

## Enhancing the Strength of Green Cement Mortar by using Fly Ash Powder, Glass Powder, and Brick Powder

✉ **Ansam Mishaal Mizaal\***   **Eethar Thanon Dawood\***   **Rabi Muyad Najem\*\***  
ansamalabadi87@ntu.edu.iq   eethardawood@ntu.edu.iq   dr.rabi.najem@uomosul.edu.iq

\*Building and Construction Techniques Engineering, Northern Technical University, Mosul, Iraq

\*\*Civil Engineering Department, College of Engineering, University of Mosul, Mosul, Iraq

Received: October 25<sup>th</sup>, 2025   Received in revised form: December 22<sup>th</sup>, 2025   Accepted: January 3<sup>rd</sup>, 2026

### ABSTRACT

The extensive utilization of cement in concrete mixtures escalates the consumption of natural resources, hence inflating costs and augmenting carbon dioxide emissions associated with cement production. Consequently, reusing waste materials increases the availability of natural resources, helps the environment in the long run, and makes it easier to manage landfills. This research aims to develop green mortar using various waste cementitious materials, including Waste Glass Powder (WGP), Waste Brick Powder (WBP), and Fly Ash Powder (FAP), with a 30 percent cement replacement rate, thereby minimizing waste and reducing CO<sub>2</sub> emissions. Different mix proportions of green mortars were tested for compressive and flexural strength, density, and water absorption. The job is split into two halves. Initially, cement was replaced by 30% of each of these materials. In the second stage, cement was replaced by different proportions of these materials, with a total replacement of 30%. The results showed that green mortar containing 30% FAP provides higher density and strength (under compression and flexural loading). The mix with a partial cement substitute (30%) (5% WGP + 10% FAP + 15% WBP) (M2) for green mortar exhibits improved density and strength (during compression and flexural) greater than M1 (10% WGP + 10% FAP + 10% WBP).

**Keywords:** Green mortar, Waste cementitious materials, Fly Ash powder, Glass powder, Brick powder.

This is an open access article under the CC BY 4.0 license (<http://creativecommons.org/licenses/by/4.0/>).

<https://jamh.uomosul.edu.iq/index.php/rengj>

Email: [alrafidain\\_engjournal3@uomosul.edu.iq](mailto:alrafidain_engjournal3@uomosul.edu.iq)

### 1. INTRODUCTION

The need for environmentally friendly, cost-effective, and high-performance cement has been growing in recent years, driven by the construction industry's increasing concern for both environmental impacts and the mechanical and durability properties of building materials [1]. Large quantities of carbon dioxide (CO<sub>2</sub>) are released into the atmosphere during cement production, which is harmful to the environment. Between 5% and 8% of the world's carbon dioxide (CO<sub>2</sub>) emissions come from cement manufacturers. So, it's important to use cement alternatives as a partial replacement [2][3].

Numerous researchers have examined various types of cementitious materials. Mohit et al. (2019) investigated Ceramic Waste Powder (CWP) as an alternative mortar-based cementitious material. Five, ten, fifteen, twenty, and twenty-five percent of CWP replaced the cement. The findings

indicate that the sample using 10% CWP as a substitute for cement exhibited the highest strength [4]. Samadi and his colleagues (2020) examined ground ceramic as an economical, environmentally favorable material for producing sustainable mortars. Cement was substituted with A percent of ground ceramic at intervals of 0, 10, 20, 30, 40, 50, and 60%. They observed that using ceramic waste as a combination of a binding agent and a fine aggregate markedly improved the compressive strength of the mortar and increased its resilience against adverse environmental conditions [5].

Deepa and Dhivya (2017) examined the use of WGP as a partial cement substitute for M25 concrete at replacement rates of 10%, 15%, and 20%, maintaining a constant 15% fly ash replacement. They conducted tests to evaluate workability, compressive, splitting, and flexural strengths at 7 and 28 days, comparing the results with those of traditional concrete. They revealed

that the compressive strength and splitting tensile strength in 28 days were greater with 10% replacement than with 15% and 20% replacement. They also found that the flexural strength was higher with 15% replacement than with 10% or 20% replacement, compared with regular concrete [6]. Pitarch and his colleagues investigated the pozzolanic activity of bricks made of red clay (RCB), tiles made of ceramic (CTW), and ceramic-based sanitary products (CSW) with environmentally friendly Portland mixed cements in 2021. The replacement of 0 to 50 percent of the traditional Portland cement PC was accomplished with each of them. This study reveals that the pozzolanic reactive materials improved over time, and that all mortars that were made with a maximum of 25 weight percent RCB, CTW, or CSW fulfilled the mechanical standards for coal fly ashes. This was the case regardless of the type of ceramic waste used. These results suggest the potential for partial substitution of PCs with locally sourced ceramic waste, hence reducing CO<sub>2</sub> emissions [7]. Mohammad et al. (2020) conducted a study on the impact of recycled ceramics, instead of cement and fine aggregates, on the long-term reliability of environmentally friendly mortar. He assessed the mortar's strength and long-term reliability, using waste ceramic powder and ceramic particles as additional materials for cementing. 40% of the cement was replaced with ceramic waste powder, and all the sand was replaced with ceramic fine aggregate. The results indicated that the characteristics of the ceramic mortar's mechanical properties were comparatively superior to those of the traditional cement mortar. Moreover, compared with traditional cement mortar, the greatest enhancement in both compressive and splitting tensile strength was achieved by substituting 40% of traditional cement with ceramic waste powder and 100% sand aggregate with ceramic fine aggregate [8].

Chen et al., 2020, looked at waste powder made of ceramic as a pozzolanic supplementary cementitious substance to make building materials that are better for the environment. They used a category of micro powder from ceramics made from ceramic waste, with particles about 3.5 µm in size. They replaced more than 40% of the cement, altering its microstructure and mechanical characteristics. The results show that the mortars can withstand compressive strengths of more than 80 MPa and bending strengths of about 10 MPa [9]. Shao, J. et al., 2019, recycled clay brick powder (CBP) from old clay bricks was used to replace some of the cement in cement pastes or mortars. The cement was substituted with (0, 10, 20, 30, 40, and 50) percent of CBP. The findings

demonstrated that an increase in the level of replacement of clay brick powder at a young age correspondingly led to a steady reduction in compressive strength. The compressive value, on the other hand, kept getting stronger over time. After 90 days, the mortar achieved an optimal compressive value of (62.2 MPa) when 20% was added [10].

Lim, N. H., and colleagues (2018). Researchers have investigated how waste powder from ceramics affects the mortar's mechanical and microstructural properties. Four mixtures (0, 20, 40, and 60) percent were fabricated using ceramic nanoparticles. The mortar samples were tested for compressive strength. The results showed that the mortar performed better with 40% ceramic substitution and excessive calcium hydroxide in the active silica [11]. Nahi, S., et al., 2020: Researchers have investigated the properties of cement pastes & mortars made from glass powder. There are different rates of cement substitution by weight: 0%, 10%, 25%, 35%, and 60%. The results indicate that the quantity of powdered glass utilized as a substitute for cement is very important in identifying the properties of the mortar. Chemical shrinkage and heat assessment demonstrate that a substantial substitution of cement paste with glass powder accelerates the hydration reaction rate. As the amount of glass powder increases, especially in mortar containing 60% glass powder, the compressive strength, dynamic Young's modulus, and shear modulus decrease [12].

Vijayakumar, et al., 2013, A glass powder was evaluated as a partial substitute for cement in concrete production. A powder of glass has been partially replaced by (10- 40) percent, and its mechanical characteristics (compressive, tensile, and flexural strength) have been evaluated against standard concrete up to 60 days of curing. The results indicate that glass powder concrete significantly enhances compressive, tensile, and flexural strength compared to conventional concrete [13]. Previous studies typically introduced individual waste products across various experimental configurations, complicating direct comparisons and constraining generalizability. It is not clear what happens when you mix different types of waste materials, or what the optimal ratios are, especially when you replace a large proportion (e.g., 30%). We don't know how well these materials work because there haven't been any controlled comparison studies. No studies have employed a two-stage evaluation to analyze waste materials before exploring their interrelationships at the same replacement ratio, highlighting the need for a more comprehensive analysis to enhance multi-waste green mortar

mixtures. The study explores the best combination to increase strength, reduce environmental effects, and promote sustainable construction.

Previous studies typically introduced individual waste products across various experimental configurations, complicating direct comparisons and constraining generalizability, such as Nahi et al. [14] and Vijayakumar, et al. [14], who used WGP alone as a partial replacement of cement; furthermore, Shihwen et al. [14] and Cho et al. [15] used FAP alone as a partial replacement of cement, while, Shao et al. [10] and Zhao et al. [16] who used WBP alone as a partial replacement of cement.

It is not clear what happens when you mix different types of waste materials, or what the optimal ratios are, especially when you replace a large proportion (e.g., 30%). We don't know how well these materials work because there haven't been any controlled comparison studies. For example, Liu et al. [17] used WGP alone (60%) and FAP alone (60%).

After that, blended WGP with FAP at (50% WGP+ 10% FAP), (30% WGP+ 30% FAP) and (10% WGP+ 50% FAP), Rosa et al. [18] studied the combined effect of 10% WBP and 10% FAP in the first time, then studied the effect of combined 10% WBP and 10% WGP. Moreover, Rabi and Mosaberpanah [19] studied the effect of 20% WBP at the first time, then utilized 20% WGP.

After that, we examined the combined effect of (5% WBP+ 15% WGP), (10% WBP+ 10% WGP), and (15% WBP+ 5% WGP). No studies have employed a two-stage evaluation to analyze waste materials prior to exploring their interrelationships at the same replacement ratio, highlighting the need for more comprehensive analysis to enhance multi-waste green mortar mixtures and to use these materials in ternary mortar. The study explores the best combination to increase strength, reduce environmental effects, and promote sustainable construction.

## 2. SCOPE OF THE WORK

This work aims to create eco-friendly mortar utilizing diverse waste cementitious materials, including WGP, WBP, and FAP, firstly, with a cement replacement 30% of each of these materials. then cement was replaced by different proportions of these materials together, with total replacement 30%, thereby minimizing waste and reducing CO<sub>2</sub> emissions.

## 3. MATERIALS

To make the mix proportions for the mortars, we used Traditional Portland Cement (TPC) with several cementitious materials, fine aggregate, superplasticizer, and water. The physical, mechanical, and chemical properties of these materials are described in Tables 1,2,4, 5, and 6.

### 3.1 Traditional Portland Cement (TPC)

It was utilized in the production of green mortar, and it was provided by the Badoosh facility, which is in the Nineveh city, northern Iraq. In the business world, it is known as Badoosh cement. Table 1 displays the chemical compositions, as well as the physical and mechanical properties of the substance.

Table 1: Physical, Mechanical and Chemical properties of TPC

Physical and Mechanical properties	Values	Iraqi specification No.5/1984
Specific gravity	3.06	-
Blaine's fineness, cm <sup>2</sup> /gm	3480	≥ 2300
Initial time of setting, min.	143	≥ 45
Final time of setting, h.	2:55	≤ 10
Compressive strength, MPa at 3days	25.57	≥ 15
Compressive strength, MPa at 7days	30.22	≥ 23
Compressive strength, MPa at 28days	39.29	-
Chemical composition	Content (%)	Iraqi specification No.5/1984
SiO <sub>2</sub>	20.991	-
Al <sub>2</sub> O <sub>3</sub>	5.991	-
Fe <sub>2</sub> O <sub>3</sub>	2.587	-
CaO	63.283	-
SO <sub>3</sub>	1.589	≤ 2.8 %
MgO	3.777	≤ 5%
Loss of ignition (LOI)	1.60	≤ 4 %
C <sub>3</sub> S	49.50	-
C <sub>2</sub> S	23.12	-
C <sub>3</sub> A	11.50	-
C <sub>4</sub> AF	7.86	-

### 3.2 Fine aggregate

Green mortar used natural river sand no larger than 1.18 mm. It came from the Kanash region of Mosul, Iraq. We used ASTM C 128 [20] to find the specific gravity of the material (2.69) and absorption (2.25%). Table 2 shows the results of the sieve examination of the sand.

Table 2: Sieve Analysis of Fine aggregate with maximum size (1.18 mm)

Sieve No.(mm)	Cumulative passing, %	BS:882:1992
No.4 (4.75)	100	100
No.8 (2.36)	100	80 – 100
No.16 (1.18)	90	70 – 100
No.30 (0.60)	56.4	55 – 100
No.50 (0.30)	19	5 – 70
No.100 (0.15)	2.8	-

**3.3 Water**

The water utilized for mixing and standard curing was uncontaminated tap water, with a temperature of 26°C.

**3.4 Waste Cementitious Materials (WCM)**

This study utilized three categories of waste materials as shown in Figure 1: Waste Glass Powder (WGP), Waste Brick Powder (WBP), and Fly Ash Powder (FAP).

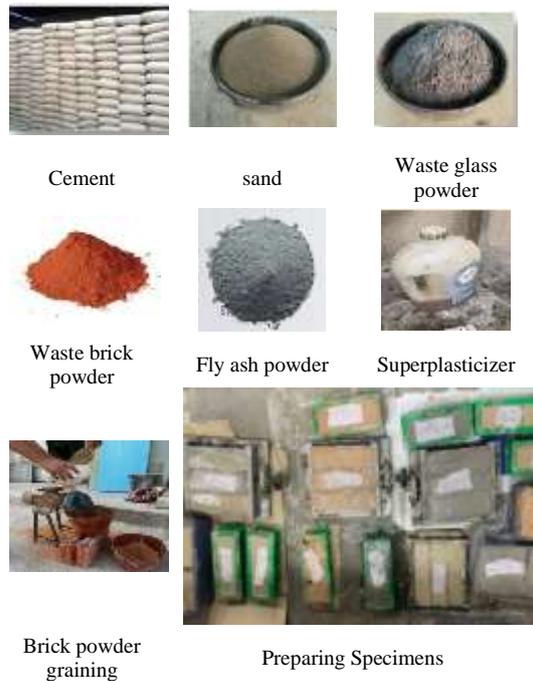


Figure 1: Preparing waste cementitious materials and specimens used in the study

The preparation and grinding of these ingredients underwent several stages to get a fineness comparable to the particle size of cement. In the beginning, The strengths of the Activity Indicator (SAI) for these materials must be assessed to evaluate their efficacy; the activity indices test was conducted using a twenty percent substitute ratio with various waste materials, such as glass, brick, or as fly ash powder, in accordance with ASTM C311 [20]. After testing, SAI at 7 days was more than 75% therefore we used these materials see Tables 3. Tables 4 and 5 show the physical properties of the WGP, WBP, and FAP used, as well as their chemical compositions.

Table 3 Strength Activity Index of different waste cementitious materials at 7 days

Waste Cementitious Materials	SAI at 7 days (%)
WGP	75.83
WBP	85.26
FAP	95.92

Table 4 Physical properties of WGP and WBP used and their chemical compositions

physical properties	Property value		ASTM C618
	WGP	WBP	
Specific gravity (unitless)	2.56	2.73	-
Blaine's fineness (cm <sup>2</sup> / gm)	2980	3605	-
Retained on sieve No. 325 (%)	24	20	≤ 34
Chemical composition	content %		ASTM C618
Silicon dioxide, SiO <sub>2</sub>	72.71	51.98	-
Aluminum oxide, Al <sub>2</sub> O <sub>3</sub>	1.487	13.975	-
Ferric oxide, Fe <sub>2</sub> O <sub>3</sub>	1.168	4.865	-
Calcium oxide, CaO	11.940	15.6	-
Sulfur trioxide, SO <sub>3</sub>	0.323	3.431	≤ 4
Magnesium oxide, MgO	1.480	6.293	-
Alkalis (Na <sub>2</sub> O+ K <sub>2</sub> O)	8.906	2.792	-
Manganese oxide, MnO	0.014	0.122	-

Table 5: Physical, Mechanical, and Chemical properties of FAP

Physical and Mechanical properties	Values
Specific gravity	2.8
Fineness	92%
Color	GREY
Chemical composition	Content (%)
SiO <sub>2</sub>	99.2
Al <sub>2</sub> O <sub>3</sub>	23.33
Fe <sub>2</sub> O <sub>3</sub>	2.9
CaO	1.1
SO <sub>3</sub>	0.3
MgO	0.3

**3.5 superplasticizer (SP)**

The superplasticizer used in this study was Floc-rete SP-42, with the specifications shown in Table 6.

Table 6: specifications of superplasticizer floc-rete SP-42

Floc-rete SP-42 used Tests	Results
State of the materials	Liquid
Color	Brown, black
Specific gravity	1.19 - 1.22
Chloride content	Nil
Air entrainment	less than 2%
Structure	sulfonated Naphthalene

**4. EXPERIMENTAL WORK**

All tests and measurements needed for this study were conducted in the building and construction techniques engineering laboratories under standard temperature and humidity conditions. The experimental program can be summarized through the following, Figure 2:

-preparing all Materials and checking the strength activity index (SAI) of cementitious materials at 7 & 28 days

-Prepare mixes that contain 30% cementitious materials to study their effect on green mortar

-Preparing mixes of green mortar GM by replacing cement with fly ash, glass powder, and brick powder in different percentages and selecting the optimum mix.

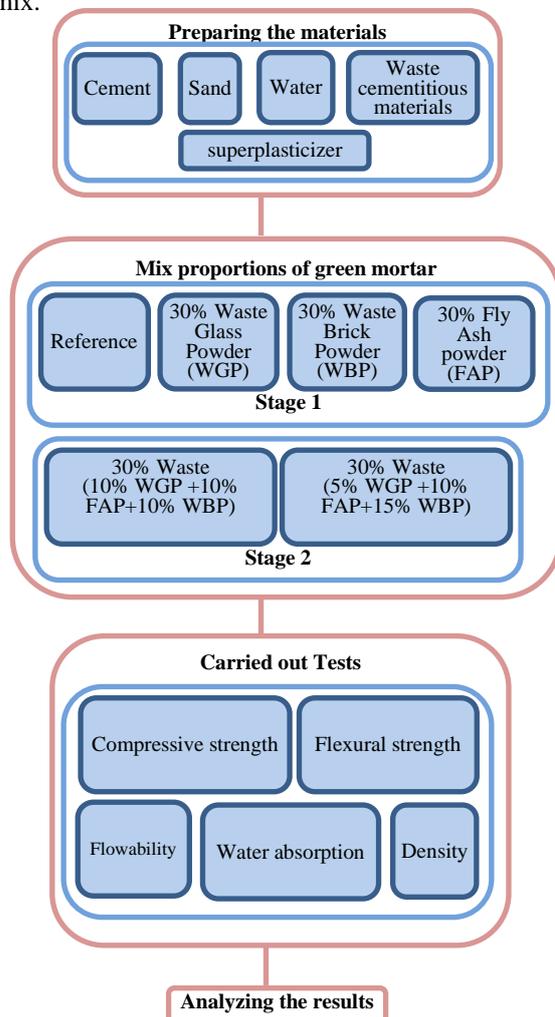


Figure 2: Experimental program Flowchart

**4.1 Mix proportions**

In the first phase, four mixtures were poured. The initial mixture was a standard (M0) with a water-to-cement ratio of 0.5 and a 1:2.75 ratio. A 30% cement substitute made with WGP was used to prepare the second mix, and a 30% cement substitute made with WBP was used to prepare the third mix. The fourth mixture was made using FAP as a substitute for some of the cement at 30%. The final three combinations all call for a cement-to-sand ratio of 1:2.75, a water-to-cement ratio of 0.3, and a superplasticizer concentration of 1.5 percent. In the second step, two green mortar mixes were poured. One mix, M1, had a 30% partial cement substitute (10% WGP + 10% WBP + 10% FAP), and the other mix, M2, had a 30% partial cement substitute (5% WGP + 15% WBP + 10% FAP). You

can find the exact ratios of the ingredients in Table 7.

Table 7: Proportions of each mix using different waste cementitious materials

Mixes	Cement Kg/m <sup>3</sup>	Sand Kg/m <sup>3</sup>	GP %	BP %	FP %	SP %	Water %	
M0	604	1661	---	---	---	1.5	0.3	
First Stage	FAP	422.8	1661	---	---	30	1.5	0.3
	WBP	422.8	1661	---	30	---	1.5	0.3
	WGP	422.8	1661	30	---	---	1.5	0.3
Second Stage	M1	422.8	1661	10	10	10	1.5	0.3
	M2	422.8	1661	5	15	10	1.5	0.3

**4.2 Mixing procedure**

For each batch of green mortar, the dry ingredients (cement, cementitious material, and sand) were measured out and mixed for two minutes until the mixture was uniform in texture. The amount of water and superplasticizer was calculated and weighted as a percentage of the weight of the binder materials. The superplasticizer was mixed very well with water and then added gradually to the dry ingredients and mixed very well. About 10 minutes was the whole time it took to combine everything. Immediately, after the green mortar mixtures were completed, as outlined in the flow table experiment, described in ASTM C1437 [21], was utilized in order to ascertain the capacities of the mixes to flow. It is important to point out that the mixing procedure was carried out by hand.

**5. CARRIED-OUT TESTS**

To check the behavior of the different mixes for the replacement of the waste cementitious materials and their impact on the results, many laboratory tests were carried out through this study to form a more comprehensive view of their effect on the compressive and flexural strength of the mortar mixes, with the aid of flowability, water absorption, and density. Three specimens were prepared under the same conditions and tested for each mixture.

**5.1 FLOWABILITY**

A flow table test, a method for assessing how well mortars flow, was used to determine their flowability. It was conducted in accordance with

ASTM C1437 [21] and shown in Figure 3. The flow table was moistened, then the cone was put in the center point of the flow table and started filling with fresh mortar in two equivalent layers, each layer was stroked 20 times with a tamping rod, and waited 30 seconds before being raised. The cone was raised to allow the mortar to spread, the diameter of the spread of the mortar was measured, and the flow% was calculated using Eq. (1).

$$\text{Flow}(\%) = \left[ \frac{(D - D_o)}{D_o} \right] \times 100 \quad \dots\dots\dots(1)$$

Where:

D: Average of three readings of flow diameter in millimeters.

D<sub>o</sub>: The diameter of the inside base of the slump cone in millimeters.



Figure 3: Flow table test

**5.2 Compressive Strength**

The compressive strength of hardened green mortar was tested using a cube (50\*50\*50) mm according to ASTM C109 [22] as shown in Figure 4. The test was conducted at different ages (7 and 28 days) by using a uniaxial testing machine. Eq. (2) was used to determine the compressive strength of the mixes.

$$f_{cu} = \frac{P}{A} \quad \dots\dots\dots(2)$$

Where:

f<sub>cu</sub>: Denotes the compressive strength (MPa).

P: Maximum applied load (N).

A: Cross-sectional area of the cube. (mm<sup>2</sup>)



Figure 4: compressive strength testing of the green mortar

**5.3 Flexural Strength (Modulus of Rupture)**

To find the flexural strength of hardened green mortar and GRPC, the prism (40\*40\*160)

mm was used according to ASTM C348 [23] as shown in Figure 5. The flexural strength was determined using Eq. (3).

$$\sigma = \frac{3PL}{2bd^2} \quad \dots\dots\dots(3)$$

Where:

σ: Flexural strength (MPa).

P: Maximum load on prism (N).

L: Clear length of prism span (mm).

b: average prism width at the rupture (mm).

d: average prism depth at the rupture (mm).



Figure 5: Flexural strength testing of the green mortar

**5.4 Water absorption**

The water absorption of green mortar was determined by using a cube (100\*100\*100) mm as shown in Figure 6 according to ASTM C642 [24]. Eq. (4) was used to determine the water absorption.

$$\text{Water absorption \%} = \left[ \frac{(W_B - W_A)}{W_A} \right] \times 100 \quad \dots(4)$$

Where:

W<sub>B</sub>: surface dry specimen's weight after soaking (in air) (g),

W<sub>A</sub>: mass of oven-dried specimen (in air) (g).



Samples in water



Samples in an oven

Figure 6: water absorption test of green mortar

**5.5 Density**

The dry density of (100\*100\*100) mm cubes were determined according to ASTM C642 [24] as shown in Figure 7. Eq. (5) was used to determine the bulk density.

$$\rho_B = \left[ \frac{W_B}{(W_H - W_W)} \right] \times \rho \quad \dots\dots\dots(5)$$

Where:

- $\rho_B$ : Bulk density after immersion value, kg/m<sup>3</sup>.
- $W_B$ : surface dry specimen's weight after soaking (in air) (kg).
- $W_H$ : surface dry specimen's weight after soaking and boiling (in air) (kg).
- $W_W$ : the apparent mass of specimen in water (kg).
- $\rho$ : the density of water = 1000 kg/cm<sup>3</sup>.



Figure 7: density test of green mortar

**6. RESULTS AND DISCUSSIONS**

Six mixes of mortars [reference], [30% Waste Glass Powder (WGP)], [30% Waste Brick Powder (WBP)], [30% Fly Ash Powder (FAP)], [30% (10%WGP+ 10% WBP+ 10% (FAP))], [30% (5%WGP+15% WBP+10% (FAP))] were prepared and tested for their compressive and flexural strength.

Table 8, Figure 8, and Figure 9 demonstrate the replacement of the different waste cementitious materials used in this study on the compressive and flexural strength. The same effect, observed in both tests, can be seen when changing the waste material. The fly ash gave almost the same compressive and flexural strength as the reference mix, especially at 28 days of age. Meanwhile, the glass powder replacement has the greatest effect on the compressive and flexural strengths of the hardened green mortar, reducing them by more than 50%. The decline in compressive strengths is attributable to an approximate 30% rise in cement substitution. The diminished performance is attributed to reduced reactivity of WGP and WBP particles, insufficient hydration of the cement, and alkali leaching from glass particles. Furthermore, there is restricted adhesion at the interface between cement and particles [25-26]. A reasonable reduction in strength was witnessed by the mix M1; the green mortar loses only 30 % of its strength using the combination of this mix. The enhancement of cement hydration by FAP, WGB, and WBP

occurs through their reactions with compounds such as silicates and aluminates, thereby facilitating the formation of dense hydration products, such as calcium-silicate-hydrate (C-S-H). This process reduces larger pores to smaller ones, as a significant quantity of hydration products occupies the initial pore structure, thereby improving the concrete matrix and contributing to strength performance [3], [27-29].

Table 8: Compressive and flexural strength of green mortar

Mixes	comp.st. (MPa) (7 days)	AV.	% Change from M0	comp.st. (MPa) (28 days)	AV.	% Change from M0	Flex. St. (MPa) (28 Days)	AV.	% Change from M0
M0	24.777	25.27	0.0	32.810	33.37	0.0	7.704	7.6	0.0
	25.074			33.902			7.213		
	25.959			33.398			7.883		
FAP	22.853	22.2	12	31.780	32.01	4	7.346	7.36	3
	21.964			31.918			7.251		
	21.784			32.332			7.483		
WBP	20.903	21.14	16	27.93	28.45	15	6.584	6.54	14
	21.45			28.776			6.572		
	21.067			28.645			6.487		
WGP	9.01	9.32	63	15.031	14.4	57	3.67	3.82	50
	9.422			14.369			3.871		
	9.528			13.801			3.914		
M1	14.59	14.65	42	24	23.45	30	5.731	5.42	29
	14.721			23.031			5.3		
	14.637			23.32			5.23		
M2	19.1	18.88	25	30.329	30.21	9	5.92	6.13	19
	18.251			29.899			6		
	19.28			30.403			6.46		

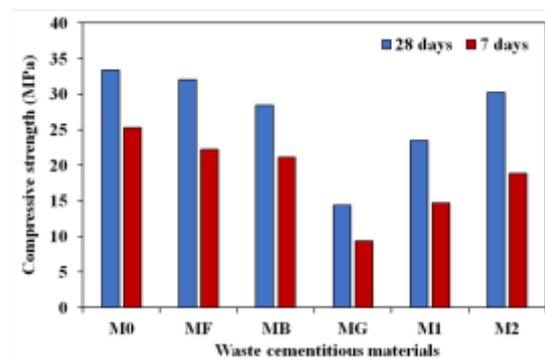


Figure 8 Compressive strength of different waste cementitious materials

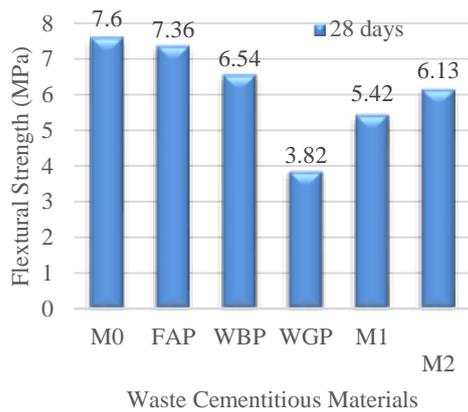


Figure 9 Flexural Strength of different waste cementitious materials

Table 9, Figure 10, and Figure 11 show the effect of the waste cementitious materials replacement on the density and water absorption of the green mortar. Again, using fly ash had the least effect on the density of the green mortar, while the glass powder reduced the density by about 9%. This agrees with the research [32]. On the contrary, the water absorption of the mortar had witnessed an increased behavior using glass powder than using the fly ash replacement. As long as the glass powder replacement had a greater effect than the fly ash replacement, this behavior was reflected in the strength activity index for the different mixes (with the same mix proportion) at both stage 1 & 2, as shown in Table 3.

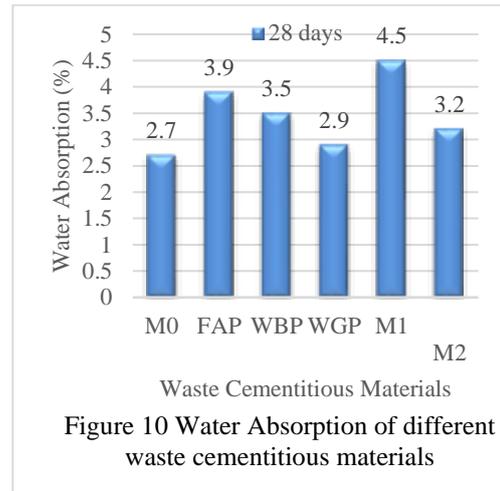


Figure 10 Water Absorption of different waste cementitious materials

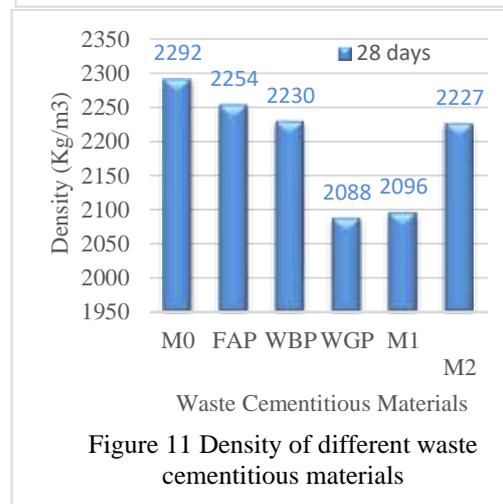


Figure 11 Density of different waste cementitious materials

Table 9: Density and water absorption of green mortar

Mixes	Density (Kg/m3) (28 days)	AV.	% Change from M0	water absorption (%) (28 days)	AV.	% Change from M0
M0	2281	2292	0.0	2.785	2.7	0.0
	2310			2.51		
	2285			2.80		
FAP	2272	2254	2	3.924	3.9	-44
	2230			3.83		
	2260			3.949		
WBP	2228	2230	3	3.4	3.5	-30
	2235			3.382		
	2227			3.628		
WGP	2092	2088	9	2.85	2.9	-7
	2085			3		
	2087			2.851		
M1	2102	2096	9	4.427	4.5	-67
	2092			4.59		
	2093			4.482		
M2	2225	2227	3	2.999	3.2	-19
	2226			3.425		
	2230			3.1		

From the previous studies, the Cement Mortar with compressive strength of (10-25) MPa and density of (2000-2200) Kg/m3 can be used in building works, plastering, flooring, screeds, and structural repair [31-33]. In addition, Sustainable (Eco-friendly) Mortar with compressive strength of (8–25) MPa and density of (1600–2200) Kg/m3 can be used in green buildings, non-structural elements, plastering, and blocks [34-36]. In this study, the results of compressive strength ranged between (14.4 to 32.01) MPa; therefore, this mortar can be used as cement mortar or as Sustainable (Eco-friendly) Mortar.

7. CONCLUSIONS

1. The waste glass powder, waste brick powder, and Fly Ash Powder have pozzolanic properties and can be used as cement substitutes. The Fly Ash Powder gives a higher SAI than the waste glass powder, followed by the waste brick powder.
2. Green mortar containing 30% Fly Ash Powder gives higher values of compressive strength, density, and flexural strength than waste brick powder.
3. The compressive strength of mortars after replacing cement with 30% waste materials,

ranging from (14.4 to 32.01) MPa, and this mortar can be used either for plastering, flooring, screeds, and structural repair or in green buildings, non-structural elements, plastering, and blocks.

4. The mix with a partial cement substitute (30%) (5% WGP +15% WBP +10% FAP) (M2) for green mortar gives higher compressive strength, density, and flexural strength than M1.

**RECOMMENDATION**

Building mortars can be used across many construction sectors, including plastering, flooring, screeds, structural repair, and blocks. Furthermore, in recent years, mortars have been used in 3D printing, ferrocement, and ultra-high-performance concrete; therefore, many studies should be conducted to enhance the properties of mortar.

**References**

[1] R. Kajaste and M. Hurme, "Cement industry greenhouse gas emissions – management options and abatement cost," *J. Clean. Prod.*, vol. 112, pp. 4041–4052, Jan. 2016, doi: 10.1016/j.jclepro.2015.07.055.

[2] K. L. Scrivener, V. M. John, and E. M. Gartner, "Eco-efficient cements: Potential economically viable solutions for a low-CO2 cement-based materials industry," *Cem. Concr. Res.*, vol. 114, pp. 2–26, Dec. 2018, doi: 10.1016/j.cemconres.2018.03.015.

[3] A. M. Mizaal, E. T. Dawood, and R. S. Fakhri, "Behavior of green reactive powder concrete exposed to aggressive solutions," *Innov. Infrastruct. Solut.*, vol. 9, no. 10, 2024, doi: 10.1007/s41062-024-01666-4.

[4] M. Mohit and Y. Sharifi, "Ceramic Waste Powder as Alternative Mortar-Based Cementitious Materials," *ACI Mater. J.*, vol. 116, no. 6, Nov. 2019, doi: 10.14359/51716819.

[5] M. Samadi *et al.*, "Waste ceramic as low cost and eco-friendly materials in the production of sustainable mortars," *J. Clean. Prod.*, vol. 266, p. 121825, Sep. 2020, doi: 10.1016/j.jclepro.2020.121825.

[6] D. Shri and K. Dhivya, "Experimental study on the effect of partial replacement of cement by using glass powder and fly ash in concrete," *Pakistan J. Biotechnol.*, vol. 14, pp. 507–510, 2017.

[7] A. M. Pitarch *et al.*, "Pozzolanic activity of tiles, bricks and ceramic sanitary-ware in eco-friendly Portland blended cements," *J. Clean. Prod.*, vol. 279, p. 123713, Jan. 2021, doi: 10.1016/j.jclepro.2020.123713.

[8] M. H. Dheyaldin, M. A. Mosaberpanah, J. Shi, and R. Alzebaree, "The effects of nanomaterials on the characteristics of aluminosilicate-based geopolymer composites: A critical review," *J. Build. Eng.*, vol. 73, p. 106713, Aug. 2023, doi: 10.1016/j.jobe.2023.106713.

[9] L. Li, W. Liu, Q. You, M. Chen, and Q. Zeng,

"Waste ceramic powder as a pozzolanic supplementary filler of cement for developing sustainable building materials," *J. Clean. Prod.*, vol. 259, p. 120853, Jun. 2020, doi: 10.1016/j.jclepro.2020.120853.

[10] J. Shao, J. Gao, Y. Zhao, and X. Chen, "Study on the pozzolanic reaction of clay brick powder in blended cement pastes," *Constr. Build. Mater.*, vol. 213, pp. 209–215, Jul. 2019, doi: 10.1016/j.conbuildmat.2019.03.307.

[11] N. H. A. S. Lim, H. Mohammadhosseini, M. M. Tahir, M. Samadi, and A. R. M. Sam, "Microstructure and Strength Properties of Mortar Containing Waste Ceramic Nanoparticles," *Arab. J. Sci. Eng.*, vol. 43, no. 10, pp. 5305–5313, Feb. 2018, doi: 10.1007/s13369-018-3154-x.

[12] S. Nahi, N. Leklou, A. Khelidj, M. N. Oudjit, and A. Zenati, "Properties of cement pastes and mortars containing recycled green glass powder," *Constr. Build. Mater.*, vol. 262, p. 120875, Nov. 2020, doi: 10.1016/j.conbuildmat.2020.120875.

[13] G. Vijayakumar, H. Vishaliny, and D. Govindarajulu, "Studies on Glass Powder as Partial Replacement of Cement in Concrete Production," *Int. J. Emerg. Technol. Adv. Eng.*, 2013, url={<https://api.semanticscholar.org/CorpusID:15918891>}

[14] S. Hsu, M. Chi, and R. Huang, "Effect of fineness and replacement ratio of ground fly ash on properties of blended cement mortar," *Constr. Build. Mater.*, vol. 176, pp. 250–258, 2018, doi: <https://doi.org/10.1016/j.conbuildmat.2018.05.060>.

[15] Y. K. Cho, S. H. Jung, and Y. C. Choi, "Effects of chemical composition of fly ash on compressive strength of fly ash cement mortar," *Constr. Build. Mater.*, vol. 204, pp. 255–264, 2019, doi: <https://doi.org/10.1016/j.conbuildmat.2019.01.208>.

[16] Y. Zhao, J. Gao, C. Liu, X. Chen, and Z. Xu, "The particle-size effect of waste clay brick powder on its pozzolanic activity and properties of blended cement," *J. Clean. Prod.*, vol. 242, p. 118521, 2020, doi: <https://doi.org/10.1016/j.jclepro.2019.118521>.

[17] G. Liu, M. Florea, and H. J. H. Brouwers, "Characterization and performance of high volume recycled waste glass and ground granulated blast furnace slag or fly ash blended mortars," *J. Clean. Prod.*, vol. 235, Jul. 2019, doi: 10.1016/j.jclepro.2019.06.334.

[18] R. Tremaño, T. Real-Herraiz, V. Letelier G., and J. Ortega, "Microstructure and mechanical properties of ternary mortars with brick powder, glass powder, slag, fly ash, and limestone," *Int. J. Appl. Ceram. Technol.*, vol. 19, Feb. 2022, doi: 10.1111/ijac.14012.

[19] B. O. Rabiou and M. A. Mosaberpanah, "Sustainable Utilization of Waste Glass Powder and Brick Dust as Cement Replacements:

- Effects on Mortar Performance and Environmental Benefits," *Sustainability*, vol. 17, no. 3, pp 1-31, 2025, doi: 10.3390/su17031298.
- [20] ASTM-C311-11, "Standard Test Methods for Sampling and Testing Coal Ash or Natural Pozzolans for Use in Concrete," *Annu. B. ASTM Stand. Am. Soc. Test. Mater.*, vol. 4, no. 8, p. 11, 2019. DOI: 10.1520/C0311\_C0311M-24
- [21] ASTM C1437, "Standard, A., C1437," *Astm C1437*, pp. 15–16, 2009, [Online]. Available: [www.astm.org](http://www.astm.org)
- [22] I. C, "Compressive Strength of Hydraulic Cement Mortars (C 109)," *Eng. Concr.*, pp. 29–31, 2009, DOI: 10.1520/C0109\_C0109M-24.
- [23] ASTM, "ASTM C348: Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars," *Annu. B. ASTM Stand.*, pp. 1–5, 2021, [Online]. Available: [www.astm.org](http://www.astm.org)
- [24] "Test Method for Density, Absorption, and Voids in Hardened Concrete," Dec. 15, 2021, *ASTM International, West Conshohocken, PA*. doi: 10.1520/C0642-21.
- [25] A. N. a A. A. Belkadi a, O. Kessal a, A. Berkouche a and T. T. S. E. Daguiani b, M. Dridi c, S. Benaniba d, e, "Experimental investigation into the potential of recycled concrete and waste glass powders for improving the sustainability and performance of cement mortars properties.", *ELSEVIER*, vol. 64, April 2024, <https://doi.org/10.1016/j.seta.2024.103710> Get rights and content
- [26] O. Y. Bayraktar, "Possibilities of disposing silica fume and waste glass powder, which are environmental wastes, by using as a substitute for Portland cement," *Environ. Sci. Pollut. Res.*, vol. 28, no. 13, pp. 16843–16854, 2021, doi: 10.1007/s11356-020-12195-9.
- [27] M. O. Mohsen *et al.*, "Fly Ash and Natural Pozzolana Impacts on Sustainable Concrete Permeability and Mechanical Properties," *Buildings*, vol. 13, no. 8, p. 1927, Jul. 2023, doi: 10.3390/buildings13081927.
- [28] H. M. Hamada, F. Abed, Z. A. Al-Sadoon, and A. Alashkar, "Enhancing pozzolanic activity of fly ash via dry and wet milling: A comparative study for sustainable construction material enhancement," *J. CO2 Util.*, vol. 83, p. 102811, May 2024, doi: 10.1016/j.jcou.2024.102811.
- [29] E. T. Dawood and A. M. Mizaal, "Proportioning of green mortar by using different cementitious materials," *J. Phys. Conf. Ser.*, vol. 1973, no. 1, 2021, doi: 10.1088/1742-6596/1973/1/012004.
- [30] O. Nasry *et al.*, "Thermophysical Properties of Cement Mortar Containing Waste Glass Powder," *Crystals*, vol. 11, no. 5, p. 488, Apr. 2021, doi: 10.3390/cryst11050488.
- [31] P. Shafiqh, I. Asadi, A. R. Akhiani, N. B. Mahyuddin, and M. Hashemi, "Thermal properties of cement mortar with different mix proportions," vol. 70, no. 339, pp. 1–12, 2020.
- [32] L. Di Maio, B. Coppola, L. Courard, F. Michel, L. Incarnato, and P. Scarfato, "Data on thermal conductivity, water vapour permeability and water absorption of a cementitious mortar containing end-of-waste plastic aggregates," *ELSEVIER.*, vol. 18, pp. 1057–1063, 2018, doi: <https://doi.org/10.1016/j.dib.2018.03.128>.
- [33] "Adam M. Neville, J. J. Brooks-Concrete technology-Longman Scientific & Technical, Second edition, (2010)."
- [34] Y. Senhadji *et al.*, "Physical, mechanical and thermal properties of lightweight composite mortars containing recycled polyvinyl chloride," *Constr. Build. Mater.*, vol. 195, pp. 198–207, 2019, doi: <https://doi.org/10.1016/j.conbuildmat.2018.11.070>.
- [35] Y. Ghernouti and B. Rabehi, "Strength and Durability of Mortar Made with Plastics Bag Waste (MPBW)," *Int. J. Concr. Struct. Mater.*, vol. 6, no. 3, pp. 145–153, 2012, doi: 10.1007/s40069-012-0013-0.
- [36] B. S. Thomas and R. C. Gupta, "A comprehensive review on the applications of waste tire rubber in cement concrete," *Renew. Sustain. Energy Rev.*, vol. 54, pp. 1323–1333, 2016, doi: <https://doi.org/10.1016/j.rser.2015.10.092>.