Proportioning of green mortar by using different cementitious materials

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Abstract. Pozzolanic materials are used extensively at the present time due to their availability in large quantities, especially materials that are considered waste from construction works and industrial waste. In this research, various pozzolanic materials were used, such as glass powder, ceramic powder, and brick powder, seven mortar mixes (M, M1, M2, M3, M4, M5 and M6). This research has been prepared and focuses on the impact of using these materials in mortars as cement replacement. M1, M2, M3 The cement was replaced as 30, 35, 40% by glass powder and ceramic powder (10% glass with 20, 25 and 30% ceramic powder) by weight of cement. M4, M5, M6 was replaced as 30, 35, 40% by glass powder and brick powder (10% glass with 20, 25, 30% brick powder) the cement by weight. The specimens were cast in a cube of 50 x 50 x 50 mm and the water curing regime was applied until the testing age. The fineness of the powder used in glass, ceramics and bricks is less than 45μm. Changes in compressive intensity for both samples have been examined. The optimal replacement that provided the better strength was found to be 40 percent replacement (10% glass with 30% brick powder).

Keyword: green mortar, cementitious materials, glass powder, ceramic waste powder, brick waste powder.

1. Introduction:
Pozzolanic materials have now been used as building material, in particular for their effect on the improvement of concrete microstructure and durability. [1]Natural resource demand has risen dramatically, which puts tremendous strain on the ecosystem. As an organic commodity, the word" green cement" takes its place. It refers to the use of new materials that can partially substitute cement in concrete without reducing its mechanical properties and durability. It is therefore a goal of replacing cement that needs to be done for sustainability. [2]Many researchers have studied different types of cementitious materials, Pitarch. et al.,2021, [3] Using 3 different types of ceramic waste: red clay bricks (RCB), ceramic tiles (CTW) and ceramic sanitary-ware (CSW), the pozzolanic activity of tiles, bricks and ceramic sanitary-ware was studied in eco-friendly Portland blended cements . Each was used to substitute
0 to 50 wt. percent Portland cement PC. This research shows that the pozzolanic reaction materials improved with healing time, and all mortars prepared with up to 25 wt. RCB, CTW or CSW percent met the mechanical requirements for coal fly ashes, regardless of the form of ceramic waste used. These findings open up the possibility of partially replacing PCs with the ceramic waste available nearby, which would minimize CO2 emissions. Mohammad, et al. 2020, [4] studied impact of waste ceramics such as cement and fine aggregates on the efficiency of sustainable mortar for durability. The strength and durability properties of a mortar, including ceramic waste powder as an additional cementing material and ceramic particles, were examined in this report. Ordinary Portland cement (OPC) was replaced by 40 percent ceramic powder and the natural river sand was replaced by 100 percent fine ceramic aggregates. The findings showed that the mechanical behavior of the ceramic mortar compared to that of the OPC mortar was relatively stronger. In addition, relative to OPC mortar, the maximum improvement in compressive and splitting tensile strength was obtained by replacing 40 percent of OPC with ceramic powder and 100 percent of the fine natural aggregate with fine aggregate waste ceramic. Mohit et al., 2019, [5] studied Ceramic waste powder (CWP) as alternative mortar-based cementitious material. The cement was replaced by 5, 10, 15, 20, and 25% of CWP. The results obtained indicate that the sample containing 10% CWP as cement replacement had the highest strength. Chen et al., 2020, [6] The waste ceramic powder was studied as a pozzolanic supplementary cement filler for the development of sustainable building materials using a type of micro ceramic powder with an average size of up to 3.5 μm produced from ceramic waste and up to 40 percent cement was replaced to modify the microstructure and mechanical properties of the cement materials. The results indicate that the mortars have an ultimate compressive strength of more than 80 MPa and a bending strength of approximately 10 MPa.

Samadi, M. et al., 2020, [7] studied ground ceramic (GC) as low cost and eco-friendly materials in the fabrication of sustainable mortars. The cement was replaced by (0, 10, 20, 30, 40, 50 and 60% of GC. The findings of this study show that the use of ceramic waste as both a binder and a fine aggregate source greatly increased the mortar's compressive strength and offered greater resistance to the negative impact of environmental conditions. Shao, J. et al., 2019, [8], Recycled clay brick powder (CBP) from waste clay bricks was used to partially substitute cement to prepare cement pastes or mortars as an additional cement material. The cement was replaced by (B0, 10, 20, 30, 40, and 50 % of CBP. The findings showed that with the replacement level of CBP rising at an early age, the compressive strength of mortars containing clay brick powder decreased regularly However, at the later curing time, the compressive strength of mortars steadily developed and the mortar contained 20% reached the maximum compressive strength of 62.2 MPa at 90 days. Lim, N. H. et. al., 2018, [9] The special effects of waste ceramic powder on the mechanical and microstructural properties of the mortar have been studied. Four mixes (0,20, 40 and 60 percent) containing ceramic nanoparticles were prepared. For compressive strength, the mortar samples were checked The results showed that the mortar showed better performance in terms of C-S-H output from active silica containing excessive calcium hydroxide content with 40% ceramic replacement. Nahi, S., et. al., 2020, [10] The properties of cement pastes and mortars that cover recycled green glass powder have been studied. Various cement replacement rates are used by weight: 0 percent, 10 percent, 25 percent, 35 percent and 60 percent. The findings show that the quantity of glass powder substitution for cement plays a critical role in deciding the properties of the mortar. Chemical shrinkage and heat evaluation indicate that high cement paste replacement of glass powder increases the rate of hydration reaction. With increasing glass powder content, particularly for mortar made with 60 percent glass powder, compressive strength and dynamic Young's and shear moduli values decrease.
As a partial replacement of cement in concrete manufacturing, a glass powder was examined. Glass powder has been partly substituted by 10 percent, 20 percent, 30 percent and 40 percent and has been compared with standard concrete for its compressive, tensile and flexural strength up to 60 days of age and demonstrates that the glass powder concrete effectively improves the compressive, tensile and flexural strength, when compared with conventional concrete.

2. Experimental program:

2.1 materials

2.1.1 Cement: the cement used was Ordinary Portland Cement (OPC) according to ASTM C150 specification of OPC. The commercial name of cement is badush as shown in Table 1

Table 1 the properties of cement badush from the factory in XRD ray.

| Compound | Percent% |
|----------|----------|
| MgO      | 3.777    |
| Al₂O₃    | 5.991    |
| SiO₂     | 20.991   |
| SO₃      | 1.589    |
| CaO      | 63.283   |
| Fe₂O₃    | 2.587    |

2.1.2 Fine aggregate: the fine sand was river sand (kanhash) after preparing it with a maximum aggregate size of 1.18 mm, and should be clean, without impurities. The bulk specific gravity is 2.48, bulk specific gravity (S.S.D) is 2.54, apparent specific gravity is 2.64, and absorption is 2.46%. The sand satisfied the limit of Iraq standard specification No. 45/1984. Table 2 shows the sieve analysis of the sand.

Table 2 the sieve analysis of the sand.

| Sieve size(ASTM) | Wt. of agg. Retained on sieve (gm) | (%) retained on each sieve | Cumulative (%) retained on each sieve | Cumulative passing on each sieve (%) |
|------------------|-----------------------------------|---------------------------|--------------------------------------|-------------------------------------|
| NO.4             | 76                                | 14.79                     | 14.79                                | 85.21                               |
| NO.8             | 58                                | 11.28                     | 26.07                                | 73.93                               |
| NO.16            | 50                                | 9.73                      | 35.8                                 | 64.2                                |
| NO.30            | 81                                | 15.76                     | 51.56                                | 48.44                               |
| NO.50            | 175                               | 34.05                     | 85.61                                | 14.39                               |
| NO.100           | 58                                | 11.28                     | 96.89                                | 3.11                                |
| PAN              | 16                                | 3.11                      | 100                                  | -----                               |
| TOTAL            | 514                               |                           | 310.72                               | -----                               |
2.1.3 Cementitious materials: In manufactured products, such as glass sheets, bottles, glassware, vacuum tubing, etc., crushed glass powder (GP) glass is widely used. The amount of crushed waste glass from the local landfill site in Mosul, Iraq, construction work, was collected. The glass was crushed and sieved into powder to obtain particle sizes smaller than 45 mm. Crushed ceramic powder (CP) was gained from construction work, Mosul, Iraq. Crushed brick powder (BP) was gained from construction work, industrial waste, Mosul, Iraq. The chemical and physical properties of these materials are shown in table 3, 4 and 5.

Table 3 The chemical and physical properties of the ceramic powder.

| Materials | CP          |
|-----------|-------------|
| SiO₂      | 72.64       |
| Al₂O₃     | 12.23       |
| CaO       | 0.02        |
| Fe₂O₃     | 0.56        |
| Na₂O      | 13.46       |
| MgO       | 0.99        |
| K₂O       | 0.03        |
| Loss on ignition (LOI) | 0.13        |
| Specific gravity | 2.61       |
| Surface area-BET (m²/g) | 12.2        |

Table 4 The chemical and physical properties of the glass powder.

| Materials | GP          |
|-----------|-------------|
| SiO₂      | 72.71       |
| Al₂O₃     | 1.487       |
| CaO       | 11.940      |
| Fe₂O₃     | 1.168       |
| Na₂O+ K₂O | 8.906       |
| MgO       | 1.480       |
| Specific gravity | 2.315   |
| Blaine fineness (cm²/gm) | 12.2        |

Table 5 The chemical properties of the brick powder.

| Materials | BP          |
|-----------|-------------|
| SiO₂      | 49.9        |
| Al₂O₃     | 16.6        |
| CaO       | 9.7         |
| Fe₂O₃     | 6.5         |
| MgO       | 5.5         |
| K₂O       | 4.4         |
| Loss on ignition (LOI) | 2.4        |
2.1.4 Super plasticizer: Flocrete SP42 complies with ASTM C494, Type B, D and G, depending on dosage used. With specifications as shown in Table 6

Table 6 the specifications of flocrete SP42.

|                  | Brown liquid        |
|------------------|---------------------|
| Color            | Brown liquid        |
| Freezing point   | -2°C                |
| Specific gravity | 1.22 ±0.02          |
| Chloride content:BS5075 | Nil            |
| Air entrainment  | Typically less than 2%additional air is entrained above control mix at normal dosages |

2.1.5 Water: Water used in all mixes was Tap water cleaned from impurities and organic matter with a temperature of 26°C.

2.2 Experimental work and test

2.2.1 Poured seven mixes of mortar in this research, the first mix was a reference (M) with a mix proportion of 1: 2.75 (cement: fine aggregate) with water / cement ratio 0.5. The second blend was prepared with a partial cement substitute (30%) by using (10% glass powder with 20% ceramic powder)(M1). The third mix was prepared by a partial replacement of cement (30%) by using (10% glass powder with 20% brick powder)(M2) The forth mix was Prepared by means of partial cement replacement (35%) by using (10% glass powder with 25% ceramic powder)(M3). The fifth mix was prepared by a partial replacement of cement (35%) by using (10% glass powder with 25% brick powder)(M4). The sixth mix was prepared by a partial replacement of cement (40%) by using (10% glass powder with 30% ceramic powder)(M5). The seventh mix was prepared by a partial replacement of cement (40%) by using (10% glass powder with 30% brick powder)(M6). All (M1,M2,M3,M4,M5,M6) with a mix proportion of 1: 2.75 (cement: fine aggregate) with water / cement ratio 0.4 and 1.5% supper plasticizer. The details of all the mixes used in the study are shown in Table 7.

Table 7 the details of all the mixes used in the study.

| Mixes | Cement (gm) | Sand (gm) | Water (gm) | Glass powder (gm) | Ceramic powder (gm) | Brick powder (gm) | Super% |
|-------|-------------|-----------|------------|-------------------|---------------------|-------------------|--------|
| M     | 1100        | 3023      | 550        | 0                 | 0                   | 0                 | 0      |
| M1    | 770         | 3023      | 423.5      | 110               | 220                 | 0                 | 1.5    |
| M2    | 770         | 3023      | 423.5      | 110               | 0                   | 220               | 1.5    |
| M3    | 715         | 3023      | 423.5      | 110               | 275                 | 0                 | 1.5    |
| M4    | 715         | 3023      | 423.5      | 110               | 0                   | 275               | 1.5    |
| M5    | 660         | 3023      | 423.5      | 110               | 330                 | 0                 | 1.5    |
| M6    | 660         | 3023      | 423.5      | 110               | 0                   | 330               | 1.5    |
2.2.2 Testing of specimen

2.2.2.1 Strength activity index (SAI)
To estimate the activity of the materials used, the activity index test was used [20% replacement ratio with any materials used such as (glass, ceramic, brick) powder according to ASTM C311 [12]]. The SAI for 7 days was more than 75%.

2.2.2.2 Mortar workability
The workability of fresh mortars was examined by a flow table test, a method used to evaluate the flow of fresh mortars. It was carried out based the requirements of ASTM C1437 [13].

2.2.2.3 Compressive strength test
Using 50* 50* 50 cm cubes, compression tests were performed according to ASTM C 109 [14] at ages 7 and 28 days. For each mixture, six samples were tested; three at 7 days, and three at 28 days, and the results were recorded.

2.2.2.4 Flexural strength tests
The test method was followed by ASTM C348[15] on the 40*40*160 mm hardened mortar sample, where the load is always applied to the center using the loading nose at three bending points at a defined rate until failure.

2.2.2.5 Bulk density of mortar mixture
The bulk density of the mortar mix was calculated by calculating the small mortar mass of a known quantity. The bulk density of mortar mixture was determined following BS EN 1015-6.17 three different methods of merging mortar with the standardized container, which should have a volume of approximately 1 L, are given in the BS standard.

2.2.2.6 Ultrasonic pulse velocity
Ultrasonic pulse velocity (UPV) is a nondestructive experiment to assess the consistency and homogeneity of mortar specimens. This test was carried out based on the requirements of ASTM C597 - 02 [16]. The UPV test measures the transfer velocity of waves within the cement mortars.

3. Results and discussion:

3.1 Strength activity index (SAI)
The results of SAI for 7 days are shown in Table 8 (greater than 75% according to ASTM C618 [17]), which proved that the (glass, ceramic, brick) powder had the pozzolanic property. Therefore, these materials are suitable to use as a replacement for cement in mortar mixes.

| Mixes                | Strength activity index % |
|----------------------|---------------------------|
| Glass powder 20%     | 80.96                     |
| ceramic powder 20%   | 90.81                     |
| brick powder 20%     | 119.62                    |

3.2 Mortar workability
The results for flow ability (workability) of mortar cement are shown in ‘ Figure 1, 2’. The figure shows the flow ability of all mortar mixtures with different substitution ratios. The flow test results revealed that the mixes containing brick powder decreases the flow. The decrease in the flow measurement may be due to brick powder absorbs more water than others.
3.3 Compressive strength

Table 9 and Figure 3, 4 show, For 7 and 28 days, the compressive strength of mortar mixes. The results indicate that mixes containing ceramic powder give less resistance to compressive than the control mix (M), while mix containing brick powder give results close to control mix (M), with replacement rates of up to 40%.
Table 9 Compressive strength of a mortar mix for seven and 28 days.

| Mixes | Compressive strength (MPA)7day | Compressive strength (MPA)28day |
|-------|-------------------------------|-------------------------------|
| M     | 32.842                        | 44.946                        |
| M1    | 24.667                        | 42.504                        |
| M2    | 36.021                        | 45.972                        |
| M3    | 25.587                        | 37.549                        |
| M4    | 34.205                        | 44.822                        |
| M5    | 23.122                        | 37.242                        |
| M6    | 31.321                        | 44.866                        |

' Figure 4' For 7 and 28 days, the compressive strength of mortar mixes.

3.4 Flexural strength
The findings of the flexural strength test have been demonstrated in ‘ Figure 5,6’. The value obtained for 28 days showed that no considerable differences in flexural strength compared to the control mix. The result can be assigned to the activity index of CP, GP, BP

' Figure 5' Labrotary work for flexural strength.
3.5 Bulk density of mortar mixture

Table 10 shows the density of the cement mortar. From the table, it can be noted that with the reference density at zero replacement ratio was 2399 Kg/m³. The density decreased when the cement was replaced. The density of the mixes containing brick powder is more than the mixes of ceramic powder.

| Mixes | Density (kg/m³) |
|-------|----------------|
| M     | 2399           |
| M1    | 2257           |
| M2    | 2297           |
| M3    | 2204           |
| M4    | 2245           |
| M5    | 2168           |
| M6    | 2259           |

Figure 6: The flexural strength of the mixes.

Figure 7: The density of the cement mortar.
3.6 Ultrasonic pulse velocity

Table 11 & ‘Figure 8,9’ shows the Mortar ultrasonic pulse velocity values specimen’s after 28 days, from the result the values of mixes containing glass with brick powder gave higher velocity than mixes containing glass with ceramic powder.

‘Figure 8’ labrotary work for ultrasonic pulse velocity.

| mixes | Pulse velocity (km/sec) |
|-------|-------------------------|
| M     | 4.30                    |
| M1    | 4.27                    |
| M2    | 4.36                    |
| M3    | 4.23                    |
| M4    | 4.35                    |
| M5    | 4.21                    |
| M6    | 4.35                    |

‘Figure 9’ the UPV values of the mortar specimen’s after 28 days.
4. Conclusions:
The present paper presented the findings of the experiment on the mechanical properties of mortar specimens used as partial cement substitute for waste ceramics, glass and brick. The following results were concluded:
- The uses of waste ceramic, glass, and brick powder as cement replacement can be done because they are active materials.
- It is concluded the optimum replacement that gave the highest strength was a replacement of 40% (10% glass with 30% brick powder).

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