DURABILITY BEHAVIOR OF BANANA FIBER-REINFORCED NATURAL POZZOLAN GEOPOLYMER

Kübra Ekiz Bariş,[1]* Leyla Tanaçan[2]

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

ABSTRACT

This research investigates the durability of waste banana fiber (BF) reinforced Earth of Datça (ED)-based geopolymer (EDBG) mortar under consecutive cycles of freeze-thaw, wetting-drying, and sulfate attack tests. ED is the volcanic tuff of the Datça Peninsula in Türkiye and was utilized as an aluminosilicate source, while sodium silicate (SS) and potassium hydroxide (KOH) solutions were used for alkaline activation. BF with a 20-mm length was added to the geopolymer mortar in the contents of 0.5, 1.0, and 1.5%. Mortars were cured at 70°C and 95±5% RH for 24h, followed by ambient air curing at 20 °C and 55±5% RH for 28 days. In parallel with the increase in the fiber content added to the geopolymer (EDG) mortar, there was a slight decrease in compressive strengths but a significant increase in flexural strengths, as expected. This trend was also observed after all aging tests except after the sodium sulfate (Na_2SO_4) attack. With the 1.5% BF inclusion, the gain in compressive strength, flexural strength and weight was 27.31%, 12.79%, and 1.58% respectively, which might be due to the crystallization of the absorbed salts inside the structure. Among the aging tests, although freeze-thaw has the most deteriorating effect on both EDG and EDBG mortars, the utilization of fiber decreased the damage to the material, and the integrity of the material was maintained. The behavior of the material under the effect of wetting-drying can be defined as "0-specimen intact." Therefore, it was proven that the use of banana fiber enhanced the durability of EDBG mortars under the aforementioned aging tests, and the building material produced within this experimental study can be used safely.

KEYWORDS

banana fiber, natural pozzolan, geopolymer, durability, mortar

1. INTRODUCTION

The cement industry accounts for around 7% of the total CO_2 emissions worldwide [1]. In Turkiye, the share of the Industry Processes and Product Use (IPPU) sector is 12.7% of the total

1. Faculty of Architecture and Design, Kocaeli University, Kocaeli, 41310, Türkiye; E-mail: kubra.ekizbaris@kocaeli.edu.tr
ORCID: https://orcid.org/0000-0002-3830-7185
2. Faculty of Architecture, Istanbul Technical University, Istanbul, 34367, Türkiye; E-mail: tanacan@itu.edu.tr
ORCID: https://orcid.org/0000-0001-7649-2441

GHG emissions (as CO_2 eq), which was recorded as 523.9 Mt for 2020. The mineral industry contributes 70.6% of CO_2 emissions from IPPU. Cement production has the dominant share within the mineral industry, accounting for 86.6% of CO_2 emissions. The second and third sectors are other processes involving the use of carbonates and lime production, each having a 6% share of CO_2 emissions [2]. Two billion tonnes of cement production exploits 3.0 billion tonnes of natural resources, particularly limestone quarries (70%) [3]. Hence, sources of CaO other than limestone should be considered [4]. Geopolymers emit up to 80% less CO_2 than ordinary Portland cement (OPC), depending on the activator type used in their synthesis [5]. On the other hand, geopolymer concrete has a higher environmental impact than OPC based on impact categories other than global warming. To solve this problem, the use of sodium silicate solution is advised to be minimized by using solid activators and precursors with a suitable Si/Al molar ratio [6].

Alkali-activated materials (AAMs), including "geopolymer" materials, are classified into three types based on the nature of their cementitious components ($CaO\text{-}SiO_2\text{-}Al_2O_3$ system): low calcium, high calcium, and blended/hybrid. Materials activated in the low calcium category were comprised of primarily aluminum and silicon and had low CaO contents. Highly alkaline media and curing temperatures (60–200°C) are necessary to start the reaction. The main reaction product formed is a three-dimensional inorganic alkaline polymer, a (K, N)-A-S-H gel. This gel is defined as a geo- or inorganic polymer. In the high-calcium category, calcium and silicon-rich materials (SiO_2+CaO > 70%) are activated under relatively moderate alkaline conditions. The main reaction product formed is a calcium silicate hydrate with Al in its structure (C-A-S-H gel). Materials activated in the blended or hybrid category have CaO, SiO_2, and Al_2O_3 contents greater than 20%. There are two types of materials under this category: blends having a low Portland cement clinker content and a high proportion (over 70%) of mineral additions, and blends containing no Portland cement. The complex reaction products comprising a mix of cementitious gels, including C-A-S-H (which takes sodium into its composition) and (N, C)-A-S-H (high calcium content N-A-S-H gels), precipitate in this group [3].

Geopolymer concrete has a highly refined pore network that creates a dense, low-calcium C-A-S-H phase. As geopolymers are considered environmentally benign, research on their durability in comparison to Portland Cement, which has a longer in-service track record, to improve geopolymer cement technology is significant [7]. The durability of AAMs depends on the calcium present in their systems [8]. Sulfate attack is one of the most significant of the durability issues. Hydration products of the calcium-containing hydrates, such as C-(A)-S-H gel, react with sulfate ions (SO_4^{2-}), forming ettringite and gypsum, which lead to expansion, cracking, and finally disintegration of the materials. Although the sulfate resistance mechanism of high-calcium AAM is similar to that of OPC because of the similarity of the reaction products (C-A-S-H gel), they have better resistance than OPC since they contain C-(A)-S-H gel with a lower Ca/Si [9, 10]. The main reaction products of low-calcium AAMs are sodium aluminosilicate hydrate (N-A-S-H gel), which don't produce sulfate-aluminate minerals (like ettringite) during the hydration process, so they have a higher resistance to sulfate attack. However, under the exposure, the ion exchange reaction occurs between the sulfate solution and the network-like structure of the N-A-S-H gel and gives rise to a progressive increase of the pores of the gel, creating microcracks, which worsens the structure [11]. According to the round-robin cyclic testing program to determine the validity of the testing methods developed for Portland cement-based concrete, it was determined that low-Ca AAM after Na_2SO_4 attack exhibited an excessive, very early expansion and then became dimensionally stable. Alkali-activated binders

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

show high resistance to freeze-thaw cycles. Four freeze-thaw cycles undertaken in this research caused more surface scaling on the mixtures of high water/binder ratio and more similarly on moderate strength mixtures than on high strength ones [10].

The durability performance of geopolymers is dependent on their inherent brittle structure, usually defined by low tensile strength and weak deformation capacity. Reinforcement with fibers is an alternative for enhancing ductility. It is known from concrete technology that fiber-reinforced concrete exhibits better durability in service than non-fiber concrete because fibers limit the propagation of cracks within the concrete, which can create easy access routes for harmful agents that cause scaling, color change, freeze-thaw damage, and corrosion [12]. Today, renewable fibers, managed sustainably that can sequester carbon over their life cycles are encouraged as an alternative to reinforcing the material.

Efficient interlocking at the fiber-matrix interface ensures the stress is transferred from the matrix to the fiber and is decisive for proper fiber reinforcement. The interface, which is generally in the form of mechanical interlocking, is a crucial factor for the composites' static and dynamic stability and durability by preventing crack propagation. Hence, both components, fiber and matrix, are involved in the durability of the composite. PC-based composites develop a durability problem because of the degradation of the natural fibers by the attack of calcium hydroxide present in the cement matrix [13]. The chemical breakdown of lignin and hemicellulose from the intermediate lamella is responsible for the durability reduction of natural fiber in concrete. The alkali in the concrete pores dissolves these compounds, causing the fiber-cell links to disintegrate. Eventually, the fibers disintegrate into smaller unitary cells, where the fiber-cell lumen is filled with calcium hydroxide. This process may also result in a decline in the flexibility and tensile strength of the fiber [14]. This situation has been solved by including pozzolanic substances within the matrix and applying fiber treatments [13]. However, although the geopolymer is highly alkaline, most of the alkali combines with other reaction products and exhibits favorable interactions with natural fibers, and usually do not need specific fiber treatments. Even though the degree of natural fiber deterioration in the geopolymer structure is less severe than that of cement, the degradation of the matrix does have a significant influence on the durability of the material [15].

Class F fly ash-based geopolymer reinforced with basalt (BF), steel (SF), and glass fibers (GF) with three fiber volume fractions of 0.4, 0.8, and 1.2% were tested under 100, 200, and 300 freeze–thaw cycles. The increase in volume fraction of the BF and SF type fibers not only increased both compressive and flexural strengths but also increased the durability of the geopolymer mortar even after 300 freeze-thaw cycles [29]. It should be noted that the fibers used are not organic.

If a natural fiber-reinforced material is used outside, the influence of wetting-drying cycles on the properties of the material should be identified [19]. Dos Santos et al. [13] activated the sludge from a water treatment plant (CaO content is lower than 1.0%) and PC (7% by weight) with potassium silicate and silica sand and reinforced the mortar with sisal fibers (2% by weight). Even after being subjected to 10 wetting-drying cycles, the material had 11 MPa of flexural strength compared to the reference specimen of 15 MPa. It was stated that the satisfactory durability of the material showed its potential for use in construction. Trindade et al. [20] investigated the effect of 15 wetting-drying cycles on the properties of jute fiber-reinforced metakaolin-based geopolymer mortars (CaO content is 0.1%). After 15 cycles, the findings showed no obvious degradation of the geopolymer, suggesting good durability. In another study, Nkwaju et al. [21] investigated the effects of sugarcane bagasse fiber addition on the properties

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

of sodium silicate-activated iron-rich laterite-based geopolymer mortars. The results showed that the geopolymers could function well after 20 wetting-drying cycles.

Sisal and PVA fiber-reinforced metakaolin-based geopolymer was exposed to sulfate attack at 5 and 15 wt% concentrations for 28 days. Higher concentrations of sulfate eroded the geopolymer and decreased its compressive strength. The reason for the degradation was explained as due to the gradual infiltration of sulfate into the geopolymer throughout the deterioration process, occupying some voids in the geopolymer [16]. Oil palm trunk fiber-reinforced high-calcium fly ash-based geopolymer concrete was exposed to sulfate attack at 5 wt% concentration for 90 days. The incorporation of oil palm trunk fiber (1,2,3% by weight) and crushed palm oil (lightweight aggregate) at any percentage reduced the sulfuric acid resistance of this geopolymer concrete. However, there was no obvious reduction in the cross-section, weight, and compressive strength of the material after acid exposure, indicating good corrosion resistance that was higher than that of traditional concrete [17]. Ribeiro et al. [18] analyzed the acid resistances of the metakaolin-based and bamboo fiber-reinforced geopolymers through the changes in their appearance, weight, and strength. Specimens were immersed in 0, 5, and 15 wt% of sulphuric (H_2SO_4) or hydrochloric (HCl) acid concentrations for up to 112 days. 2.7%, 3.5%, and 4.4% of weight losses were detected parallel to the increase in sulphuric acid concentrations. Both geopolymer and fiber-reinforced geopolymer specimens exhibited high compressive strength losses when they were exposed to H_2SO_4 than to HCl, and they concluded that both materials could be used as building materials in environments containing up to 15 wt% sulphuric or hydrochloric acid.

The literature survey reveals that low-calcium geopolymers particularly using artificial pozzolans and natural fiber-reinforced geopolymers materials are vulnerable to accelerated cycles of freeze-thaw, wetting-drying, and sulfate attack. However, it is also observed that the durability of the geopolymers varies according to the type of raw materials used, chemical composition (especially Ca content), mixing ratio, and applied aging test conditions. In our previous research, in order to transform the brittle fracture into ductile and to increase the flexural strength of Earth of Datça-based geopolymer mortar (EDG), it was reinforced with waste banana fiber (BF), and the mentioned disadvantages were eliminated. However, durability tests as an indicator of real climatic conditions are decisive in predicting the parameters affecting the performance and exploring its potential to be used as a building material. In this context, the aim of this research is to evaluate the behavior of natural pozzolan (ED) based waste banana fiber-reinforced geopolymer (EDBG) mortar under the effects of consecutive cycles of freeze-thaw, wetting-drying, and sulfate attack.

2. MATERIALS AND METHODS

To develop geopolymer mortar, a natural pozzolan from the Datça Peninsula in Türkiye was used as an aluminosilicate source (Figure 1a). To preserve the integrity of the original granular form, open-pit extraction was used to remove this natural earth from the reserve. It was then dried at 60°C for 48 h before being pulverized into particles that were 90% smaller than 90 μm (Figure 1b). It had a specific gravity of 2.52 g/cm^3 and 5467 cm^2/g of specific surface area. Table 1 displays the chemical characterizations that were attained using an X-ray fluorescence spectrometer (XRF). Pozzolanic oxides (SiO_2 and Al_2O_3) were the most prevalent oxides, followed by K_2O and Na_2O.

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

TABLE 1. Chemical analysis of the natural Datça Pozzolan.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5	K_2O	Na_2O	TiO_2	MnO_2	Cr_2O_3	NiO
Wt%	75.29	15.99	0.98	1.22	0.62	0.07	3.02	2.21	0.14	0.04	0.005	0.004
	CuO	ZnO	Rb	SrO	Y_2O_3	ZrO_2	Nb_2O_5	BaO	Cl	SO_3	LOI	Total
Wt%	0.002	0.002	0.006	0.015	0.002	0.01	0.001	0.097	0.092	0.1	0.15	100

Standard quartz sand with a maximum diameter of 2.0 mm was added to produce geopolymer mortar (Figure 1c). 12.5 molar (M) potassium hydroxide (KOH) (Figure 1e) and technical-grade liquid sodium silicate (Na_2SiO_3) with a silica modulus of 3.2 (SiO_2/Na_2O) (Figure 1f) were used for alkaline activation. KOH solution was made by dissolving KOH pellets in distilled water and allowing them to cool for 24 h before the mixing process.

Banana stalk is a waste product of banana cultivation and was obtained from Anamur in Türkiye. Banana fiber (BF) obtained from the stalk is composed of 31.5% cellulose, 15% hemicellulose, 15% lignin, and 38.5% other substances by weight. It has a tensile strength of 355 MPa, an elastic modulus of 33.8 GPa, and an elongation at failure of about 5.30% [22]. The

FIGURE 1. Raw materials used to produce fiber-reinforced (EDBG) mortar: (a) Datça Earth as found in nature; (b) Datça Earth after pulverized into particles; (c) Standard quartz sand; (d) Banana fibers; (e) Pellets of potassium hydroxide (KOH); (f) Sodium silicate solution (SS: Na_2SiO_3).



Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

waste banana stalks (Figure 2a) were manually cut into longitudinal and thin slices, then they were fed to the fiber-extracting machine. When the fiber-extracting machine runs, the water from the banana stalk was extracted and the fibers were obtained (Figure 2b). Afterwards, they were dried at 50°C for 24 h and cut into a length of 20 mm (Figure 2c).

Table 2 displays the mixing proportions of the geopolymer mortars by volume, along with the calculated unit weight of each component in the study. The sodium silicate (SS: Na_2SiO_3)-to-KOH ratio (activator ratio) and the total alkali activator-to-dry pozzolan ratio were 2.5 and 0.30 by weight, respectively. The dry pozzolan/sand ratio was 1/3. The BF content was arranged as 0.5, 1.0, and 1.5% by weight of natural pozzolan. The workability of the fresh mortar was identified with the flow table test in conformity with ASTM C1437-20 [23]. The optimum flow was found to be 120, and the water-to-binder ratio was kept constant in all specimens.

Natural pozzolan (ED), sand, and BF were dry-mixed to provide a uniform distribution of the fibers in the mixture. As the mixing continued, the alkali activators were added and mixed until a homogenous mortar was obtained. The fresh mortar was cast into 40×40×160 mm molds and covered with polyethylene (PE) in order to prevent rapid evaporation of water. The mortars were cured at 70 °C and 95±5% RH for 24 h. Then, the specimens were demoulded and left to air cure at 20 °C and 55±5% RH until the day of testing at 28 days.

FIGURE 2. Waste banana stalks (a); Feeding the longitudinal slices cut from the banana stalks to the fiber-extracting machine (b); Banana fibers after they were dried and cut (c).



Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

TABLE 2. Mixture proportions for the geopolymer mortars (kg/m^3).

%	Earth of Datça (ED)	Na_2SiO_3 (SS)	KOH	Standard Sand	Banana Fiber (BF)
EDG-0	562.50	120.54	48.21	1687.50	0.00
EDBG-0.5	562.50	120.54	48.21	1687.50	2.81
EDBG-1.0	562.50	120.54	48.21	1687.50	5.63
EDBG-1.5	562.50	120.54	48.21	1687.50	8.44
Specific Gravity (g/cm^3)	2.52	–	–	2.65	1.35
Density (g/ml)	–	1.30	1.05	–	–

The specimens were exposed to freeze-thaw cycles according to TS 699 [24]. Each cycle consisted of freezing under atmospheric conditions at –20°C for 20 hours, followed by thawing in water at 20±5°C for 4 hours. This cycle was repeated 25 times. The specimens were exposed to 20 wetting-drying cycles according to TS EN 14066 [25]. Each cycle consisted of drying the specimens at 70±5°C in an oven for 18 hours, then submerging them in water at 20±5°C for 6 hours.

The sulfate resistance was assessed by exposing samples to the simulated extreme marine environment. Consecutive wetting and drying cycles intensify the degradation of the sulfate effect. Na_2SO_4 solution with a concentration of 14 wt% was prepared and Na_2SO_4 solution-immersed specimens were exposed to 15 wetting-drying cycles according to the TS EN 12370 [26]. Each cycle consisted of immersing the specimens in the solution for 2 h and drying them at 105±5°C for 20 h. Afterwards, they were left to cool to the ambient temperature for 2 hours.

The resistance of the specimens to durability tests was assessed through ultrasound pulse velocity (UPV) change in accordance with TS EN 14579 [27] and mass change. Compressive and flexural strength tests (TS EN 196-1 [28]) are crucial for determining a material's durability because mechanical characteristics directly affect durability [29]. In addition, to identify the integrity of the specimens, a visual inspection on a macroscale was applied and compared with the reference specimens. The visual changes of the specimens were scored according to TS EN 12371 [30]: 0, specimen intact; 1, very little damage (rounding of edges and corners, but the integrity of the specimen is preserved; 2, one or several minor cracks (with smaller than 0.1 mm width) or tearing of small fragments (smaller than 30 mm^2 per fragment); 3, one or several cracks or tearing of fragments larger than those defined for the '2' rating, or the specimen shows important evidence of dissolution; 4, a specimen with wide cracks or broken into two or more parts. Three specimens were produced for each test, whereas the compressive strength test was conducted on six specimens.

3. RESULTS AND DISCUSSION

3.1 Resistance to freeze-thaw

The compressive strength of the EDBG mortar with 1.5% fiber content (8.75 MPa) was found 0.95 times lower than EDG mortar (9.25 MPa) and the compressive strength reduction rate

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

parallel to the increase of the fiber ratio was very low (Figure 3a). Similar results were also detected by the UPV values which reduced very low at the 1.5% fiber content (0.98 times) compared to the EDG (Figure 4). The prime objective of using natural fibers such as bananas in brittle geopolymer is to improve the properties of the brittle matrix by combining two different kinds of materials with contrasting properties of strength and elasticity. In an ideal two-phase composite, the strength of the weak fiber phase is thus improved by the strong phase, and they realize a great portion of the strength of the stronger component. In composites that contain fewer fibers arranged in random orientations, since the flexural strength of the matrix is very much lower than the ultimate strain of the fibers, matrix cracking occurs at the same level of loading before the maximum strength of the composite is reached. In the post-cracking stage, the failure is by a pull-out rather than by fiber fracture and the resistance to full separation of the composite is provided by the fibers bridging across the crack surfaces [41]. Indeed, as shown in Figure 3b, the flexural strengths of the mortars dramatically increased with the fiber addition, even at a 0.5% ratio (3.22 times). The rate of the flexural strength rise became lower when the fiber content increased from 0.5 to 1 and 1.5%, where there was 1.18 times strength gained compared to 0.5%. The addition of fiber increased the flexural strength/compressive strength ratio of EDG mortar from 20% to an average of 71%.

Freeze-thaw cycles allow the determination of the mortar's resistance to the water pressures caused by the expansion of the specific volume of the water when its phase changes from liquid to ice, which may result in inducing cracks and enlarging voids [29]. Figure 3 shows the influence of freeze-thaw cycles on the mechanical properties of EDG and EDBG mortars, including (a) compressive strength and (b) flexural strength.

Applying freeze–thaw cycles to the mortars decreased the compressive strength by 12.43% compared to the reference (unreinforced) ED-based geopolymer (EDG) mortar, which has 9.25 MPa. The compressive strength loss was lower for the fiber-reinforced EDBG mortar than the EDG mortar. This ratio of reduction in compressive strength was found to be 7.61% with 0.5 wt% fiber inclusion and was further decreased by 6.34% and 4.23%, respectively, with the ascending values of fiber ratios of 1.0% and 1.5%. The flexural strength of the unreinforced reference EDG mortar was found to be 1.81 MPa. 17.13% loss was detected after the mortar was subjected to 25 cycles of freeze–thaw. Reinforcing the material with 0.5%, 1.0%, and 1.5% by weight of banana fiber gradually decreased the flexural strengths of the EDBG mortars under the freeze-thaw effect by 6.70%, 5.64%, and 3.78%, respectively. Inhomogeneous pores in the matrix can mitigate the hydraulic pressures caused by the freezing water in the pores to certain levels. However, when these pores are completely filled up with water, internal pressure by the freezing water may deteriorate the matrix. When this pressure threshold surpasses the matrix's strength, microcracks may form, and their propagation could cause deterioration of the material [29]. In this study, the main reason for the decrease in mechanical properties due to the freeze-thaw effect in parallel with the increase in the fiber content is that banana fibers counterbalance the internal stresses driven by water freezing. This finding is also consistent with the findings of other studies reported in the literature. Yunsheng et al. [31] stated that adding PVA fibers to geopolymer mortars is an effective way to improve durability against 20 freeze–thaw cycles. Ali et al. [32] stated that basalt fibers decreased the strength loss of metakaolin-based geopolymers after freeze–thaw tests. Thus, the geopolymers have a strong resistance to the freeze–thaw effects because their matrices have a compact structure and a substantial degree of adhesion with the fiber [29].

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

FIGURE 3. The influence of freeze-thaw cycles on the mechanical properties of EDG and EDBG mortars: (a) Compressive strength; (b) Flexural strength.

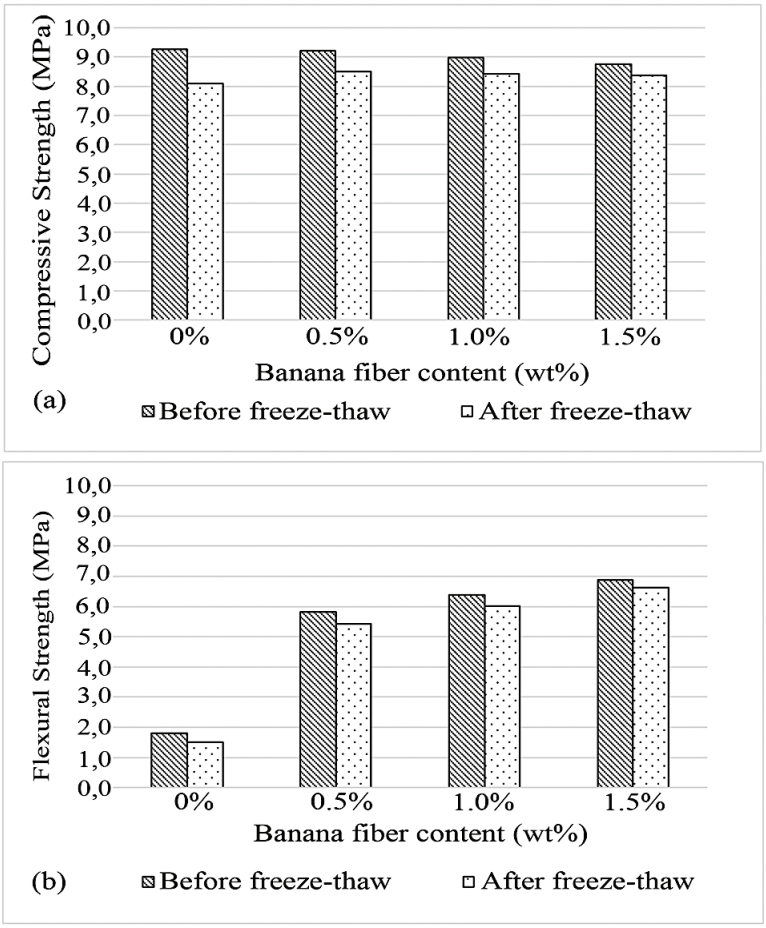


Figure 4 shows the effect of the freeze-thaw cycles on the UPV and the weight loss of the EDG and EDBG mortars.

The UPV of the EDG mortar dropped 9.26% after being exposed to 25 freeze–thaw cycles, which was also in line with the results determined by the mechanical properties. This drop observed in the UPV of the EDG mortar indicates the evolution of the microstructure towards porosity by the effect of freeze-thaw. However, BF incorporation lowers the reduction rate of UPV, where the lowest reduction (1.42%) was determined with 1.5% fiber addition. Reinforcing the material with BF and increasing the fiber content effectively provided a more compact microstructure free of voids even after the freeze-thaw effect. As a matter of fact, this result is compatible with the results of the visual inspection, as shown in Figure 5.

When the internal pressure caused by freeze-thaw cycles overcomes the stress of the matrix, microcracks might form and deterioration might begin. Finally, the spalling of the material occurs [29]. The visual change observed in the EDG mortar was scored as "3" because it had several larger cracks and holes and showed signs of spalling (Figure 5a). By contrast, the mortar with 0.5% fiber content was scored as "2" with several minor cracks that were less than 0.1 mm wide (Figure 5b), whereas the mortar with 1.0% fiber content may be scored as "1" (very little

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

FIGURE 4. The influence of freeze-thaw cycles on the UPV and weight loss of EDG and EDBG mortars.

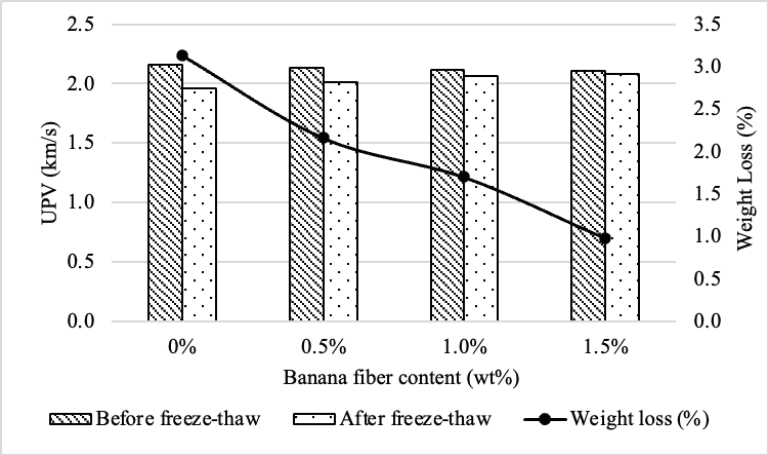
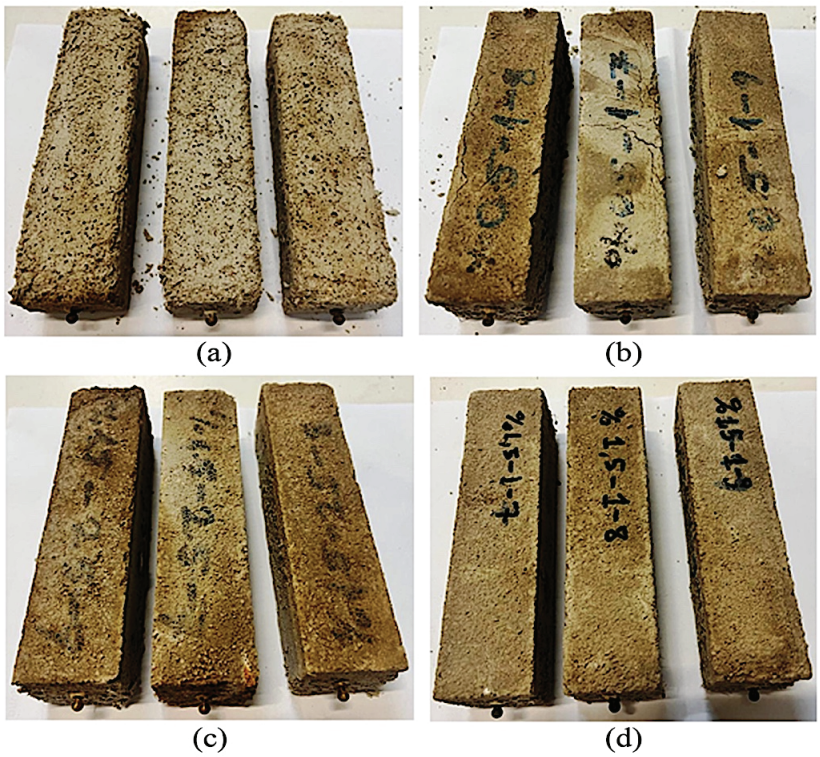


FIGURE 5. Visual inspection of the EDG and EDBG mortars after 25 freeze-thaw cycles: (a) unreinforced reference mortar; (b) 0.5%; (c) 1.0%; (d) 1.5% fiber contents.



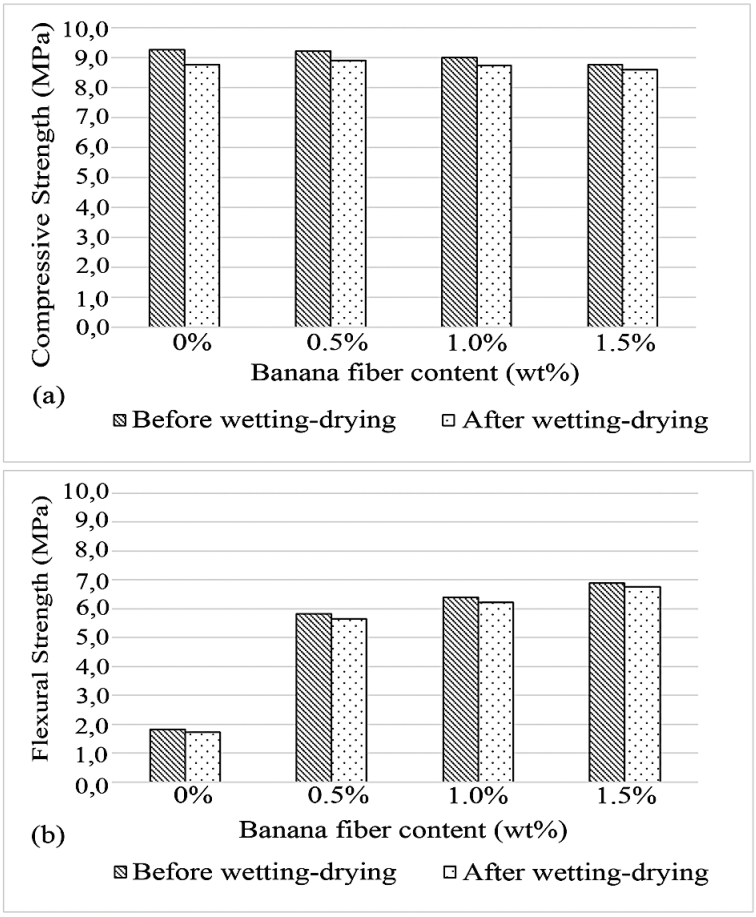
Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

damage) with slightly rounded corners, but the integrity of the mortars was preserved (Figure 5c). Visual changes of the mortars with 1.5% BF content were scored as "0" because there was almost no change in the appearance of the mortars, and they kept their integrity after being exposed to 25 freeze–thaw cycles (Figure 5d). Thus, the inclusion of fibers served to compensate for the hydraulic pressures that resulted from the freezing of water. These findings are also compatible with the weight loss values given in Figure 4. Weight loss at the end of the freeze-thaw cycles of the EDG mortar was 3.13%. There was a noticeable impact when including the BF on the decrease in weight loss. Reinforcing the EDGM matrix with 0.5, 1.0, and 1.5% BF reduced weight loss to 2.16, 1.70, and 0.98%, respectively. It may be stated that the 0.5, 1.0, and 1.5% BFGM have high durability against the freeze-thaw cycles because the weight loss can be negligible and they sustain their stability and integrity [29].

3.2 Resistance to wetting-drying

The wetting-drying cycle test makes it possible to assess how the materials will behave during weathering caused by frequent wet and dry periods. If a natural fiber-reinforced material is used for exterior applications, the effect of wetting-drying cycles on the properties of the material should be identified [19]. Figure 6 shows the influence of wetting-drying cycles on the

FIGURE 6. The influence of wetting-drying cycles on the mechanical properties of EDG and EDBG mortars: (a) Compressive strength; (b) Flexural strength.



Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

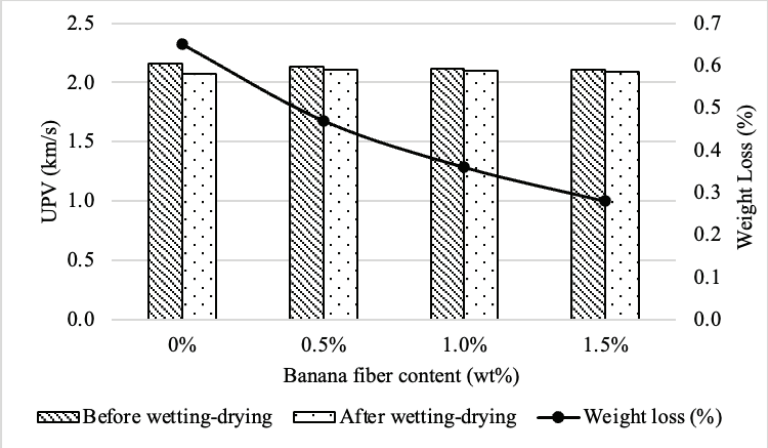
mechanical properties of EDG and EDBG mortars, including (a) compressive strength and (b) flexural strength.

The mechanical performance of the mortars after 20 wetting-drying cycles shows little variation. While the compressive strength of the EDG mortar was found to be 9.25 MPa after aging, it could only reach 8.75 MPa, where a 5.41% decrease was recorded in its compressive strength. The compressive strength loss was found to be lower for EDBG than for the EDG mortar. While 0.5% fiber addition reduced the compressive strength at the end of 20 wetting-drying cycles by 3.26%, this reduction was getting lower with the increase of the fiber to 1.0% and 1.5% and was 3.00% and 1.94%, respectively. Furthermore, the flexural strength of the EDG mortar was 1.81 MPa. A slight loss (4.97%) in flexural strength was recorded after 20 wetting-drying cycles, which means the matrix still has satisfying durability after wetting-drying cycles. Reinforcing the material with 0.5%, 1.0%, and 1.5% fiber by weight of the matrix gradually decreased the reduction in flexural strength after the wetting-drying cycles to 3.09%, 2.51%, and 1.74%, respectively. These findings are also consistent with the UPV and weight loss results, as can be seen in Figure 7.

UPV and weight loss of the EDG mortar decreased by 4.17% and 0.65%, respectively, after exposure to wetting-drying cycles. The addition of 0.5, 1.0, and 1.5% fiber into the mortar reduced the UPV by 0.94, 0.94, and 0.95%, respectively, while 0.47, 0.36, and 0.28% weight losses were recorded in the same materials. This means that the fiber-reinforced geopolymer mortar remains stable and the fibers are not degraded. These results reveal that both EDG and EDBG mortars maintain their durability against 20 wetting-drying cycles, and they have the potential to be used in real outdoor conditions without suffering significant deteriorations under wetting-drying effects. The strong adhesion between the fiber and the matrix prevents the material from degrading and ensures its integrity.

These results were in conformity with the visual inspection results of the mortars. No degradation, color change, or crack formation was observed on the surface of the mortars after wetting-drying, meaning that the behavior of the material under the effect of wetting-drying can be defined as "0-specimen intact" according to TS EN 12371 [30] (Figure 8). Numerous studies have presented similar results with regard to the impact of fiber utilization in the manufacturing

FIGURE 7. The influence of wetting-drying cycles on the UPV and weight loss of EDG and EDBG mortars.



Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

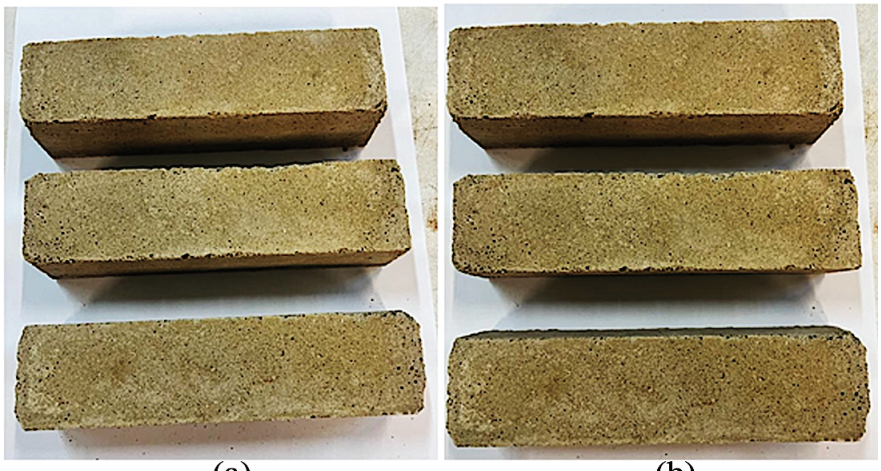
of geopolymer mortar on wetting-drying durability. Dos Santos et al. [13] exposed the sisal fiber-reinforced water treatment plant sludge to 10 cycles. Although the flexural strength decreased by 26.7%, the researchers stated that the material indicated satisfactory durability against wetting-drying cycles. Trindade et al. [20] exposed the jute fiber-reinforced geopolymer mortars to 15 wetting-drying cycles and determined that there were no important changes in the mechanical characteristics, suggesting superior durability of jute fiber-reinforced geopolymers in comparison to composites made of Portland cement. Nkwaju et al. [21] determined that the mechanical properties of sugarcane bagasse fiber-reinforced geopolymer mortars were not considerably changed after 20 wetting-drying cycles. They demonstrated that the geopolymer matrix stayed intact and the fibers were not destroyed. On the other hand, according to Melo Filho et al. [33], after 10 cycles, a strong degradation was already observed in sisal fibers incorporated into the Portland cement matrix, which has high-calcium content.

3.3 Resistance to Sulfate Attack

Especially in coastal areas, seawater splashing and drying-wetting cycles intensify the damage of sulfate-containing solutions [34]. Figure 9 shows the influence of sulfate attack under 15 wetting-drying cycles on the mechanical properties of EDG and EDBG mortars, including (a) compressive strength and (b) flexural strength.

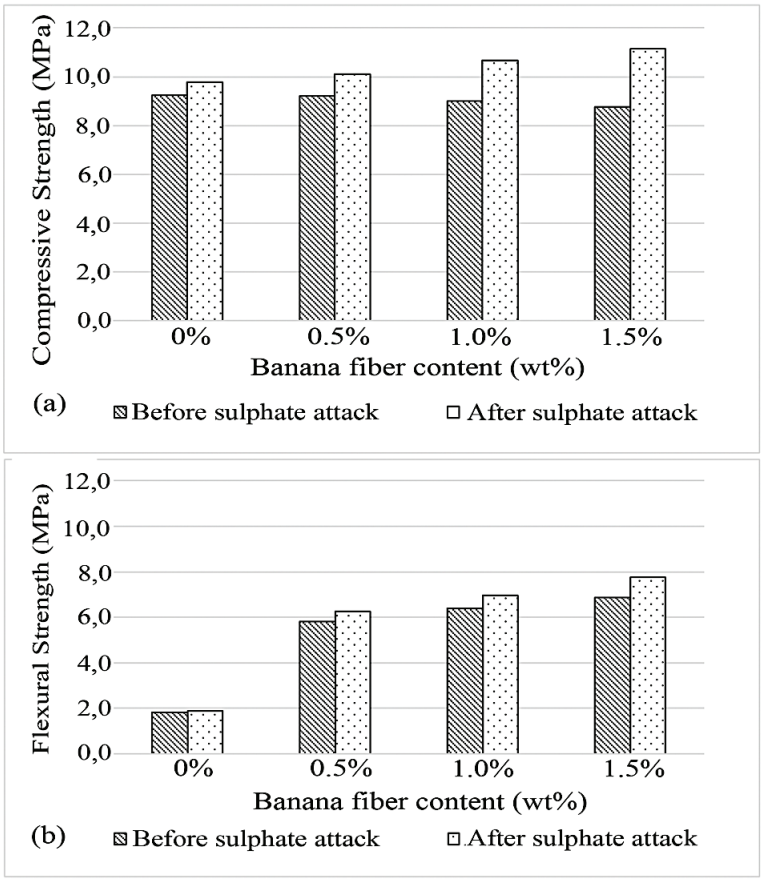
It is determined from Figure 9a that the compressive strengths of all the mortars increased after the sulfate attack with 15 wetting-drying cycles in comparison to their initial strengths before the sulfate attack. The increase in compressive strength was the lowest (5.84%) in EDG mortar. Increasing the fiber content from 0.5% to 1.0% and 1.5% led to an increase in the rate of compressive strength from 10.00% to 18.69% and 27.31%, respectively. As can be seen in Figure 9b, the flexural strengths of the mortars also changed in parallel with their behavior in terms of compressive strength. The increase in mechanical strength indicates that geopolymer mortars will perform sufficiently when exposed to sodium sulfate. Several earlier investigations identified an identical tendency for strength gain for fly ash-based geopolymers within the sodium sulfate solution [35–37]. The neutralized, cross-linked aluminosilicate structure is what

FIGURE 8. The appearance of the EDBG mortars with 0.5% BF content before (a) and after (b) 20 wetting-drying cycles.



Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

FIGURE 9. The influence of sulfate attack under 15 wetting-drying cycles on the mechanical properties of EDG and EDBG mortars: (a) Compressive strength; (b) Flexural strength.

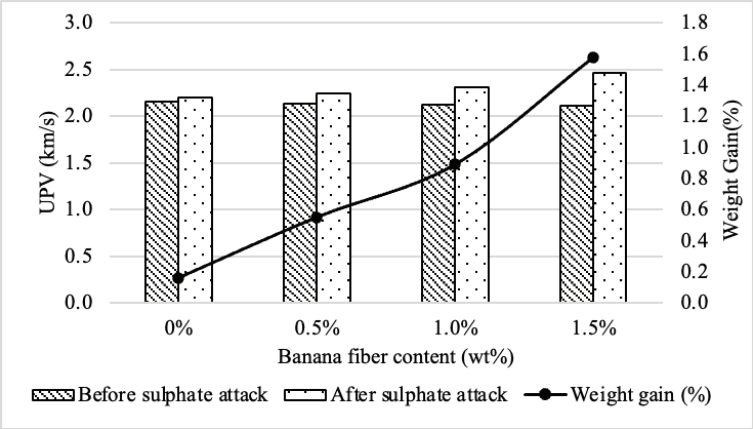


gives the geopolymer its strong resistance to sodium sulfate. This cross-linked aluminosilicate structure formed a dense matrix that reduced the sodium sulfate solution entry [37]. Hence, the primary mechanism has similarities to what is happening in cement, and the mechanism of the contribution to the strength is that the crystallization of the hydration products that can occur inside the pores of the matrix results in a higher density in the microstructure [38]. The highest increase in compressive strength (27.31%) occurred in the mortars with the highest fiber ratio (1.5%), which had the highest porosity before sulfate exposure. So, the geopolymer paste with high porosity before the test resulted in the highest densification effect in its microstructure.

The formation of a condensed microstructure with increased strength is also consistent with the increased values obtained in UPV values (Figure 10). While the UPV of the EDG mortar increased by 1.85% after the experiment, increment rates of UPV in mortars reinforced with 0.5, 1.0, and 1.5% BFs are gradually ascending (5.16, 8.96, and 16.59%, respectively). According to Bakharev et al., the strength gain is associated with the continued reaction with the Na^+ from the Na_2SO_4 solution [40]. These improvements detected in the microstructure and mechanical strength may also be attributed to the low calcium content (1.22%) of the Datça Earth. Fernandez-Jimenez et al. [39] stated that the calcium content of the precursor has an important influence on its durability. Expanding gypsum and ettringite were not produced

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

FIGURE 10. The influence of sulfate attack under 15 wetting-drying cycles on the UPV and weight loss of EDG and EDBG mortars.



due to the low content of calcium [37]. While metakaolin-based and bamboo fiber-reinforced geopolymer with low-calcium content had high resistance to sulfuric acid attack up to 15 wt% concentration [18], the compressive strength of the high calcium content fly ash geopolymer reinforced with oil palm trunk fiber decreased even at 5 wt% sulfate acid concentration. Strength reduction was attributed to the high calcium content of the fly ash. Sulphuric acid reacted with calcium oxide and produced leachable calcium salts that were mainly responsible for strength degradation [17]. After the mortars were submerged in Na_2SO_4 solution, no splitting, cracking, or spalling occurred under wetting-drying cycles (Figure 11). In addition, the presence of BF in the material may prevent possible stresses and cracks that may occur due to the crystallization of the hydration products inside the pores of the matrix. A very slight abrasion was detected on the surface of the mortars after the sulfate attack. However, the visual inspection grade can be stated as "1," which means very little impact since crack formation or fragmentation did not occur in the mortars, and the integrity of the mortars was preserved.

The weight gain was detected for all the mortars after the sulfate attack under wetting-drying cycles (Figure 10). The rate of weight gain for the EDG mortar was only 0.16% after the experiment, while the rate of increase was gradually getting higher in the mortars reinforced with 0.5, 1.0, and 1.5% BF inclusion (0.55, 0.89, and 1.58%, respectively). Depending on the rise of fiber inclusion the increase of the absorbed acid solution, and precipitation of the salts in the pores of the mortar during the drying stage may be the reason for the weight gain [37]. UPV values also increased parallel to the increase in fiber content. However, further study is required to determine whether this rise in weight particularly in fibrous composite will cause efflorescence.

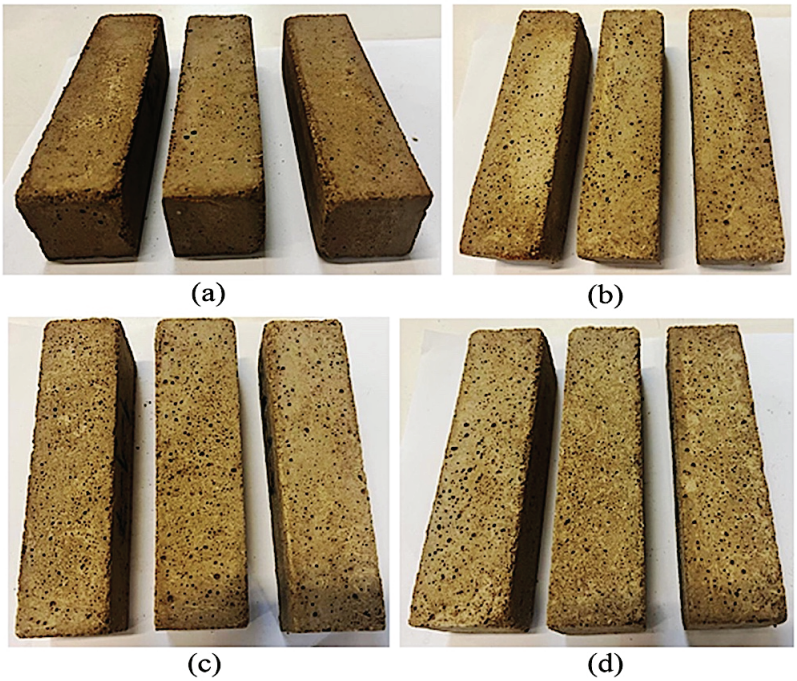
4. CONCLUSION

This experimental research assessed the durability performance of the natural-based geopolymer reinforced with natural fiber under three accelerated aging tests. The findings and observations obtained from the study are given below:

- It has been determined that the long-term performance of geopolymer mortar based on natural pozzolan (EDG) and its composite reinforced with waste banana fiber (EDBG)

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

FIGURE 11. Visual inspection of the EDG and EDBG mortars after the sulfate attack: (a) EDG mortar; EDBG mortar with (b) 0.5 %; (c) 1.0 %; (d) 1.5 % BF contents.



under the effects of freeze-thaw, wetting-drying, and sulfate attack is sufficient to be used as wall material in buildings.

- Freeze-thaw, wetting-drying, and sulfate attack tests had relatively adverse effects on EDG mortars compared to fiber-contained mortars.
- Reinforcing the geopolymer matrix with BF was able to prevent the formation of cracks and fragmentation of the material due to internal stresses by providing an internal structure that could compensate for the hydraulic pressure caused by the freezing of water under the effect of freeze-thaw.
- By the inclusion of BF into the matrix, internal stresses caused by the repeated wetting-drying cycles as well as the possible stresses that might occur in the mortars due to the crystallization of the hydration products under sulfate attack were able to be inhibited, and hence the mortars were well preserved from degradation.
- Freeze-thaw testing had the most deleterious effect on both EDG and EDBG mortars. The influence of wetting-drying and sulfate attack tests on the mortars was found to be negligible compared to the frost effect.
- An increase in the mechanical properties, UPV, and the weight of the all mortars after being exposed to the high concentration of sulfate concentration may be defined as good resistance against sodium sulfate attack. The main mechanism of the contribution to the strength might be due to the crystallization of the absorbed salts inside the structure; however, further study is required to determine whether this rise in the weight of particularly fibrous composite will cause efflorescence.

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

- In addition, the low calcium content of the natural pozzolan (ED) limited the production of expansive components and restrained the generation of cracks in the microstructure of the mortars.

ACKNOWLEDGEMENTS

The ITU Center for Scientific Research Projects [grant number FHD-2022-44014] provided funding for this work. The authors gratefully acknowledge the assistance of Ibrahim Oztürk and Gökhan Büyükkurt in Building Materials Laboratory, ITU, Faculty of Architecture.

REFERENCES

[1] F. Pacheco-Torgal, Z. Abdollahnejad, A.F. Camões, M. Jamshidi, Y. Ding, Durability of alkali-activated binders: A clear advantage over Portland cement or an unproven issue?, *Construction and Building Materials*, 30 (2012) 400-405. https://doi.org/10.1016/j.conbuildmat.2011.12.017.

[2] National Inventory Report for submission under the United Nations Framework Convention on Climate Change 1990–2020, https://enerji.gov.tr/evced-cevre-ve-iklim-ulusal-sera-gazi-emisyon-envanteri, (accessed 10.03.2023).

[3] I. Garcia-Lodeiro, A. Palomo, A. Fernández-Jiménez, An overview of the chemistry of alkali-activated cement-based binders, Editor(s): F. Pacheco-Torgal, J.A. Labrincha, C. Leonelli, A. Palomo, P. Chindaprasirt, *Handbook of Alkali-Activated Cements, Mortars and Concretes*, Woodhead Publishing, (2015) 19–47. https://doi.org/10.1533/9781782422884.1.19.

[4] G. Habert, S.A. Miller, V.M. John, J.L. Provis, A. Favier, A. Horvath, K.L. Scrivener, Environmental impacts and decarbonization strategies in the cement and concrete industries, *Nature Reviews Earth & Environment*, 1 (2020) 559–573. https://doi.org/10.1038/s43017-020-0093-3.

[5] R. Firdous, D. Stephan, J.N.Y. Djobo, Natural pozzolan based geopolymers: A review on mechanical, microstructural and durability characteristics, *Construction and Building Materials*, 190 (2018) 1251–1263. https://doi.org/10.1016/j.conbuildmat.2018.09.191.

[6] G. Habert, J.B. d'Espinose de Lacaillerie, N. Roussel, An environmental evaluation of geopolymer based concrete production: Reviewing current research trends, *Journal of Cleaner Production*, 19(11) (2011) 1229–1238. https://doi.org/10.1016/j.jclepro.2011.03.012.

[7] J.S.J. Van Deventer, J.L. Provis, P. Duxson, Technical and commercial progress in the adoption of geopolymer cement, *Minerals Engineering*, 29 (2012) 89–104. https://doi.org/10.1016/j.mineng.2011.09.009.

[8] H.A. Alcamand, P.H.R. Borges, F.A. Silva, A.C.C. Trindade, The effect of matrix composition and calcium content on the sulfate durability of metakaolin and metakaolin/slag alkali-activated mortars, *Ceramics International*, 44(5) (2018) 5037–5044. https://doi.org/10.1016/j.ceramint.2017.12.102.

[9] I. Ismail, S.A. Bernal, J.L. Provis, S. Hamdan, J.S.J. van Deventer, Microstructural changes in alkali activated fly ash/slag geopolymers with sulfate exposure, *Materials and Structures*, 46 (2013) 361–373. https://doi.org/10.1617/s11527-012-9906-2.

[10] F. Winnefeld, G.J.G. Gluth, S.A. Bernal, et al. RILEM TC 247-DTA round robin test: sulfate resistance, alkali-silica reaction and freeze–thaw resistance of alkali-activated concretes, *Materials and Structures*, 53(140) (2020). https://doi.org/10.1617/s11527-020-01562-0.

[11] A. Wang, Y. Zheng, Z. Zhang, K. Liu, Y. Li, L. Shi, D. Sun, The durability of alkali-activated materials in comparison with ordinary Portland cements and concretes: A review, *Engineering*, 6(6) (2020) 695–706. https://doi.org/10.1016/j.eng.2019.08.019.

[12] M. Hassanpour, P. Shafigh, H.B. Mahmud, Lightweight aggregate concrete fiber reinforcement—A review, *Construction and Building Materials*, 37 (2012) 452–461. https://doi.org/10.1016/j.conbuildmat.2012.07.071.

[13] G.Z.B. dos Santos, D.P. de Oliveira, J.A.M. Filho, N.M. da Silva, Sustainable geopolymer composite reinforced with sisal fiber: Durability to wetting and drying cycles, *Journal of Building Engineering*, 43 (2021) 102568. https://doi.org/10.1016/j.jobe.2021.102568.

[14] H.E. Gram, Durability of natural Fibers in concrete, *Swedish Cement and Concrete Research Institute*, Research Fo. 1(83) (1983) Stockholm.

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

[15] J. Liu, C. Lv, Durability of cellulosic-fiber-reinforced geopolymers: A review, *Molecules*, 27(3) (2022) 796. https://doi.org/10.3390/molecules27030796.
[16] J. Fan, Y. Jiang, L. Wang, F. Ding, L. Guo, P. Duan, Sulfate attack resistance of Sisal-PVA hybrid fiber reinforced geopolymer, *Bulletin of Chinese Ceramic Society*, 39 (2020) 1430–1437.
[17] A.B. Malkawi, M. Habib, J. Aladwan, Y. Alzubi, Engineering properties of fibre reinforced lightweight geopolymer concrete using palm oil biowastes, *Australian Journal of Civil Engineering*, 18(1) (2020) 82–92. DOI: 10.1080/14488353.2020.1721954.
[18] M.G. Sá Ribeiro, M.G. Sá Ribeiro, P.F. Keane, M.R. Sardela, W.M. Kriven, R.A. Sá Ribeiro, Acid resistance of metakaolin-based, bamboo fiber geopolymer composites, *Construction and Building Materials*, 302 (2021) 124194. https://doi.org/10.1016/j.conbuildmat.2021.124194.
[19] B.J. Mohr, H. Nanko, K.E. Kurtis, Durability of kraft pulp fiber–cement composites to wet/dry cycling, *Cement and Concrete Composites*, 27 (2005) 435–448. https://doi.org/10. 1016/j.cemconcomp.2004.07.006.
[20] A.C.C. Trindade, F.A. Silva, H.A. Alcamand, P.H.R. Borges, On the durability behavior of natural fiber reinforced geopolymers, Editor(s): W.M. Kriven, N.P. Bansal, M. Kusnezoff, T. Ohji, Y. Zhou, K.L. Moon, J. Matyas, K. Shimamura, S. Kirihara, *Proceedings of the 41st International Conference on Advanced Ceramics and Composites: Ceramic Engineering and Science Proceedings*, 38(3) (2018). https://doi.org/10.1002/9781119474746.ch20.
[21] R.Y. Nkwaju, J.N.Y. Djobo, J.N.F. Nouping, P.W.M. Huisken, J.G.N. Deutou, L. Courard, Iron-rich laterite-bagasse fibers based geopolymer composite: Mechanical, durability and insulating properties, *Applied Clay Science*, 183 (2019) 105333. https://doi.org/10.1016/j.clay.2019.105333.
[22] H.A. Santana, N.S.A. Júnior, D.V. Ribeiro, M.S. Cilla, C.M.R. Dias, Vegetable fibers behavior in geopolymers and alkali-activated cement based matrices: A review, *Journal of Building Engineering*, 44 (2021) 103291. https://doi.org/10.1016/j.jobe.2021.103291.
[23] ASTM C1437-20, Standard test method for flow of hydraulic cement mortar, *ASTM International*, West Conshohocken, (2020).
[24] TS 699, Natural building stones—Methods of inspection and laboratory testing, *Turkish Standard Institution*, Ankara, (2009).
[25] TS EN 14066, Natural stone test methods—Determination of resistance to ageing by thermal shock, *Turkish Standard Institution*, Ankara, (2015).
[26] TS EN 12370, Natural stone test methods—Determination of resistance to salt crystallisation, *Turkish Standard Institution*, Ankara, (2001).
[27] TS EN 14579, Natural stone test methods—Determination of sound speed propagation, *Turkish Standard Institution,* Ankara, (2006).
[28] TS EN 196-1, Methods of testing cement—Part 1: Determination of strength, *Turkish Standard Institution*, Ankara, (2009).
[29] K. Mermerdaş, S. İpek, Z. Mahmood, Visual inspection and mechanical testing of fly ash-based fibrous geopolymer composites under freeze-thaw cycles, *Construction and Building Materials*, 283 (2021) 122756. https://doi.org/10.1016/j.conbuildmat.2021.122756.
[30] TS EN 12371, Natural stone test methods—Determination of frost resistance, *Turkish Standard Institution*, Ankara, (2011).
[31] Z. Yunsheng, S. Wei, L. Zongjin, Z. Xiangming, C. Chungkong, Impact properties of geopolymer based extrudates incorporated with fly ash and PVA short fiber, *Construction and Building Materials*, 22(3) (2008) 370–383. https://doi.org/10.1016/j.conbuildmat.2006.08.006.
[32] W. Ali, O. Canpolat, Y. Aygörmez, M.M. Al-Mashhadani, Evaluation of the 12–24 mm basalt fibers and boron waste on reinforced metakaolin-based geopolymer, *Construction and Building Materials*, 251 (2020) 118976. https://doi.org/10.1016/j.conbuildmat.2020.118976.
[33] J.A. Melo Filho, F.A. Silva, R.D. Toledo Filho, Degradation kinetics and aging mechanisms on sisal fiber cement composite systems, *Cement and Concrete Composites*, 40 (2013) 30–39. https://doi.org/10.1016/j.cemconcomp.2013.04.003.
[34] Z. Tang, N. Deng, Effect of Salt Solution on the Mechanical Behaviours of Geopolymer Concrete under Dry-Wet Cycles, *Advances in Materials Science and Engineering*, (2022) 9120821, 1–9. https://doi.org/10.1155/2022/9120821.

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

[35] M.A.M. Ariffin, M.A.R. Bhutta, M.W. Hussin, M. Mohd Tahir, N. Aziah, Sulfuric acid resistance of blended ash geopolymer concrete, *Construction and Building Materials*, 43 (2013) 80–86. https://doi.org/10.1016/j.conbuildmat.2013.01.018.
[36] M.A.R. Bhutta, W.M. Hussin, M. Azreen, M.M. Tahir, Sulphate resistance of geopolymer concrete prepared from blended waste fuel ash, *Journal of Materials in Civil Engineering*, 26 (2014) 04014080. https://doi.org/10.1061/(asce)mt.1943-5533.0001030.
[37] J.C. Kuri, M. Nuruzzaman, P.K. Sarker, Sodium sulphate resistance of geopolymer mortar produced using ground ferronickel slag with fly ash, *Ceramics International*, 49(2) (2023) 2765–2773. https://doi.org/10.1016/j.ceramint.2022.09.258.
[38] L. Guo, Y. Wu, F. Xu, X. Song, J. Ye, P. Duan, Z. Zhang, Sulfate resistance of hybrid fiber reinforced metakaolin geopolymer composites, *Composites Part B: Engineering*, 183 (2020) 107689. https://doi.org/10.1016/j.compositesb.2019.107689.
[39] A. Fernandez-Jimenez, I. García-Lodeiro, A. Palomo, Durability of alkali-activated fly ash cementitious materials, *Journal of Materials Science*, 42 (2007) 3055–3065. https://doi.org/10.1007/s10853-006-0584-8.
[40] T. Bakharev, J.G. Sanjayan, Y.B. Cheng, Sulfate attack on alkali-activated slag concrete, *Cement and Concrete Research*, 32 (2002) 211–216. https://doi.org/10.1016/S0008- 8846(01)00659-7.
[41] V.S. Parameswaran, Fibre-reinforced concrete: a versatile construction material, Building and Environment, 26(3) (1991) 301–305. https://doi.org/10.1016/0360-1323(91)90054-F.

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

Downloaded from http://meridian.allenpress.com/jgb/article-pdf/18/4/149/3297197/i1943-4618-18-4-149.pdf by greenjournal@verizon.net on 10 December 2023

About the Editors

Co-Editors-in-Chief

Simi Hoque, Ph.D.
Civil, Architectural, and Environmental Engineering
Drexel University
https://simi734.wixsite.com/simi



Jian Zuo, Ph.D.
School of Architecture and Built Environment
The University of Adelaide
https://www.adelaide.edu.au/directory/Jian.Zuo



Recognised as a leading national researcher in Sustainable Development in the Australian's Research Awards 2023.

Advisory Board

Cathryn Copper

Head, Eberhard Zeidler
Architecture Library
University of Toronto



Mark Gorgolewski, Ph.D.
Department of Architectural Science
Ryerson University



Giuliana Iannaccone, Ph.D.
Department of Architecture & Construction
Politecnico di Milano



David Sailor, Ph.D.
Director, Urban Climate Research Center
Arizona State University



Professor Geoffrey Q.P. Shen
Chair Professor of Construction Management
The Hong Kong Polytechnic University



Professor Jianzhuang Xiao
College of Civil Engineering
Tongji University



Editorial Assistant

Mr. Daniel Oteng
University of Adelaide, Australia

Senior Editorial Board

Lola Ben-Alon, Ph.D.
Graduate School of Architecture, Planning and Preservation
Columbia University

Edwin H W Chan, Ph.D.
Building and Real Estate Department
The Hong Kong Polytechnic University

Qian (Victoria) Chen, Ph.D.
Construction Systems Management
The Ohio State University

Tom Collins, Ph.D.
Department of Architecture
Ball State University

Corey Griffin, Ph.D.
Associate Dean & Professor of Architecture
Penn State Altoona

Matthias Haase, Ph.D.
Institute for Facility Management
Zurich University of Applied Sciences

Liv M. Haselbach, Ph.D.
Department of Civil and Environmental Engineering
Lamar University

Erin Hopkins, Ph.D.
Department of Property Management
Virginia Polytechnic University

Ming Hu, Assistant Professor
School of Architecture, Planning & Preserveration
University of Maryland

Lotte Bjerregaard Jensen, Ph.D.

Department of Civil Engineering
Technical University of Denmark

Karen Kensek, Professor of Practice
School of Architecture
University of Southern California

Oliver Kinnane, Ph.D.
Architecture Planning & Environmental Policy
University College Dublin

Sandeep Langar, Ph.D.
Department of Construction Science
University of Texas at San Antonio

Wilson W.S. Lu, Ph.D.
Department of Real Estate and Construction
The University of Hong Kong

Colin MacDougall, Ph.D.
Department of Civil Engineering
Queen's University

Mikesch Muecke, Ph.D.
Architecture Department
Iowa State University

Masa Noguchi, Ph.D.
Faculty of Architecture, Building & Planning
The University of Melbourne

Christine O'Hara, Associate Professor
Landscape Architecture Department
California Polytechnic State University

Annie Pearce, Ph.D.
Myers-Lawson School of Construction
Virginia Tech

Emina Petrovic, Ph.D.

School of Architecture
Victoria University of Wellington

Tiziano Li Piani, Ph.D.
Civil Engineering
Technical University of Delft (TUD)

Svetlana Pushkar, Ph.D.
Department of Civil Engineering
Ariel University

Raviduth Ramful, Ph.D.
Faculty of Engineering
University of Mauritius

Alan Richardson, Ph.D.
School of the Built Environment
Northumbria University

Brian A. Rock, Ph.D.
Department of Civil, Environmental and
Architectural Engineering
The University of Kansas

Monica Rossi-Schwarzenbeck, Ph.D.
College of Civil Engineering
Leipzig University of Applied Sciences

Friedrich Sick, Ph.D.
FHTW Berlin
University of Applied Sciences

Brett Tempest, Ph.D.
Department of Civil and Environmental
Engineering
University of North Carolina at Charlotte

Zezhou Wu, Ph.D.
College of Civil and Transportation Engineering
Shenzhen University

Eunhwa Yang, Ph.D.
School of Building and Construction
Georgia Institute of Technology

Editorial Board Members

Dr. Ruidong Chang
The University of Adelaide, Australia

Dr. Hanliang Fu
Xi'an University of Architecture and Technology,
China

Dr. Yilong Han
Tongji University, China

Dr. Jian Li Hao
Xi'an Jiaotong-Liverpool University, China

Dr. Wengui Li
University of Technology Sydney, Australia

Dr. Chao Mao
Deputy Head, School of Management Science and
Real Estate
Chongqing University

Dr. Kim Maund
Deputy Head of School, School of Architecture
and Built Environment
The University of Newcastle

Dr. Neda Sadeghi
Department of Construction Science
Texas A&M University

Dr. Nilupa Udawatta
Deakin University, Australia

Dr. Ge Wang
Huanzhong Agricultural University, China

Professor Tao Wang
Chongqing University, China

Dr. Dujuan Yang
Department of the Built Environment
Eindhoven University of Technology

Dr. Xueliang Yuan
Shandong University, China

Professor Jingxiao Zhang
Chang'An University, China

Dr. Xianbo Zhao
Central Queensland University, Australia

JOURNAL OF greenbuilding
College Publishing

eISSN: 1943-4618 **ISSN:** 1552-6100

General Inform...
Web of Science ...
Journal Citatio...
Peer Review Inf...
PubMed® Infor...

Return to Search Results

JOURNAL OF GREEN BUILDING

Share This Journal

ISSN / eISSN **1552-6100 / 1943-4618**
Publisher **COLLEGE PUBLISHING, 12309 LYNWOOD DR, GLEN ALLEN, USA, VA, 23059**

General Information

Journal Website	Visit Site	**Publisher Website**	Visit Site
1st Year Published	2006	**Frequency**	Quarterly
Issues Per Year	4	**Country / Region**	UNITED STATES OF AMERICA
Primary Language	English		

Web of Science Coverage

Collection	Index	Category	Similar Journals
Core Collection	Arts & Humanities Citation Index (AHCI)	Architecture	Find Similar Journals
Current Contents	Arts & Humanities	Art & Architecture	Find Similar Journals

Search a topic within this journal

Search a topic within this journal...

Search

Journal Citation Report™ (JCR)

Journal Citation Repor

Journal Impact Factor™ (JIF)

JCR SUBSCRIPTION ACTIVE

2023	2022

Downloaded on 10.03.2025 11:09:55

2023 Journal Performance Data for: Journal of Green Building

ISSN
1552-6100

EISSN
1943-4618

JCR ABBREVIATION
J GREEN BUILD

ISO ABBREVIATION
J. Green Build.

Journal Information

EDITION
Arts & Humanities Citation Index (AHCI)

CATEGORY
ARCHITECTURE

LANGUAGES
English

REGION
USA

1ST ELECTRONIC JCR YEAR
2020

Publisher Information

PUBLISHER
COLLEGE PUBLISHING

ADDRESS
12309 LYNWOOD DR, GLEN ALLEN, VA 23059

PUBLICATION FREQUENCY
4 issues/year

 © 2025 Clarivate

Rank by Journal Impact factor

Note: While journals indexed in AHCI and ESCI receive a JIF from the 2022 release in June 2023 onward, journals in the 25 arts & humanities categories will not receive ranks, quartiles, or percentiles.Learn more

Rank by Journal Citation Indicator (JCI)

Journals within a category are sorted in descending order by Journal Citation Indicator (JCI) resulting in the Category Ranking below. A separate rank is shown for each category in which the journal is listed in JCR. Data for the most recent year is presented at the top of the list, with other years shown in reverse chronological order.Learn more

CATEGORY

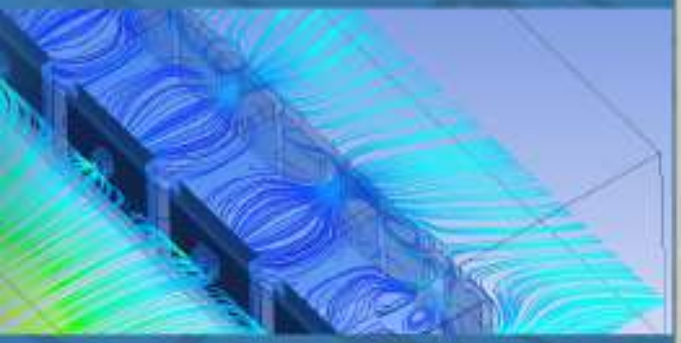
ARCHITECTURE

8/97

JCR YEAR	JCI RANK	QUARTILE	JCI PERCENTILE
2023	8/97	Q1	92.27
2022	4/97	Q1	96.39
2021	5/93	Q1	95.16
2020	7/91	Q1	92.86
2019	7/90	Q1	92.78
2018	8/88	Q1	91.48
2017	11/87	Q1	87.93

 © 2025 Clarivate

JOURNAL OF
greenbuilding
VOLUME 18 NUMBER 4 **FALL 2023**







IN THIS ISSUE

RESEARCH ARTICLES

Quick Protocol for Integrating the Attribute Information of Unstructured Point Cloud Data Into a Solar Envelope Simulation *Miktha Farid Alkadri, Francesco De Luca, Michela Turrin, Muhammad Rafif Cahyadi Agung*

Hygrothermal Analysis of Double-Stud Wood Walls in Non-Residential Construction *Diana A. Brito Picciotto; Christopher Nielson, AIA.; L. Carl Fiocchi, Ph.D.*

CNN-LSTM Models Combined With Attention Mechanism for Short-Term Building Heating Load Prediction *Kuo Lan, Xin Xin, Songlin Fang, Pangong Cao*

Evaluating the Health and Safety Maturity of Sustainable Building Projects Using a Sustainable Health and Safety Maturity Model *Bezalel Orogun, PhD and Mohamed H Issa, PhD*

Students' Awareness, Expectations, and Perceptions about Sustainability: A Case Study in an Ordinary University in China *Wanxia Zhao, Yonghua Zou*

A Study on the Evaluation Methods of Indoor Light Environment for Occupant Comfort and Well-being *Ki Rim Kim, Kyung Sun Lee and Jaewook Lee*

Ontology Development for Green Building by Using a Semi-Automatic Method *Hang Yan, Yiming Shi, Xuteng Lu*

Durability Behavior of Banana Fiber-Reinforced Natural Pozzolan Geopolymer *Kübra Ekiz Barış, Leyla Tanaçan*

Exploring the Characteristics of WELL-Certified K–12 Schools: A Comprehensive Study on International Cases *Qinchuan Chen, Suk-Kyung Kim, Juyeon Han, Cherry Kim*

Thermal Performance Evaluation of Passive Design Techniques for Green Buildings In Temperate Climates *Nam-Young Jeong, Jiyoung Lee,*

NEW DIRECTIONS IN TEACHING AND RESEARCH

Quantitative Approaches in Architectural Design for User-Oriented Indoor Environmental Quality *Jeehwan Lee*

Issues

Select Year 2023

Select Issue Fall - Volume 18, Issue 4

RESEARCH ARTICLES

QUICK PROTOCOL FOR INTEGRATING THE ATTRIBUTE INFORMATION OF UNSTRUCTURED POINT CLOUD DATA INTO A SOLAR ENVELOPE SIMULATION

Miktha Farid Alkadri; Francesco De Luca; Michela Turrin; Muhammad Rafif Cahyadi Agung

Abstract View Article PDF

HYGROTHERMAL ANALYSIS OF DOUBLE-STUD WOOD WALLS IN NON-RESIDENTIAL CONSTRUCTION: Case study: R.W. Kern Center (Amherst, MA)

Diana A. Brito Picciotto; Christopher Nielson, AIA.; L. Carl Fiocchi, Ph.D.

Volume 18, Issue 4

Fall 2023

Get Email Alerts

Latest Issue Alert

Latest Most Read Most Cited

EVALUATING THE HEALTH AND SAFETY MATURITY OF SUSTAINABLE BUILDING PROJECTS USING A SUSTAINABLE HEALTH AND SAFETY MATURITY MODEL

Bezalel Orogun, PhD, Mohamed H Issa, PhD



ISSN 1552-6100

eISSN 1943-4618

In this Issue

RESEARCH ARTICLES

NEW DIRECTIONS IN TEACHING AND RESEARCH

Abstract | View Article | PDF

CNN-LSTM MODELS COMBINED WITH ATTENTION MECHANISM FOR SHORT-TERM BUILDING HEATING LOAD PREDICTION

Kun Lan; Xin Xin; Songlin Fang; Pangong Cao

Abstract | View Article | PDF

EVALUATING THE HEALTH AND SAFETY MATURITY OF SUSTAINABLE BUILDING PROJECTS USING A SUSTAINABLE HEALTH AND SAFETY MATURITY MODEL

Bezalel Orogun, PhD; Mohamed H Issa, PhD

Abstract | View Article | PDF

STUDENTS' AWARENESS, EXPECTATIONS, AND PERCEPTIONS ABOUT SUSTAINABILITY: A CASE STUDY IN AN ORDINARY UNIVERSITY IN CHINA

Wanxia Zhao; Yonghua Zou

Abstract | View Article | PDF

DURABILITY BEHAVIOR OF BANANA FIBER-REINFORCED NATURAL POZZOLAN GEOPOLYMER

Kübra Ekiz Bariş, Leyla Tanaçan

STUDENTS' AWARENESS, EXPECTATIONS, AND PERCEPTIONS ABOUT SUSTAINABILITY: A CASE STUDY IN AN ORDINARY UNIVERSITY IN CHINA

Wanxia Zhao, Yonghua Zou

THERMAL PERFORMANCE EVALUATION OF PASSIVE DESIGN TECHNIQUES FOR GREEN BUILDINGS IN TEMPERATE CLIMATES

Nam-Young Jeong, Jiyoung Lee

CNN-LSTM MODELS COMBINED WITH ATTENTION MECHANISM FOR SHORT-TERM BUILDING HEATING LOAD PREDICTION

Kun Lan, Xin Xin, Songlin Fang, Pangong Cao

A STUDY ON THE EVALUATION METHODS OF INDOOR LIGHT ENVIRONMENT FOR OCCUPANT COMFORT AND WELL-BEING

Ki Rim Kim; Kyung Sun Lee; Jaewook Lee

Abstract | View Article | PDF

ONTOLOGY DEVELOPMENT FOR GREEN BUILDING BY USING A SEMI-AUTOMATIC METHOD

Hang Yan; Yiming Shi; Xuteng Lu

Abstract | View Article | PDF

DURABILITY BEHAVIOR OF BANANA FIBER-REINFORCED NATURAL POZZOLAN GEOPOLYMER

Kübra Ekiz Bariş; Leyla Tanaçan

Abstract | View Article | PDF

EXPLORING THE CHARACTERISTICS OF WELL-CERTIFIED K-12 SCHOOLS: A COMPREHENSIVE STUDY ON INTERNATIONAL CASES

Qinchuan Chen; Suk-Kyung Kim; Juyeon Han; Cherry Kim

Abstract View Article PDF

THERMAL PERFORMANCE EVALUATION OF PASSIVE DESIGN TECHNIQUES FOR GREEN BUILDINGS IN TEMPERATE CLIMATES

Nam-Young Jeong; Jiyoung Lee

Abstract View Article PDF

NEW DIRECTIONS IN TEACHING AND RESEARCH

QUANTITATIVE APPROACHES IN ARCHITECTURAL DESIGN FOR USER-ORIENTED INDOOR ENVIRONMENTAL QUALITY

Jeehwan Lee

Abstract View Article PDF

Cover Image

All Issues

JOURNAL OF greenbuilding
College Publishing

eISSN: 1943-4618 **ISSN:** 1552-6100

Privacy Policy Get Adobe Acrobat Reader Support