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Comparative Study of Sustainable Mortar Using Different Strength Indices

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Abstract: - Cement is the most effective construction material, but at the same time, it has a negative environmental impact. Therefore, researchers take such an impact seriously after decades of using various techniques. Massive waste accumulation has had a negative impact on both city elegance and human health. So it was necessary to employ crushed brick waste powder (CBWP) as supplemental cementitious materials (SCM) to reduce the waste bricks produced by the brick industry. Clay brick industry waste that has been fired can be obtained. This waste can be used for SCM, which minimizes industrial waste and protects natural resources. X-ray fluorescence (XRF) was used to analyze the chemical composition of (CBWP). The mortar testing program included: workability, compressive strength, the ultrasonic pulse velocity (UPV) test, compressive strength of portions of prisms, and flexural strength. Moreover, the cement mortar samples with 0%, 30%, 35%, and 40% replacing cement with CBWP were conducted to achieve the research aim. Results indicate that the chemical composition of the brick powder complies with the pozzolanic material requirements.

Furthermore, with 30% cement replacement, the compressive strength significantly improved; inversely, strength decreased as the CBWP percentage increased. Therefore, for mortar manufacturing of, it was advised to utilize no more than 30 percent of the CBWP used as a replacement for cement.

Keywords: Fresh properties, Hardened properties, Sustainable mortar, Waste clay bricks powder.

I. Introduction

Brick waste makes up a significant amount of the solid waste produced by construction and demolition projects worldwide, simultaneously, its disposal uses up more land and pollutes to the environment. On the other side, Cement acts as the main raw ingredient for cement-based products. Cement manufacture puts huge impact on environmental, because it uses resources and emits greenhouse gases. However, researchers would wide have conducted extensive investigation to use supplementary cementitious materials SCM to produce Green Cement. They tried wide range of waste and/or by product materials, such as Cement kiln dust, Pulverize fuel ash, rice husk ash, silica fume, leaves ash,…etc[1], [2]. Pozzolanic materials are currently used extensively due to their widespread availability in enormous quantities, especially those that are classified as building and construction waste[3].

Recently, clay brick waste powder CBWP is taken into consideration as a viable raw material replacement for Portland cement in cement-based products[4]. The utilization of CBWP not only frees up a lot of space from piled-up brick debris, but also lessens the need for the Portland cement used in the concrete industry. It can ensure the lifetime of building materials and advance wealth on a global scale[5].

Although cement is a strong adhesive and is frequently used in building, its production results in continually increasing CO_2 emissions. Therefore, cement manufacturers have concentrated on alternative binding materials to reduce CO_2 emissions. Currently, no alternative substance can meet cement's specifications, especially in term of cost. To find alternatives to cement as a replacement material in the construction industry, numerous studies have been conducted[6]. Through testing of workability and some mechanical features, the viability of using brick powder as a replacement for in part of cement in the mortar and concrete production has been established. [7].

Nevertheless, dehydroxylation takes place during the burning process of clay minerals, an amorphous material with high reactivity, leading to pozzolanic activity (the ability of reacting with water and calcium hydroxide to form hydration product compounds). As a result, CBWP might theoretically be used in cement-based materials,

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resulting in benefits for the environment by lowering waste that is rejected, and CO_2 emissions produced during cement manufacture can be reduced [8].

Larger amounts of C-S-H and C4AH13 are created as a result of the rapid interactions between the alumina and silica from calcined clay and the lime released from the cement, which enhance a variety of the finished mortar's or concrete's properties, including high strength and low permeability[9].

It has been found that CBWP is a pozzolanic compound[10]. In a study, researchers elaborated on the durability of mortars made from clay brick waste. They disclosed that a 40% replacement for cement by clay bricks had an increase in compressive strength. They blamed microscopic clay brick particles for the mortar's decreased pore structure[11].

Nevertheless, burned clay may not have pozzolanic activity. Feldspar and quartz are two common crystalline minerals found in clay. Clay cannot be categorized as a pozzolan as a result. However, the silicate's crystal structure frequently changes when the clay is heated to 600–1000°C, creating an irregular molecule that reacts with lime at ambient temperature[12]. Therefore, this research study is an attempt to sustain the current knowledge of the role that could be done by CBWP as a SCM, whereas three types of available (CBWP) were prepared for comparison purpose.

II. Materials and Methods

A. Base Materials

Cement, sand, water, three different types of crushed brick powder, and a superplasticizer make up the base material for casted specimens. The following definitions describe its characteristics and sources:

1) Ordinary Portland Cement (OPC), which has strong adhesive and cohesive qualities, is the most often used binder in the production of mortar. Locally, OPC (type I) was supplied from the Lafarge cement plant in the Karbala Governorate. The physical and chemical properties are shown in Tables (1) and (2) confirm that used OPC is satisfied the requirements of Iraqi Standard Specification "IQS: 5/2019" [13] and ASTM[14].

TABLE 1 LAFARGE OPC'S PHYSICAL CHARACTERISTICS

Test	Results	Limits of IQS: 5/2019[13]	Limits of ASTM C150[14]
Initial setting time	143	Min. 45 minute	Min. 45 minute
Final setting time	190	Max. 600 minute	Max. 375 minute
Fineness (Air Blain)	404	Min. 250 m^2/kg	Min. 260 m^2/kg
50 mm cubic mortar specimen Compressive strength 2 days 28 days	20	Min. 10 MPa	Min. 12 MPa
	43.3	Min. 42.5 MPa	Min. 19 MPa

TABLE 2 CHEMICAL COMPOSITION OF OPC

Basic ingredients	Component of OPC (%)	Limits of IQS 5/2019[13]	Limits of ASTM C150 [14]
Silicon dioxide (SiO_2)	21.6	-----	-----
Aluminium oxide (Al_2O_3)	4.92	-----	-----
Ferric oxide (Fe_2O_3)	3.25	-----	-----
Calcium oxide (CaO)	64.47	-----	-----
Magnesium oxide (MgO)	1.67	≤ 5 % max.	6 % max.
Sulfur tri oxide (SO_3)	2.45	2.8 % max.	3 % max.
Loss on ignition (LOI)	2.37	4 % max.	3 % max.
Insoluble residue	0.75	1.5 % max.	0.75 % max.
Free CaO	1.08	-----	-----
L.S.F.	----	0.66-1.02 %	-----
C3S	51.7	----	----
C2S	23.25	----	----
C3A	7.36	----	----
C4AF	11.33	----	----

2) Natural Silica Sand : It is used as fine aggregate, in accordance with ASTM C33[15]. The fineness modulus and specific gravity were 2.68 and 2.65, respectively, and the gradation curve was consistent with Zone II. Less than 4.75-mm-sized particles made up the fine aggregate. Table 3 contains the grade ranges.

TABLE 3 FINE AGGREGATE GRADING

Sieve No.(mm)	Passing (%)	Limits of ASTM C 33[15]	Limits of Iraqi Standard Specification No. 45:1984 (Zone2)
3⁄8-in. (9.5)	100	100	100
No.4 (4.75)	94	95-100	90-100
No.8 (2.36)	80	80-100	75-100
No.16 (1.18)	68	50-85	55-90
No.30 (0.6)	51	25-60	35-59
No.50 (0.3)	22	May-30	Aug-30
No.100 (0.15)	5	0-10	0-10
No.200 (0.075)	2.8	0-3	0-5
Chemical property			
SO_3 content %	Limits of Iraqi Standard Specification No. 45:1984		
0.20%	≤0.5%		

3) Crushed Brick Powder: Clay brick waste ground into fine particles passing through sieve No.325 (0.045mm), before utilized in mortar. Crushed Brick Powder has pozzolanic activity, resulting in a denser combination. In this study three CBWP with a physical and chemical properties shown in Tables 4 and 5, were selected as follow:

- Crushed Red Perforated Brick Powder (RPBP) which was manufactured recently in Sulaymaniyah Governorate in the north of Iraq.
- Crushed Yellow Perforated Brick powder (YPBP) From Al Nahrawan Area which is commonly used in the construction of buildings.
- Crushed Yellow Solid Brick Powder (YSBP) From Al Kut Governorate which is commonly used in construction of buildings.

TABLE 4 PHYSICAL PROPERTIES OF CBWP

Physical property	RPBP	YPBP	YSBP	Comparison with Cement requirements ASTM C618[16]
Specific gravity	2.37	2.41	2.44	---------
Fineness (Air Blain) m^2/kg	519	487	471	Min.260 kg/m^3
Colour	Red	Light yellow	Yellow	Gray

4) *Water*: Tap water is free of sulfates, acids, alkalis, oils, organic compounds, and hazardous substances used in the preparation of mortar mixes.

TABLE 5 *CHEMICAL COMPOSITION OF CLAY BRICK POWDER*

Chemical oxides %	RPBP	YPBP	YSBP	Comparison with ASTM C618 criteria
Silicon dioxide (SiO_2)	42.83	39.26	38.48	$\sum(SiO_2)$ +(Al_2O_3) +(Fe_2O_3) +(CaO) > 70%
Aluminium oxide (Al_2O_3)	14.63	10.59	11.21	
Ferric oxide (Fe_2O_3)	10.33	6.94	8.77	
Calcium oxide (CaO)	11.69	22.1	15.93	
Magnesium oxide (MgO)	4.75	4.93	6.44	5 % max

Sulfur tri oxide (SO_3)	0.035	0.42	0.57	4 % max
Sodium oxide (Na_2O)	0.1	0.23	0.29	
Loss of ignition (LOI)	3.63	3.82	3.95	10 % max
Insoluble residue %	0.37	0.41	0.52	1.5 % max

5) *Superplasticizer*: Hyperplast PC600 is a high-performance superplasticizing additive based on long-chain polycarboxylic polymers that is designed to enhance the water content of concrete's performance produced at DCP company. This effect can be utilized in, high-strength, flowable concrete mixes and low W/C ratio to achieve the maximum performance and durability in the ready-mix and precast concrete sectors. 0.5 to 2.5 liters of Hyperplast PC600 are recommended by manufacture per 100 kg of cementitious materials in the mixture. superplasticizer that complies with Type F and Type G standards of ASTM C494 [17].

B Experimental Program and Test Methods:

To achieve the research aim, different test methods in order to characterize the fresh and hard mortar characteristics were nominated. The studied properties and test methods tested in this research, curing period, the number of the specimens to be used per age, and dimensions of specimens are listed in Table 6. All the studied properties conform to ASTM requirements

C Mixing Composition

1 part of OPC and 2.75 parts of SSD sand were proportioned by mass in the mortar mixed. Before the materials mixed, they were weighed. The mixing done according to ASTM C109[19], where the cement and different three types of Crushed brick powder precents mixed severally (as Can be seen in Table 7), the superplasticizer was mixed and add with a part of the mixing water after the mixing of proportioned materials. The flow Test done according to ASTM C1437[18]. Within 24 hours, the molds were disassembled and cured for 7 and 28 according to ASTM C192 [23] , respectively. Standard testing techniques were followed when the specimens were tested in a compressive and flexural strength test machine (UTM).

TABLE 6 STANDARD TESTING METHODS AND THE EXPERIMENTAL PROGRAM

Studied Properties	Curing (Days)	No. of Samples Per Test	Specimens Dimensions	Standard Testing Method
Flow	After mixing	1	---	ASTM C1437 [18]
Compressive Strength	7, 28	3	50x50x50 mm	ASTM C 109 [19]
Ultrasonic pulse velocity	7, 28	3	40x40x160 mm	ASTM C 597 [20]
Broken beam compressive strength (portion of prisms)	7, 28	3	70x70x70 mm	ASTM C 349 [21]
Flexural Strength	7, 28	3	40x40x160 mm	ASTM C 348 [22]

TABLE 7 MATERIALS COMPOSITION AND FLOW OF MORTAR

Mixes	Replacement Percent from Cement %	RPBP %	YPBP %	YSBP %	Water/ Binder %	Water %	Superplasticizer %	Flow% (110±5)
M0	Nill	------	------	-------	51	51	Nill	110
M1	30	13	8.5	8.5	35	34.25	0.75	111
M2	30	8.5	10.75	10.75	35	34.25	0.75	107
M3	30	8.5	13	8.5	35	34.25	0.75	108
M4	35	15	10	10	35	34.2	0.8	112
M5	35	10	12.5	12.5	35	34.2	0.8	110
M6	35	10	15	10	35	34.2	0.8	109
M7	40	17	11.5	11.5	35	34.15	0.85	110
M8	40	11.5	14.25	14.25	35	34.15	0.85	110
M9	40	11.5	17	11.5	35	34.15	0.85	109

III RESULTS AND DISCUSSION

A Compressive Strength

Compressive strength testing was done in accordance with ASTM C109/C109M [19] for (7, 28) days. Table 8 explains the (7, 28) days compressive strength of mortar for the mixtures (M0-M9). The relative compressive strength of mortar provided throughout (7,28) days shown in Figure 1.

TABLE 8 (7,28) DAYS COMPRESSIVE STRENGTH

Mixes	Compressive Strength after 7 Days (N/mm2)	Compressive Strength after 28 Days (N/mm2)
M0	27.45	35.71
M1	35.2	41.92
M2	36.4	47.38
M3	32.8	43.63
M4	31.3	40.54
M5	33.1	41
M6	34.67	42.9
M7	30.67	38.84
M8	32.47	41.57
M9	33.5	42.27

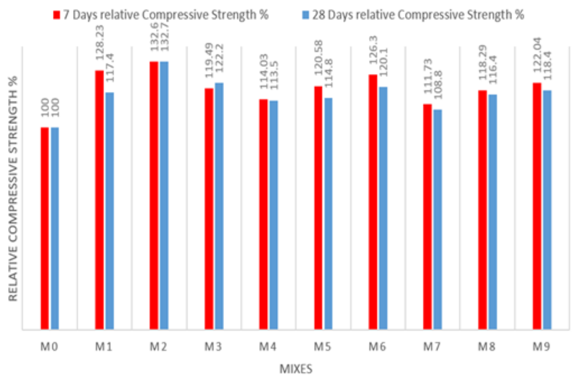

Fig 1. Relative compressive strength of mortar after (7, 28) days.

Comparing the relative compressive strength values for various mixtures (M1-M9) at 7, and 28 days with the control mix (M0) is shown in Table 8. The superplasticizer (Hyperplast PC600) was added to all mixes (M1-M9) to increase compressive strength by reducing water consumption and enhancing workability, with the exception of the control plain mortar mix (M0).

Figure 1 shows that when 30% (8.5% of RPBP and 10.75% of both YPBP and YSBP) of the cement is replaced with CBWP (M2), the relative compressive strength is improved to 32.6% and 32.7%, at age of 7and 28 days, respectively, as compared to control mix (M0). There are two causes for the increase in compressive strength. First, brick dust is a naturally occurring pozzolan that combines with cement's lime and calcium hydroxide to produce more C-S-H and C-A-S-H, as well as higher gel to space ratio. Secondly, a compact mass made of the smaller brick dust particles fills the pores in the concrete, as confirmed by [24]. It was noticed that compressive strength of the M7 mix decreased in comparison with M8 and M9, which have the same cement replacement percent (40%) due to the difference in chemical composition of the three types of CBWP mentioned in Table 5.

B Ultrasonic Pulse Velocity (UPV) Test

The UPV test was performed at 7and 28 days, To analyze the quality of concrete, the presence of voids, and the efficacy of fracture treatment, an ultrasonic pulse velocity test is performed under the ASTM C597 [20]. Table (9) explains UPV test of three readings were used on average of mortar at 7and 28 days of the mixes mortar (M0-M9).While Figure (2) illustrates the Relative UPV of mortar at 7 and 28 days.

From Table (9) the results of ultrasonic pulse velocity at 28 days for various mixes (M1-M9) compare with the control mix (M0). The (M2) mix increase in UPV of about 14.47 %, 11% respectively for (7,28) days as shown in Figure (2), due to the fine materials of CBWP compared to cement particles that fill the pores between particles and increase density at the mix [25]. The UPV readings decreased when increasing the cement replacement percent by CBWP as mentioned in Table 7, Due to the matrix's lesser uniformity and enhanced porous structure, which influenced the UPV reading, it had negative effects on the properties[26].

TABLE 9 (7 AND 28) DAYS ULTRASONIC PULSE VELOCITY TEST OF MORTAR.

Mixes	7 Days UPV test km/sec	28 Days UPV test km/sec
M0	3.8	4.08
M1	4.21	4.35
M2	4.35	4.53
M3	4.08	4.44
M4	3.99	4.3
M5	4.12	4.32
M6	4.18	4.4
M7	3.87	4.28
M8	4.09	4.31
M9	4.14	4.38

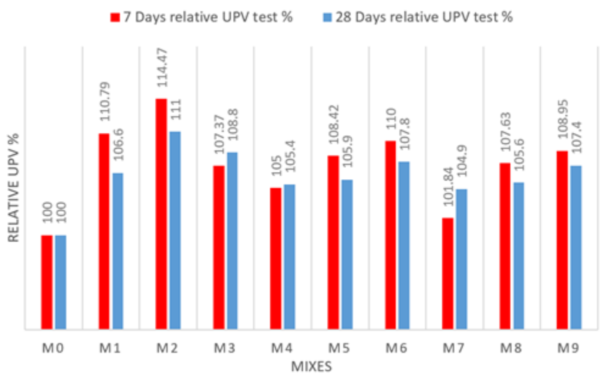

Fig 2. (7,28) Days relative UPV test.

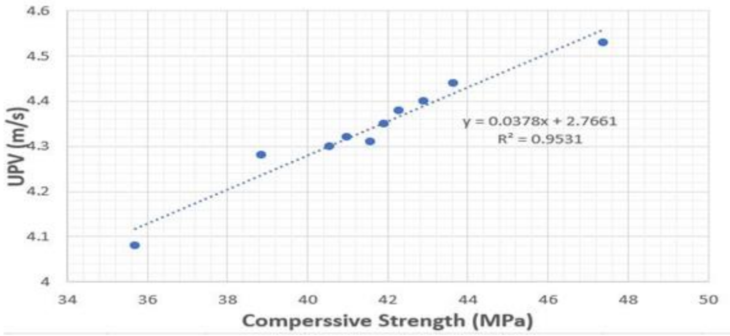

Fig 3**.** The linear relationship between compressive strength and UPV

C Broken Beam Compressive Strength (Portions of Prisms).

This test measures the cement mortar compressive strength using parts of prisms that have been bent and broken into flexural strength test specimens in accordance with Test Method [21].

Table (10) explains cement mortar compressive strength using portion of broken prisms resulted from flexural strength test of three readings were used on average of mortar at 7and 28 days of the mixes mortar (M0-M9).While Figure (3) illustrates the Relative UPV of mortar at 7 and 28 days.

TABLE 10 (7 AND 28) DAYS COMPRESSIVE STRENGTH OF PORTION OF PRISMS

Mixes	Compressive Strength of Portions of Prisms Broken in Flexure after 7 Days (N/mm2)	Compressive Strength of Portions of Prisms Broken in Flexure after 28 Days (N/mm2)
M0	29.77	37.48
M1	39.61	45.19
M2	41.16	49.8
M3	37.9	47.6
M4	36.03	42.79
M5	35.79	43.89
M6	36.87	45.94
M7	34.04	40.52
M8	34.96	44.8
M9	36.2	46.38

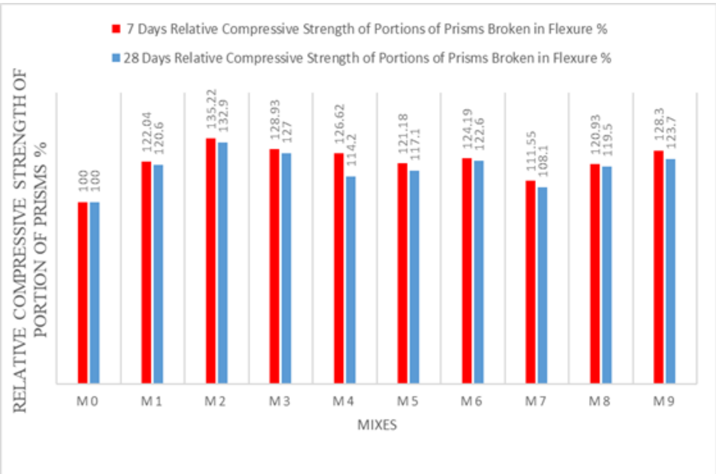

Figure 4. Relative compressive strength of portion of prisms after (7 and 28) days.

From Table (10) compressive strength (Portion of prisms) at 7 and 28 days results for various mixes (M1-M9) are compared with the Control mix (M0). The (M2) mix increase in relative compressive strength of portion of prisms of about 35.22 %, 32.9 % respectively for 7and 28 days as shown in Figure (4), due to the fine material CBWP fill the pores between particles and increase density at the mix. Many research [11], [27]–[30] findings, CBWP and $Ca(OH)_2$ reacted to generate C-S-H, and C-A-S-H gel. It is possible to summarize the formation mechanism as follows. The active SiO_2 and Al_2O_3 in CBWP, on the other hand C-S-H gel, and C-A-S-H gel are produced through direct reaction with $Ca(OH)_2$. Yet, when the C-S-H gel surrounds the brick powder particles, Ca^{2+} enters the brick powder particles to create

C-A-S-H gel.

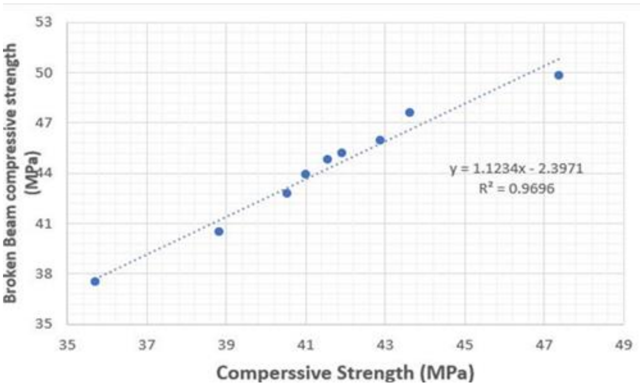

Fig 5. The linear relationship between compressive strength and Broken beam compressive strength.

D Flexural Strength

The flexural strength test was performed at 7and 28 days under the ASTM C348 requirements [22]. Table 11 illustrates the flexural Strength of mortar at 7 and 28 days, while Figure 3 explains relative flexural strength at 7 and 28 days of the mixes mortar (M0-M9).

TABLE 11 (7 AND 28) DAYS FLEXURAL STRENGTH OF MORTAR

Mixes	28 Days Flexural Strength (N/mm2)
M0	5.86
M1	6.43
M2	6.91
M3	6.48
M4	5.97
M5	6.13
M6	6.24
M7	5.89
M8	6.38
M9	6.46

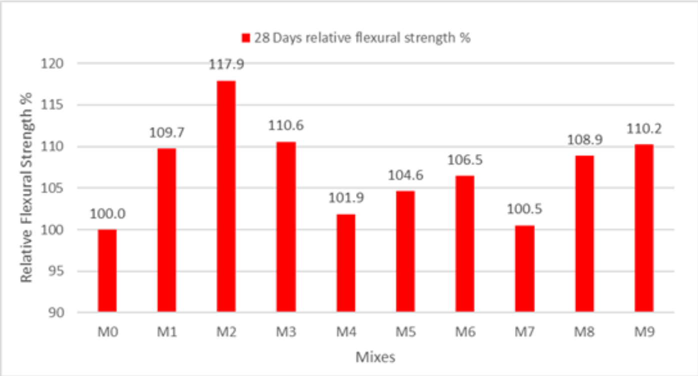

Fig 6 (28) Relative Flexural Strength.

The flexural strength was increased due to increased bonding between the binder and fine aggregate. The similar mentioned explanation of the compressive strength increment can be adopted here for the flexural strength increment. From Table 11, the results of the flexural strength of (28) days prisms for various mixes (M1-M9) are compared with the control mix (M0). The flexural strength for all mixes was increased, except for M8, M9. From Figure 6, the higher relative flexural strength for 8.5% of RPBP and 10.75% of both YPBP and YSBP replacement of CBWP by OPC (M2) was increased to 17.92 % at (28) days, as compared with the control mix (M0) without replacement of cement. The flexural strength decreased with increasing cement replacement in the M7 mix, as shown in Fig (6). That was due to the reduced Ca(OH)2 reacting with pozzolanic materials, forming a porous mixture [31].

IIII. Conclusions

The possibility of using CBWP as a partial replacement of cement to produce sustainable mortar summarize is in this paper. The following can be concluded based on the findings of the experiment program achieved to investigate the ability of triple CBWP on enhancing the mortar properties:

1) Because CBWP as a partial cement replacement reduces flowability qualities, more superplasticizer must be added to the fresh properties of green mortar.

2) Compressive strength is improved by approximately 32.7% when 30% of the cement is replaced by CBWP, which contains (8.5% of RPBP and 10.75% of both YPBP and YSBP). Flexural strength is improved by 17.92% at 28 days as compared to other mixtures.

3) For the objective of producing sustainable mortar, using brick powder in place of some of the cement is permitted up to 40%.

4) In comparison to the control mix (M0) , the wave speed in the UPV increases that contain (8.5% of RPBP and 10.75% of both YPBP and YSBP) up to 11% at 28 days.

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