacturing. The recycling of such waste provides the benefits of reducing the need to extract new raw materials and limiting the air pollution due to incineration. Ahmed et al. investigated the potential of wood sawdust as a replacement of fine aggregates in concrete [25], and confirmed the utilization of this material for structure application. Besides, lightweight concrete incorporated sawdust presented a thermal conductivity 23% lower than conventional concrete [26].

To the best of our knowledge, few studies have reported incorporating bamboo sawdust (BS) in a cementitious matrix. This study contributes to the design of a new cementitious material containing local BS. The effect of different pretreatment methods for BS on the composite were firstly assessed through their morphological, physical, and mechanical behaviors, which aimed to choose a more efficient treatment. Furthermore, the characteristics of composites incorporating different proportions of alkali-treated BS were analyzed.

2. Materials and Methods

2.1. Raw Materials

The bamboo particles that were used in this study were recycled sawdust from a local bamboo furniture manufacturing industry (Zhejiang, China). The species of bamboo was moso (Phyllostachys edulis), which is most common in China.

The particle size distribution of the recycled BS is presented in Figure 1. The average particle size (D50) of the BS was 0.09 mm. A BS particle size of between 0.037 and 0.16 mm was used. The basic characteristics of the moso BS are summarized in Table 1. The particle density was determined by the Archimedes method, where the apparent mass of BS was measured in air and after immersion in distilled water with a pycnometer. The bulk density was calculated from the BS mass divided by the volume occupied.

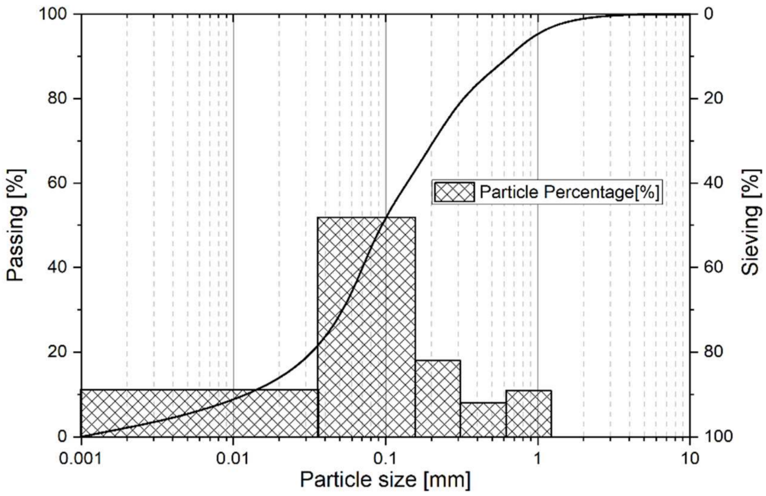

Figure 1. Recycled bamboo particle size distribution.

Table 1. Characteristics of moso BS.

Particle density (kg/m^3)	1563
Bulk density (kg/m^3)	390
Initial moisture content	6.089%
Water absorption capacity (1 min)	277.5%
Water absorption capacity (1 h)	320%

Sawdust treatment modifies the rheological, physical, and mechanical properties of mortar that is reinforced with vegetable particles. Three types of treatment were used to remove excessive lignin and hemicellulose, and to improve the wettability [22]:

- Aqueous treatment: BS was soaked in cold water for 24 h.
- Hot aqueous treatment: BS was soaked in hot water at 100 °C for 16 h.
- Alkali treatment: BS was soaked in 10% sodium hydroxide solution for 30 min at room temperature and rinsed with distilled water until neutral pH.

After treatment, the BS was dried in an oven at 60 °C for 48 h, and then stored in a desiccator.

2.2. Mixture Proportion

Ordinary Portland cement CEMI 42.5 and standard sand with a proportion of 1:3 were used to prepare the control mortar with no added BS in accordance with EN 196 [27]. The relative specific gravity of cement and sand was 3.12 and 2.64, respectively. The water to binder (W/C) ratio was fixed at 0.5 for mortar and 0.25 for cement paste. Similar to most cellulosic fibers, the BS adsorbs large amounts of water. The BS was pre-wetted to prevent the inner structure from absorbing water from the mixture. The quantity of pre-wetting water (PW) was calculated from:

$$\text{Mass of pre-wetting water} = \frac{\text{mass at saturation state } - \text{dry mass}}{\text{dry mass}} \times \text{BS dosage} \quad (1)$$

The pre-wetting time was determined by the saturation state of the bamboo particles, as shown in Figure 2. The water absorption increased to 86.7% saturation in 1 min, the growth rate slowed in the following 4 min, and then the growth was stable until complete saturation. The study of Monreal et al. [28] showed that the pre-wetting water should be below complete saturation, otherwise excessive water may result in the mixture. From a perspective of mixing time and energy saving, the pre-wetting time was set to 3 min, at 95% particle saturation, where the pre-wetting water quantity was three times the BS. With the same cement and sand ratio, 1 wt.%, 3 wt.%, 5 wt.%, and 7 wt.% cement was substituted by BS, and the new biomaterials were designated as bamboo sawdust cement mortar BSC1, BSC3, BSC5, and BSC7, respectively. The limit of substitution was set at 7 wt.% due to the very low workability of composite at fresh state (nearly 0), which is not suitable for construction. The results of the slump test are discussed in Section 3.2.1. Details of mixture proportions for formulations are recapitulated in Table 2.

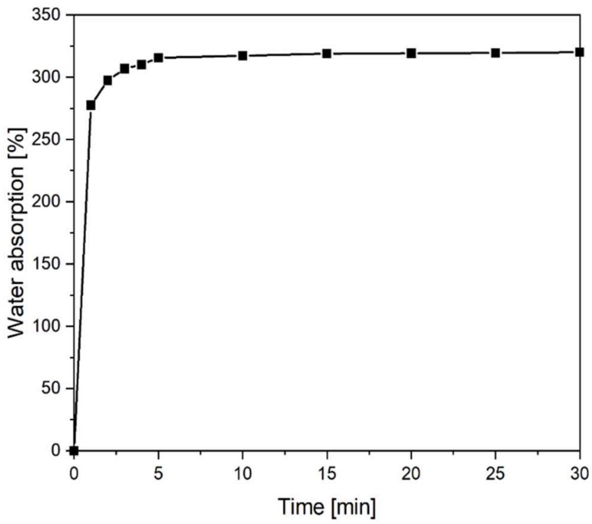

Figure 2. BS particle water-absorption rate.

Table 2. Compositions of different formulations.

Designation	Cement [kg/m^3]	Fine Aggregate [kg/m^3]	Bamboo Sawdust [kg/m^3]	Pre-Wetting Water [l/m^3]	Water [l/m^3]
Control	511.018	1533.055	0.000	0.000	255.509
BSC 1	509. 336	1528.009	5.145	16.463	254.668
BSC 3	505. 903	1517. 709	15.646	50.069	252.951
BSC 5	502. 374	1507. 121	26.441	84.610	251.187
BSC 7	498. 745	1496. 235	37.540	120.128	249.372

2.3. *Mixture Preparation*

The BSC composite was prepared by using a mortar mixer. The bamboo particles were pre-wetted for 3 min, and then mixed at a low speed of 140 ± 5 r/min^{-1} for 3 min. Cement and sand were added and mixed for 2 min at a low speed. Mixing continued for 1 min 30 s, after which water was added. After 1 min 30 s, the mixer was stopped as it was scraping the bowl. The last step involved restarting the mixer and running at 285 ± 10 r/min^{-1} for 1 min. The mixing procedure is summarized in Table 3.

Table 3. Mixture procedure.

Operation	Introduction of Pre-Wetting Water and BS	Addition of Cement and Sand	Addition of Water	Scrape the Bowl	Mixture
Duration	3 min	2 min	1 min 30 s	30 s	1 min
State of mixer	Stop	Slow speed		Stop	High speed

All molds that contained specimens were kept in a humid atmosphere (50 ± 5 RH%) for 24 h at 20 ± 2 °C before being demolded, and the demolded specimens were kept under water in a temperature-controlled wet preservation cabinet until the tests. A general view of the BSC specimens is presented in Figure 3.

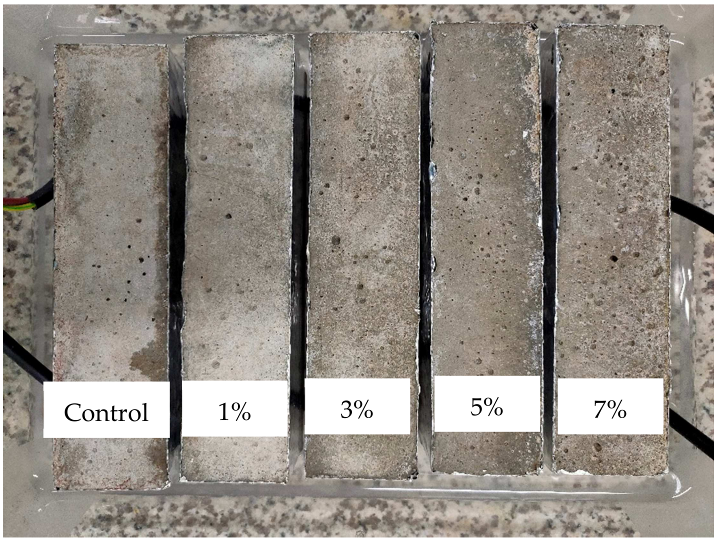

Figure 3. BSC mortar specimens.

2.4. Morphology

The BS microstructure with and without treatment, and the composite mortar at 28 days were investigated by scanning electron microscopy (SEM, HITACHI Model TM3000). The BS samples were placed directly on aluminum stub with a diameter of 25 mm. The BSC samples were sputter coated with Au alloy in order to reduce white regions on the image, which were caused by electron charging. The observation condition mode 15kV was applied.

2.5. Rheological Properties

The cement paste and mortar that contained BS were evaluated according to their setting time and workability in the fresh state, respectively. The setting time of the cement paste was measured by using a Vicat apparatus in accordance with NF P15-431 [29]. Slump tests were performed by using a mini slump cone with diameters of 50 mm and 100 mm at the top and base, respectively, and a height of 150 mm, in accordance with MBE (method to design mortar concrete containing admixture) [30] to evaluate the workability of the composite mortar.

2.6. Physical and Mechanical Properties

The density, porosity, and compressive and flexural strength in the hardened state were determined for all specimens. The specimen density was calculated from the measured dry mass at 28 days and the volume. The porosity was characterized according to the AFPC-AFREM testing protocol [31]. The specimens that were cured at 28 days were placed in a desiccator, where a maximum internal constant pressure of 25 mbar was maintained by a vacuum pump. After 4 h, water was introduced to immerse the specimens, and the same pressure was maintained in the desiccator for 68 h. The water-accessible porosity was calculated from:

$$\text{Porosity} = \frac{M_{air} - M_{dry}}{M_{air} - M_{sat}} \times 100\% \quad (2)$$

where M_{air} and M_{sat} are the mass of vacuum-saturated specimens measured in air and water, respectively, and M_{dry} is the mass of specimen that was oven-dried at 105 °C for 24 h.

The compressive and flexural strengths were measured according to EN 196 [27] at 3, 7, 14, and 28 d curing. Cubic specimens (40 × 40 × 40 mm) were prepared for a study of their compressive behavior. Tests were carried out using a compressive machine model STYE-1000, with a force-controlled rate of 2500 N/s. The flexural behavior was evaluated using an electric three-point bending testing machine, model DKZ-6000. The set-up was force controlled with a rate of 50 N/s. Specimens of 40 × 40 × 160 mm were characterized for flexural strength.

3. Results and Discussion

3.1. Effect of BS Treatment on BSC Composite

3.1.1. Mass Loss of BS

A remarkable mass loss was observed during the BS treatment. The percentage mass loss because of the treatment was calculated from:

$$\text{Percentage weight loss} = \frac{W_1 - W_2}{W_1} \times 100\% \quad (3)$$

where W_1 (g) and W_2 (g) represent the BS dry mass before and after treatment, respectively.

Figure 4 shows the BS mass variation between the different treatments. The mass loss was rapid in 1 min, and then slowed to a plateau. The BS lost 13.7% of its mass after aqueous treatment. The mass stabilized after 8 h. However, the hot aqueous accelerated the component removal, and improved the efficiency with 17.5% of the components eliminated in 4 h. The mass variation of alkali-treated particles was most important, with an earlier plateau and a mass loss of 28.2% higher than in the aqueous treatment and 23.6% higher than in the hot aqueous treatment. Das et al. [22] reported the similar significant mass loss of bamboo fibers occurred by alkali attack. It can be noted that the fiber cell wall contains an amount of hydroxyl groups (-OH), which can react with alkaline solution [32]:

$$\text{Cell-OH} + \text{NaOH} \rightarrow \text{Cell-O-NA}^{+} + H_2O + \text{Surface impurities} \quad (4)$$

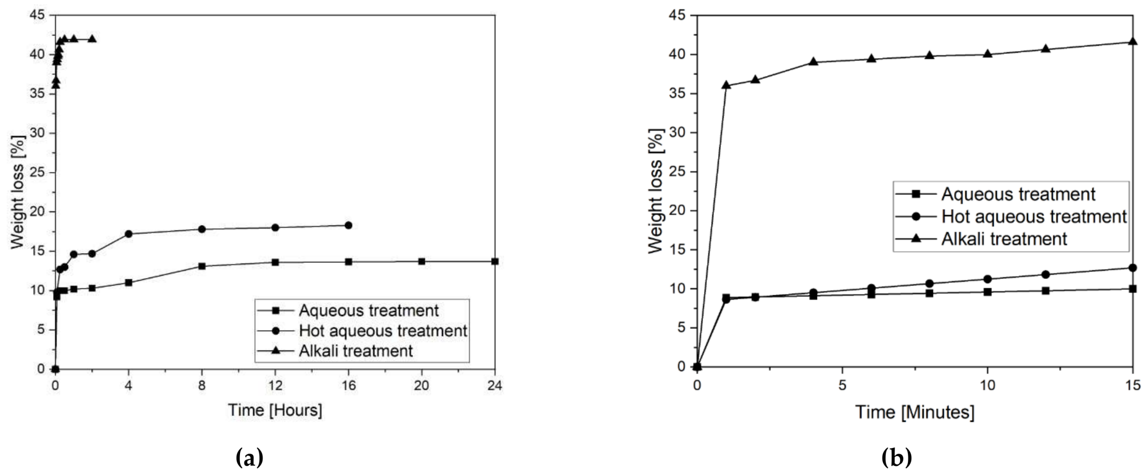

Figure 4. BS mass variation during different treatments (**a**) in 24 h (**b**) in the first 15 min.

The removal of alkali-sensitive components (hemicellulose and lignin) results in the mass loss of fiber. The good side is to provide the mechanical and thermal stability of fiber in the composite matrix. The alkali concentration and immersion time both affect mass loss [33].

3.1.2. Morphological Properties

The morphological changes to the bamboo particles from the different treatments are presented in Figure 5. Compared with (hot) aqueous treated particles (Figure 5b,c), cell walls of the untreated particles were wrapped in wax, pectin, and impurities (Figure 5a).

Figure 5b shows that cold water removed the impurities, where the particle surface was neater and smoother compared with the untreated particles. Cellulosic defibrillation is shown in Figure 5c,d, where rougher and larger surfaces are visible. Alkali treatment was more violent and intensive than hot water. The surface area increased and the network porosity decreased because of the disruption in hydrogen bonding in the network structure by alkali attack, so the surface roughness increased [34]. This effect may improve the particle compatibility with cement by creating a more effective bonding area. Some authors reported that alkali treatment could break the microfibril bundles and produce individual fibers, so that the mechanical interaction between the particles and the matrix can be improved [35,36].

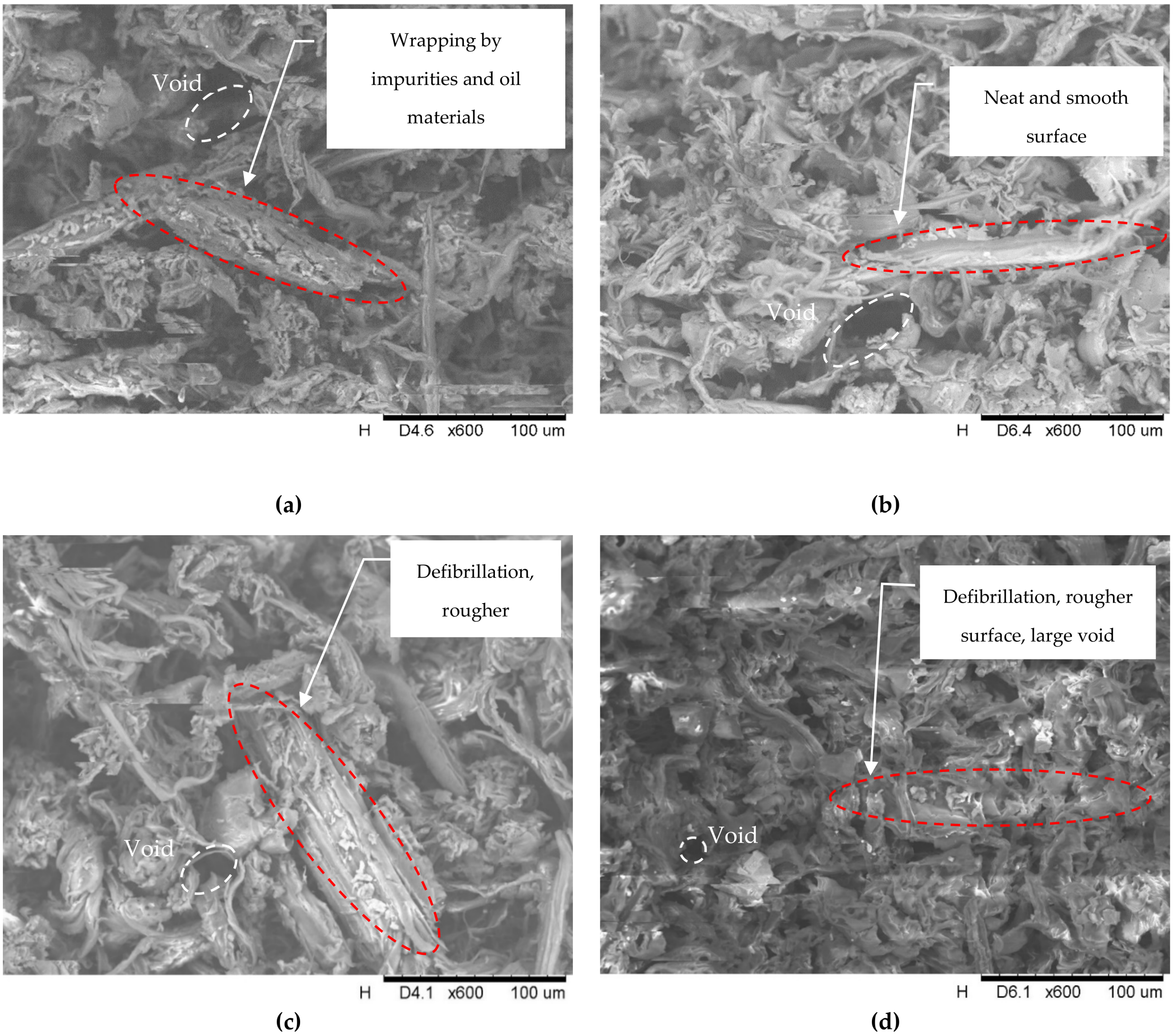

Figure 5. SEM analysis of BS (**a**) without treatment, (**b**) with aqueous treatment, (**c**) with hot aqueous treatment, (**d**) 10% concentration alkali treatment.

3.1.3. Setting Time and Workability

Plant particle addition delays the setting and inhibits strength development due to the presence of hemicellulose and lignin [37]. The initial and final setting times of cement paste with 3% BS by mass with different treatments were measured to meet construction material requirements. Table 4 shows the initial and final setting time of BSC paste using different treatments BS. Meanwhile, the final setting of aqueous-treated BSC paste occurred more than 2 h after the control. Owing to the removal of lignin, which is soluble in water, the final setting time of hot aqueous-treated was 40 min faster than the aqueous-treated. The setting was accelerated by approximately 1 h for the alkali-treated particle compared with the control paste due to the dissolution of hemicellulose in alkaline solution. These results confirmed that adding vegetable particles may inhibit the cement hydration and delay the setting time. Cold and hot water treatment can remove some extractives. However, plant particles require a more violent alkaline extraction to remove hemicellulose.

Table 4. Evolution of setting time with different treatments.

	Control	Aqueous Treatment	Hot Aqueous Treatment	Alkali Treatment
Initial setting time (min)	110	230 (+109%) *	190 (+73%) *	160 (+45%) *
Final setting time (min)	140	310 (+121%) *	270 (+93%) *	200 (+43%) *

* Value compared with control cement paste.

Even though the same amount of pre-wetting water was used in each treatment, slump was measured at 41 mm, 40.7 mm, 34.5 mm, and 9.8 mm for the control mortar, cold aqueous, hot aqueous, and alkali-treated BSC3, respectively. Hot aqueous and alkali-treated BSC3 showed a weak slump. A possible explanation for these results is cellulosic defibrillation, whereas the expanded rougher fiber surface probably absorbed more water. The same results have been reported previously in [35]. The water absorption was more significant for the sodium-hydroxide treatment because of the removal of the lignin layer, which is an impermeable layer of vegetable fiber.

3.1.4. Physical and Mechanical Properties

Despite the various treatments, no significant difference resulted for the density and porosity, which were ~1994 ± 10 kg/m^3 and 16.4 ± 0.04%, respectively. The same results were reported in [38] that only 0.7% difference was found between mortar incorporated alkali-treated and non-treated jute fiber.

The experimental results for the mechanical behavior are shown in Figure 6; Figure 7. Figure 6 shows that the compressive strength of BSC3 was lower than that of the control mortar. The compressive performance between the cold and hot water treatments were close, with only a 3% difference observed. The alkali-treated BSC3 exhibited a higher compressive strength of 16.1% and 13.9% than the cold and hot aqueous treatments, respectively. The alkali-treated BSC3 strength was 73% of the control mortar strength.

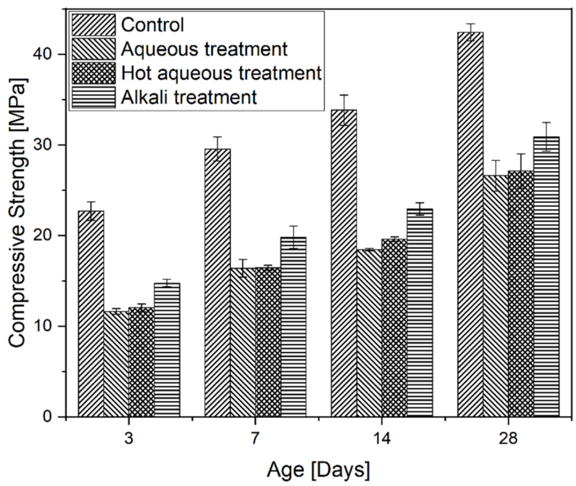

Figure 6. Compressive strength of BSC3 with different treatments.

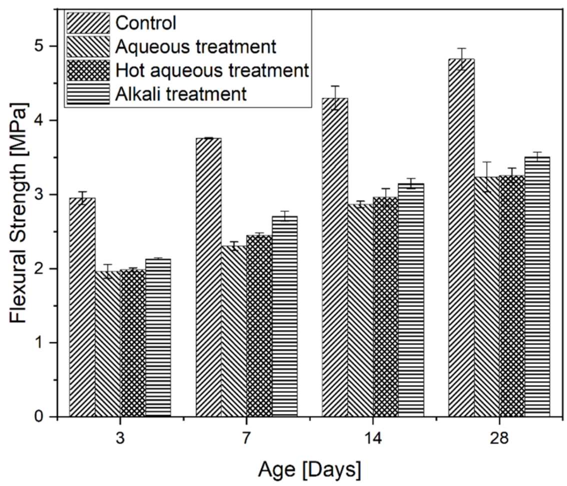

Figure 7. Flexural strength of BSC3 with different treatments.

The flexural strength f_b was obtained from:

$$f_b = \frac{3F \times l}{2b \times h^2} \quad (5)$$

where F is the applied load and l, b, and h are the specimen length, width, and height, respectively.

Data from the three-point bending tests indicate that the flexural strength of the cement matrix was attenuated because of the addition of BS (Figure 7). The degraded mechanical behavior of the BSC is related to the lower modulus of the bamboo particles compared with the cement. No significant difference in bending performance resulted between the three treatments using the ANOVA analysis. The alkali-treated BSC3 had an 8.2% and 7.6% higher flexural strength than the cold and hot aqueous treatments, respectively. The flexural strength of the alkali-treated BSC3 decreased by 37% compared with the control mortar.

Both the compressive and flexural strength value of alkali-treated BSC were higher than for the two other treatments, which confirmed the efficiency of alkali treatment. Besides, a more obvious advantage of alkali-treated BSC can be noticed on compressive behavior. It can be explained that after alkaline attack, the particles bundle into microfibrils (Figure 5d), which simplified their dispersion in the matrix, making the composite more homogenous.

3.2. *Effect of BS Content on Composite*

Results in Section 3.1 show that the BSC with alkaline treatment had a quicker setting and better mechanical behavior than the other treatments, which indicates that a better compatibility exists between BS and the cementitious matrix. Hence, alkaline treatment was chosen in the following studies to evaluate the effect of particle proportion on the physical and mechanical properties.

3.2.1. Setting Time and Workability

Table 5 provides the setting time of the cement paste with BS and indicates that cement setting was delayed. BSC7 showed the most significant delay, at 64% later than the control. The slowest final setting occurred for BSC7, which was postponed by 230 min (~3.8 h). As mentioned in [39], all cement specimens with an initial setting time of less than 45 min or a final setting time of longer than 6.5 h should be considered as unqualified and sub-quality products. Hence, even though the final setting time was delayed, BSC pastes still achieved a satisfactory setting time.

Table 5. Evolution of setting time with different treatments.

	Control	BSC1	BSC3	BSC5	BSC7
Initial setting time (min)	110	140 (+27%) *	160 (+45%) *	160 (+45%) *	170 (+55%) *
Final setting time (min)	140	170 (+21%) *	200 (+43%) *	220 (+57%) *	230 (+64%) *

* Value compared with control cement paste.

The workability is an important parameter in concrete mixture design. Therefore, slump tests were performed for all BSC specimens, and the results are shown in Figure 8. A marked loss in workability resulted in an increase in the number of particles in the matrix. A higher replacement of BP with cement led to a weaker slump. Nearly zero slump was observed for BSC5 and BSC7 because the increasing content of BS may absorb additional water from the mixture, which requires further investigation.

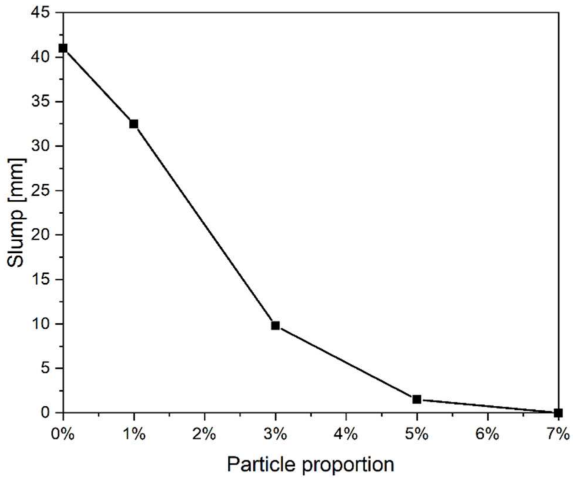

Figure 8. Slump evolution of alkali-treated BSC.

3.2.2. Morphology and Physical Properties

An analysis of BSC at 28 days by SEM in Figure 9 showed a favorable interface between the BS and matrix. The particles were spherical or cylindrical, distributed nearly uniformly in the matrix, and no large pores were observed. Some microcracks were visible, which may be because of the dehydration of cement.

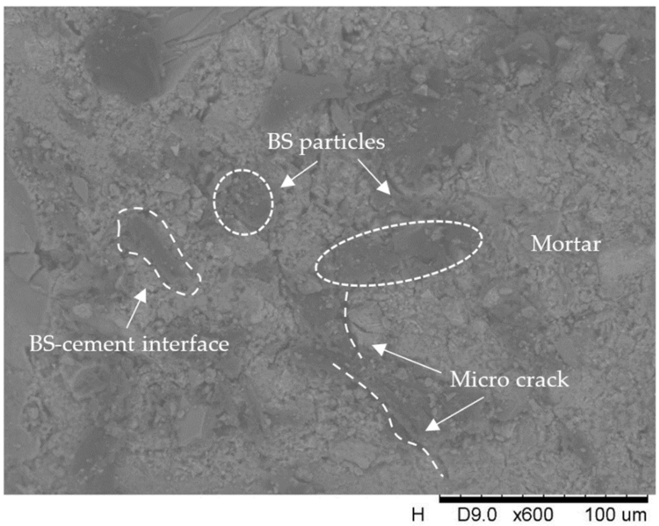

Figure 9. SEM analysis of alkali-treated BSC.

Figure 10 compares the density and porosity for different BSC contents. A correlation between the density and porosity showed that the specimens became lighter and more porous with an increase in BS proportion. The same observation is possible in Figure 3. BS addition to the mixture resulted in an increased void exposure at the specimen surface. The substitution of 7 wt.% cement by BS yielded a matrix that was 14.1% lighter and 6.1% more porous than the control mortar, which agrees with previous research [40].

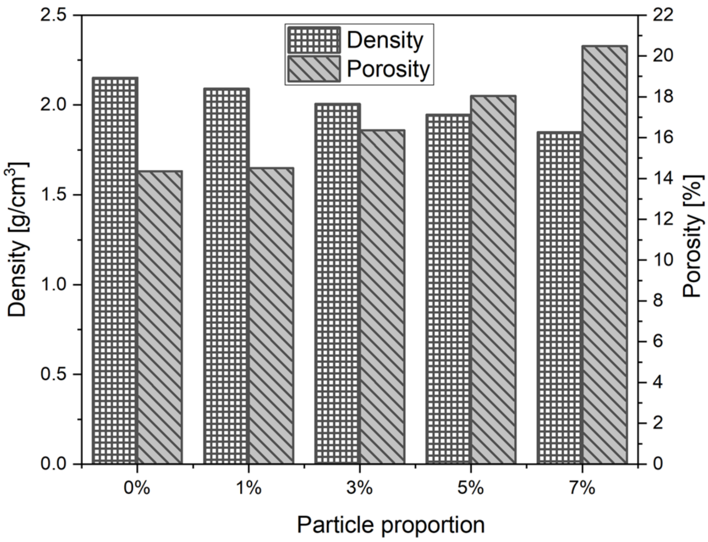

Figure 10. Density and porosity of alkali-treated BSC.

3.2.3. Mechanical Properties

The compressive strength and flexural strength evolution of BSC with different BS contents at three, seven, 14, and 28 days are presented in Figure 11; Figure 12. An increasing substitution of alkali-treated BS content from 1% to 7% decreased the composite compressive and flexural strengths in comparison to the control mortar. The reason for this is that BS addition increased the porosity of matrix, while the strength of porous matrix was consequently weakened. The composite with 1% BS behaved like the control mortar. Only a 10.9% reduction in compressive strength and 7.3% bending strength resulted after 28 days. However, the composite with 7% BS showed a decrease of 66.7% and 50.5% in compression and bending, respectively. The BSC was more resistant to bending than to compression. The difference in strength reduction between the bending and compression was significant with an increase in particle proportion. Ren et al. [41] reported similar results for cement-blended bamboo charcoal with a particle size between 23 and 359 µm, and the mechanical strength decreased after particle addition. All designed specimens met the minimum strength required in Chinese specifications for masonry mortar [42], whereas the compressive strength exceeded 5 MPa. Besides, according to RILEM [43], concrete with a unit weight range of 1600–2000 kg/m^3 and a compressive strength minimum at 15 MPa can be classified as lightweight concrete and can be applied as a load bearing wall. In our case, BSC7 has a compressive strength lower than 15 MPa, which cannot apply to structural components, while both BSC3 and BSC5 are in the light weight concrete class. The density of BSC1 was superior than 2000 kg/m^3, classified as normal concrete.

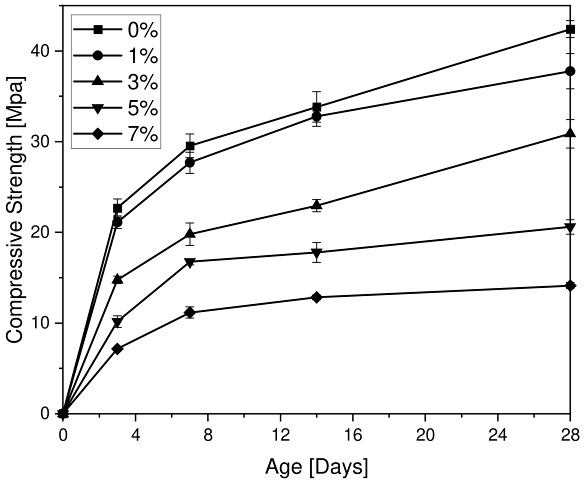

Figure 11. Compressive strength of alkali-treated BSC.

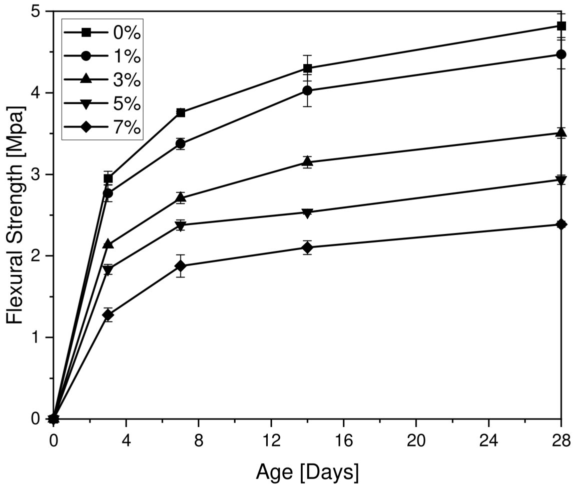

Figure 12. Flexural strength of alkali-treated BSC.

4. Conclusions

This work evaluated the potential of BS as a sustainable substitute for cementitious materials. Bamboo incorporation into mortar as a recycled byproduct of the bamboo industry has not been described previously in the literature. In this work, a new bio-based material that contained recycled BS (BSC) was prepared. The effect of different treatments and particle proportions on the physical, rheological, and mechanical properties of the BSC was evaluated. On the basis of the experimental results, the following conclusions were drawn:

1. Different BS pretreatment (cold, hot aqueous, and alkali) methods have no influence on the composite density and porosity. Unlike the physical properties, the addition of BS in the composite results in increasing the setting time and decreasing the workability and compressive and flexural strength compared with the control mortar.
2. Alkali-treated particles exhibited superior compatibility compared with other pretreatment methods. The SEM results showed a better microstructural interface between the alkali-treated BS and cement matrix. The mechanical behavior of the alkali-treated BSC was higher than that for the other two treatments. Hence, alkaline treatment is recommended in future work.
3. The BS content in the matrix affects the physical, rheological, and mechanical behavior of the composite. The replacement of BS with cement in the mortar makes the composite lighter and more porous. However, a greater particle content addition increases the setting time, reduces the slump, and the composite compressive and flexural strength

decrease. All BSC composite mortars satisfied the strength requirements for masonry mortar. BSC3 and BSC5 can be classified as load-bearing lightweight concrete.

Compared with traditional building materials, the cementitious composite with BS valorizes local waste, reduces cement consumption, and decreases the carbon emissions. The replacement of recycled BS with cement in the mortar yields a new lightweight and structural material. Further studies should focus on humidity control performance and building comfort regulations of this bio-based composite with recycled bamboo wastes.

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