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Mechanical Properties of Self-Curing Concrete Produced from Crushed Bricks and Ceramic Waste

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ABSTRACT

Recently, the prevailing strategy has been to dispose of building waste safely. The objective of this research is to study the feasibility of using crushed bricks (CB) and ceramic waste (CW) along with PEG 400 to produce low-cost concrete with acceptable properties, preserve natural resources, and protect the ecosystem from waste. Nine concrete mixtures were produced. CB and CW were used as a partial substitution for coarse aggregate by 20%, 40%, and 60% of its weight. Three curing methods were utilized: air curing, water curing, and self-curing with Polyethylene glycol 400 (PEG 400). Various properties of hardened concrete were investigated, such as compressive strength, flexural strength, splitting tensile strength, elastic modulus, water absorption rate, water sorptivity, and density. The results demonstrated that the compressive strength, flexural strength, splitting tensile strength, and elastic modulus of CW mixtures were greater than those of CB mixtures. The mix with 40% CW and PEG 400 achieved the highest compressive strength, flexural strength, splitting tensile strength, and elastic modulus by 19.42%, 23.5%, 23.94%, and 27.6%, respectively, with respect to the reference mix cured in water. The workability of CB and CW mixtures improved, and slump values increased with the increasing ratio of CB and CW. The water sorptivity reduced until the replacement ratio reached 40% of dolomite with CB and CW. SEM images indicated that the pores decreased, and more crystals of calcium silicate hydrate formed in a mixture with 40% CW and PEG 400 compared to the reference mix.

Keywords: Crushed bricks, Ceramic waste, Self-curing concrete, Water sorptivity, Polyethylene glycol 400.

1. INTRODUCTION

Recycling construction waste can be one of the numerous ways to reduce the construction industry's dependency on finite natural resources. D.J. Anderson et al. [1] used three distinct waste ceramics as an alternative to coarse aggregate in concrete mixtures at different substitution levels. Findings indicated that waste ceramic made negligible mechanical characteristics changes. Nepomuceno et al. [2] made concrete mixtures with ceramic waste as a replacement material of course aggregate. The outcomes demonstrated that the mechanical properties of hardened concrete, such as compressive strength, splitting tensile strength, and modulus of rupture, declined when more ceramic waste was substituted with coarse aggregate. S.A. Zareei et al. [3] produced two sets of concrete mixtures. The cement was substituted by wollastonite at ratios of 10%-50% in the first group. In the second group, 50% of the coarse aggregate was substituted with recycled waste ceramic aggregate (RWCA), and wollastonite was added at the previously specified doses. Micro-silica was put into each mixture. It was observed that the mixture containing 50% wollastonite showed a 24% improvement in compressive strength at 28 days of curing compared to the control mix. It was deduced that adding RWCA as a partial replacement of coarse aggregate increases the concrete's strength and durability. S. Siddique et al. [4] investigated the effect of fine bone China ceramic aggregate (FBA) with different ratios on the variations in mass, compressive strength, and chloride penetration. It was discovered that the mixtures including 40% and 60% FBA had the lowest embodied energy and CO_2 emissions. The outcomes showed that recycled FBA waste as a substitute for aggregate can give high durability and resilience to concrete. The mixture with 100% FBA is the most cost-effective concrete. M. Amin et al. [5] studied the influence of replacement cement with silica fume (SF) and metakaolin (MK) to enhance ultra-high-performance concrete (UHPC) made from ceramic wastes as a substitute for coarse aggregate. According to the findings, the physical and mechanical characteristics of UHPC can be enhanced by substituting cement with either SF or MK. The outcomes demonstrated that strengthening UHPC using SF or MK produces positive results, especially when the ratio of SiO_2/CaO rose to 2.98. C. Zheng et al. [6] utilized two grades of concrete (C25 and C50) with various percentages of water to cement. Coarse aggregate was replaced at different ratios with recycled concrete aggregate (RCA) or recycled brick aggregate (RBA). The results showed that compressive strength decreased for C25 and C50 at a replacement ratio of 100% of natural coarse aggregate with RCA and RBA. RCA concrete mixtures had a better effect than RBA concrete mixtures. The compressive strength enhanced by utilizing the ideal gradation of RCA. M.O. Younis et al. [7] showed that the optimal dosage of Polyethylene glycol 6000 is 1.5% of cement weight, which increased compressive strength, durability test results improved at 2% PEG, and chloride penetration resistance enhanced at 4% PEG with respect to mixtures curing in air. The mechanical properties of concrete got better at a replacement ratio of 50% coarse aggregate with crushed ceramic and 1% PEG compared to mixtures curing in air. The compressive strength, splitting tensile strength, modulus of rupture, and modulus of elasticity increased with respect to air-curing mixtures. K. Singh [8] deduced that PEG 400 improves compressive strength due to its internally retained water. Self-curing concrete enhances hydration over time compared to traditional concrete. In addition, it can be used in high-rise buildings or structures built in deserts because of water scarcity. My Ngoc et al. [9] studied the influence of brick waste powder (BWP) and ceramic waste aggregate (CWA) on compressive strength and durability. The Taguchi and Box-Behnken design method was applied to determine the ideal circumstances for maximum compressive strength. Findings indicated that the quantity of BWP used as a replacement for cement had the greatest impact on compressive strength. The highest compressive strength was attained at the replacement level of 100% of coarse aggregate with CWA. The concrete's sulfate resistance and permeability of chloride ions were enhanced by the addition of CWA and BWP compared to the reference mix. In contrast, the reference concrete's abrasion resistance was higher than that of the concrete incorporating CWA and BWP. Elemam et al. [10] substituted 20–100% natural fine aggregate with fine ceramic waste (FCW) and 10–30% cement with ceramic waste powder (CWP). It was observed that the workability of concrete decreased when substitution ratios of CWP and FCW rose. Compressive and flexural strength improved when replacement levels of FCW and CWP rose to 50% and 10%, respectively, as fine aggregate and cement replacements. At 28 days of curing, there was a noticeable increase in compressive and flexural strength compared to the reference mixture. When the substitution ratio of FCW rose, the water permeability of the concrete increased, and the addition of CWP lessened this detrimental effect. A microstructure study showed that incorporating CWP and FCW enhanced cement hydration with respect to the control mixture. The impact of subjecting self-curing concrete to a temperature of 800°C was studied. Five kinds of curing methods were used. The first method is putting samples of concrete in water. The second method involves exposing the samples to air. The third method is self-curing with PEG. The fourth method involves substituting 10%, 15%, 20%, and 25% of the coarse aggregate with porous ceramic waste aggregate. The fifth method combines PEG and ceramic waste aggregate; PEG was added by 1% and 2% with 10% of the ceramic waste aggregate. The mixture with 2% PEG and 10% ceramic waste aggregate had the highest compressive strength of concrete. The compressive strength increased by 14.7% and 19.3% for normal-strength concrete and high-strength concrete, respectively, with respect to the reference concrete mixture. Substituting the coarse aggregate up to 25% with ceramic waste aggregate decreased the negative effects of elevated temperatures on compressive strength and unit weight loss [11]. C. Medina et al. [12] investigated the influence of ceramic waste as a partial replacement of coarse aggregate by 25% directly interacting with drinking water. The results demonstrated that adding ceramic aggregate increases the concentration of alkali in the water, like Na and K, while decreasing the concentration of various components, such as B, Si, Cl, and Mg. All the components that had leached were found to be at lower levels than those allowed by the laws that govern drinking water. These innovative concretes maintain water quality; thus, they are suitable for usage in these kinds of applications.

2. RESEARCH SIGNIFICANCE

Previous research studied the effect of CB and CW with polyethylene glycol 400 on the properties of concrete but in different proportions than the current experimental work. The purpose of this study is to demonstrate the viability of using CB and CW along with PEG 400 to produce sustainable self-curing concrete. The coarse aggregate was partially replaced with CB and CW by 20%, 40%, and 60% of its weight, to produce sustainable concrete and reduce the consumption of natural resources. Three methods of curing were utilized, air curing, water curing, and self-curing with PEG 400. Various properties of hardened concrete were investigated, such as compressive strength, flexural strength, splitting tensile strength, elastic modulus, water absorption, water sorptivity, and density. The results of tests for self-curing mixtures were compared to those of the reference mix. The workability of fresh concrete for all mixtures was determined by the slump test. SEM was utilized to indicate the influence of PEG 400, CB, and CW on the microstructure of mixtures.

3. EXPERIMENTAL PROGRAM

3.1. Materials

Cement (CEM): Portland cement (CEM I 42.5 N) was used in this experimental work following (ASTM C-150–3) [13]. It had an initial setting time of 80 min, a final setting time of 265 min, and a specific gravity of 3.15. The chemical composition of cement is indicated in Table 1.

Table 1. Chemical composition of cement (CEM I 42.5N)

Composition	% by weight
SiO_2	20.1
Fe_2O_3	2.9
MgO	2.2
CaO	62.2
SO_3	2.6
Fe_2O_3	3.4
AL_2O_3	5.4

Aggregates: The used fine aggregate was silicious sand with a fineness modulus of 2.74, and the used coarse aggregate was silicious dolomite with a maximum nominal aggregate size of 10 mm. They were produced locally. Table 2 illustrates the properties of sand (S) and dolomite (D). The sieve analysis findings for sand and dolomite are presented in Table 3.

Table 2. Properties of sand and dolomite

Characteristics	Sand	Dolomite
Unit weight (kg/m^3)	1650	1620
Absorption ratio	1.5%	0.9%
Fineness modulus	2.74	6.04
Specific gravity	2.62	2.62
Maximum Nominal Aggregate Size(mm)	-	10

Table 3. Sieve analysis of sand and dolomite

Sieve size (mm)	Passing %	
	Sand	Dolomite
37.5	100	100
19	100	98
9.5	100	95
4.75	96.4	3
2.36	88.5	0
1.18	77.2	0
0.6	51.3	0
0.3	10.4	0
0.15	1.9	0

Superplasticizer (SP): To enhance workability, superplasticizer (type F) was utilized by 1% of cement weight in accordance with ASTM C494 [14]. The characteristics of the superplasticizer are shown in Table 4.

Table 4. The characteristics of the superplasticizer

Characteristics	
Base	Aqueous solution of modified polycarboxylates
Color	Clear liquid
Density	1.08 kg/lt (ASTM C494)
pH value	4
Solid content	40% by weight

Polyethylene Glycol 400: PEG 400 was used as a self-curing agent for concrete. It is manufactured by Morgan Specialty Chemicals Company. Table 5 demonstrates the properties of PEG 400. Figure 1 shows the utilized PEG 400 in concrete mixtures.

Table 5. The properties of PEG 400

Properties	
Weight per ml @20 °C	About 1.12 gm
Average molecular weight	380-420

Figure 1: Utilized PEG 400 in concrete mixtures

Crushed bricks and ceramic waste: Figure 2 indicates CB and CW used in concrete mixtures. Properties and a sieve analysis of CB and CW are shown in Tables 6 and 7. The grading curves of CB, CW, and the limits of Egyptian code are shown in Figure 3.

(a) **(b)**

Figure 2: (a): Crushed bricks, (b): Ceramic waste

Table 6. The properties of CB and CW

Properties	CB	CW
Unit weight (kg/m^3)	1170	1385
Specific gravity	2.17	2.25
Absorption ratio	12.9%	8.8%

Table 7. Sieve analysis of CB and CW

Sieve size (mm)	% Passing		Limits of code
	CB	CW	
37.5	100	100	-
19	100	100	100
9.5	80	75	50-85
4.75	3	2	0-10
2.36	0	0	0
1.18	0	0	0
0.6	0	0	0
0.3	0	0	0
0.15	0	0	0

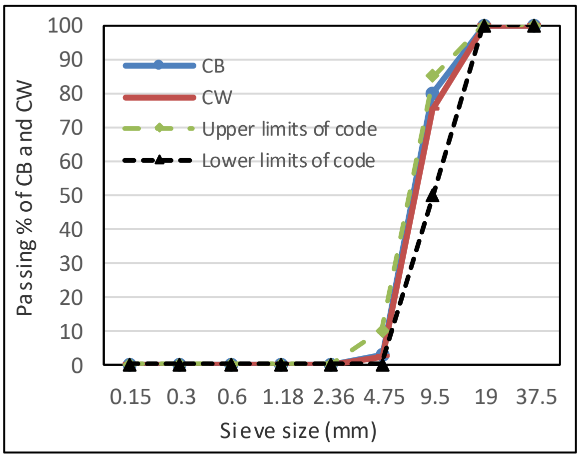

Figure 3: Grading curve of CB, CW, and limits of Egyptian code

3.2. Mixture Proportions

Dolomite, CB, and CW were used in this research after submersion in water for 24 hours, followed by surface drying to have a saturated surface dry condition. To fulfill the objective of the research, nine concrete mixtures were performed. The mixes M1 and M2 don't have CB, CW, or PEG 400; they are reference mixes. The M1 mixture was cured in water, while the M2 mixture was cured in air. The M3 mixture contained sand and dolomite; it was self-cured with PEG 400. Mixes from M4 to M9 included CB and CW; they were self-cured with PEG 400. Dolomite was partially replaced with CB by 20%, 40%, and 60% of its weight in mixtures M4, M5, and M6. Mixtures M7, M8, and M9 had CW by 20%, 40%, and 60% as a partial replacement of dolomite. PEG 400 was added to M3, M4, M5, M6, M7, M8, and M9 by 1.5% of the cement weight. Three methods of curing were used, air curing, water curing, and self-curing with PEG 400. The water-to-cement ratio was 0.4. The concrete mix components were designed in compliance with the British method. Table 8. presents the concrete mixture components (Kg/m^3).

3.3. Testing Procedure

Many tests were conducted in this study to determine the mechanical and physical properties of concrete at different ages. Three samples were used for each age, and the average values were taken. The compressive strength test was performed on concrete cubic samples with dimensions of 15×15×15 cm under a compression machine with an applied load rate of 140 kg/cm^2/minute in accordance with ISO 4012 [17]. The flexural strength test was carried out on concrete beams with a 10×10×50 cm size conforming to ISO 1920 and ISO 4013 [19, 20]. A flexure testing machine with a 4-point load was used. Cylindrical samples with a 15×30 cm size were utilized for determining splitting tensile strength using a compression machine following BS-1881 [22]. The water sorptivity test was conducted on concrete cubic specimens with dimensions of 10×10×10 cm according to ASTM C1585–13 [28]. Density was determined for all mixtures using cubes of concrete measured at 10×10×10 cm at 28 days following BS 1881 [26].

Table 8. The concrete mixture components (Kg/m^3)

Mix	CEM	S	D	CB	CW	SP	W	PEG-400
M1-Water	400	752	1128	0	0	4	160	0
M2 – Air	400	752	1128	0	0	4	160	0
M3-PEG	400	752	1128	0	0	4	160	6
M4-20%CB	400	752	902	226	0	4	160	6
M5-40%CB	400	752	676	452	0	4	160	6
M6-60%CB	400	752	450	678	0	4	160	6
M7-20%CW	400	752	902	0	226	4	160	6
M8-40%CW	400	752	676	0	452	4	160	6
M9-60%CW	400	752	450	0	678	4	160	6

4. RESULTS & DISCUSSION

4.1. Fresh Concrete Testing

4.1.1. Workability

To determine the workability of fresh concrete, a slump test was used according to ASTM C143 [15]. Figure (4) shows slump values for fresh concrete mixtures. It was observed that slump values of mixtures M3, M4, M5, M6, M7, M8, and M9 rose by 26.7%, 44%, 73.3%, 84%, 33.3%, 56%, and 76%, respectively, with respect to reference mix M1. The reason for the increase in slump values is that PEG 400 acts as a lubricant material in concrete mixtures. The slump values of CW mixtures were lower than those of CB mixtures. Slump values increased with the increasing ratio of CB and CW. This is because of the lightweight and porosity of CB and CW, in addition to the smoothness of the ceramic surface compared to dolomite. These results matched previous studies [3,7,11,16].

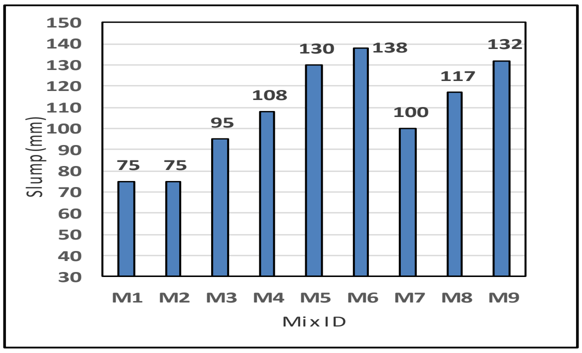

Figure 4: Slump values of fresh concrete mixtures

4.2. Hardened Concrete Testing

4.2. 1. Compressive Strength

The compressive strength test was conducted at 7,28,56 days of curing. Three samples were utilized for each age, and the mean value of compressive strength was determined. Figure (5) indicates the findings of compressive strength for all mixtures. There is a significant increase in compressive strength for mixtures M3, M7, M8, and M9 compared to M1, and M2. The compressive strength increased by 7.1%, 10.76%, 19.42%, and 13.9% for M3, M7, M8, and M9, respectively, with respect to M1 at 56 days. It rose by 39.25%, 44.03%, 55.3%, and 48.12% for M3, M7, M8, and M9, respectively, compared to M2 at 56 days. It can be explained that the objective of PEG is to keep water from evaporating out of concrete by strengthening the hydrogen bonds in water, which leads to the production of more crystals of calcium silicate hydrate (CSH) [8]. These crystals fill the pores in the interior of the concrete, increasing the concrete's compressive strength [7,18]. Also, CW can preserve water, which improves the hydration of cement. M8 achieved the highest compressive strength with respect to all mixtures; it had a compressive strength of about 45.5 MPa, which is approximately 19.42% higher than the reference mix (M1). Contrarily, the compressive strength of CB mixtures decreased by 16.5%, 25.72%, and 32.55% for M4, M5, and M6, respectively, compared to M1 at 56 days. The reduction in compressive strength is because CB is weak, brittle, and has a low density. Many recent studies agree with these results [3,7]. The mixture M6 fulfilled the lower compressive strength, it had a compressive strength of 25.7 MPa. The compressive strength of CW mixtures was greater than that of CB mixtures.

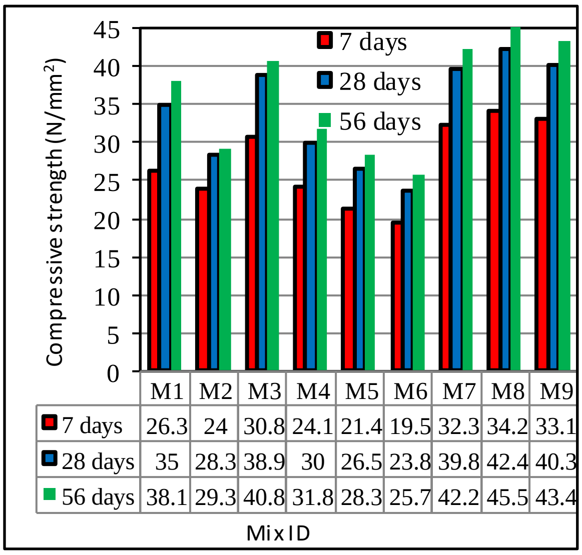

Figure 5: Compressive strength for all concrete mixtures at 7, 28, and 56 days

4.2.2. Flexural Strength

Figure (6) indicates the results of flexural strength at 28 days. The effect of PEG 400 on flexural strength was obvious where M3 increased by 10.2%, and 33.8%

compared to M1, and M2, respectively. The flexural strength of CB mixtures decreased by 13.33%, 25.5%, and 34.7% for M4, M5, and M6 while it increased by 13.73%, 23.5%, and 17.1% for M7, M8, and M9, respectively, with respect to M1. M8 mixture had the maximum flexural strength. The increment of flexural strength for CW mixtures is due to CW preserving water which leads to improved concrete curing. Also, PEG 400 decreases water evaporation forming CSH that fills voids which improves flexural strength. Various studies approve of these results [3,7,11,21].

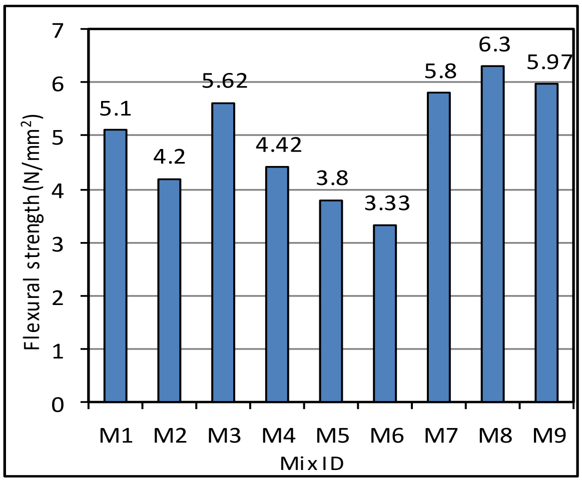

Figure 6: Flexural strength for all concrete mixtures at 28 days

4.2.3. Splitting Tensile Strength

Splitting tensile strength was carried out after 28 days of curing. The results are shown in Figure (7). Splitting tensile strength increased by 11.27%, 15.5%, 23.94%, and 19.72% for M3, M7, M8, and M9, respectively, compared to M1. This increase can be explained that PEG 400 completes the cement hydration mechanism and CW maintains water, which enhances the curing of concrete. Splitting tensile strength reduced by 11.55%, 22.54%, and 30.14% for M4, M5, and M6, respectively, with respect to M1. The decrease in splitting tensile strength for CB mixtures is because of the nature of CB, which has a low dry unit weight and is weak and brittle. A lot of researchers agree with these findings [3,7,11].

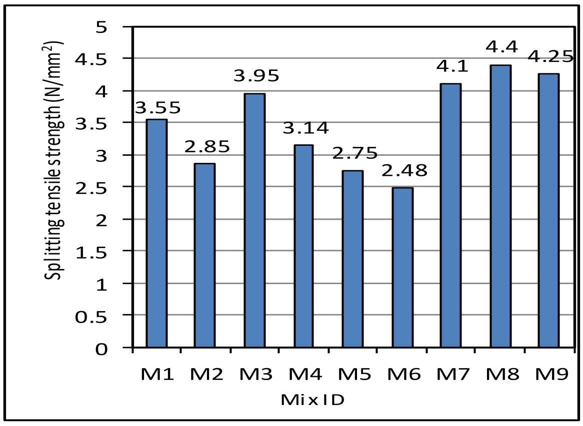

Figure 7: Splitting tensile strength for all concrete mixtures at 28 days

4.2.4. Elastic Modulus

The elastic modulus for all mixtures was determined at 28 days from the stress-strain curve in accordance with ASTM C-469 [23]. The results are presented in Figure (8). It was noticed that elastic modulus for M4, M5, and M6 reduced by 8.2%, 15.2%, and 19.7%, while it increased by 5.1%, 6.3%, 14.14%, and 7.5% for M3, M7, M8, and M9, respectively, with respect to M1. The maximum value of elastic modulus was 27.6 GPa at M8, while the minimum value of elastic modulus was 19.4 GPa at M6. The main reason for this increase in CW mixtures is that CW retains water, giving better curing of concrete, and PEG 400 reduces the evaporation of water. This leads to the formation of more crystals of CSH that enhance elastic modulus. Several authors have confirmed this observation [3,7].

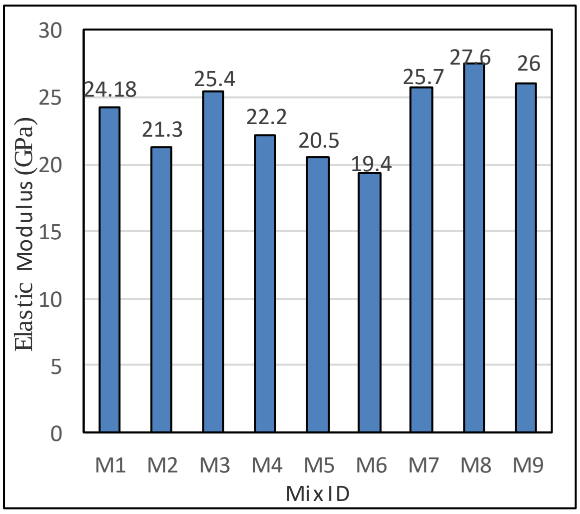

Figure 8: Elastic Modulus for various concrete mixtures at 28 days

4.2.5. Water Absorption Rate

The water absorption rate is an indicator of the durability of concrete. A water absorption test was conducted on concrete cubic samples with dimensions of 10×10×10 cm at 28 days, conforming to ASTM C642 [24]. Three concrete cubes were used for each mixture, and the average value of water absorption was taken. Figure (9) indicates the values of the water absorption rate for different mixtures. Water absorption reduced by 25.15%, 21.47%, 19.01%, 26.7%, 23.93%, and 21.47% for M4, M5, M6, M7, M8, and M9, respectively, compared to that of M2. Also, the water absorption for mixtures M3, M4, M7, and M8 decreased by 7.45%, 4.3%, 6.27%, and 2.75%, respectively, with respect to M1. This can be explained that the presence of PEG 400 improving the hydration of cement and generating crystals of CSH which fill the voids. SEM images confirmed this explanation. These findings are in line with other studies [25,7,11]. Water absorption for CB mixtures was higher than that of CW mixtures.

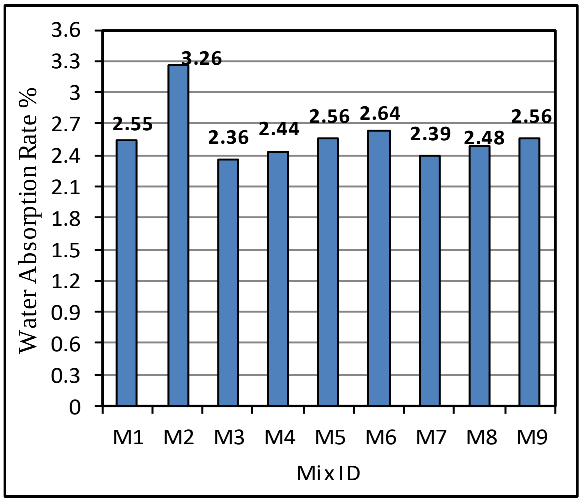

Figure 9: The water absorption rate for all mixtures at 28 days

4.2.6. Density

The effect of CB and CW on the density of concrete cubic samples was studied. The results of density are indicated in Figure (10). It was observed that the density of M3 increased by 3.2% with respect to the control mix, where it achieved the maximum density of about 2515 kg/m^3. This is because of the formation of excess crystals of CSH, which fill pores. Density reduced by 5.7%, 7.87%, 9.5%, 2.5%, 4.6%, and 5.3% for M4, M5, M6, M7, M8, and M9, respectively, compared to the reference mix. The reduction in density for M4, M5, M6, M7, M8, and M9 is due to the lower density of CC and CW compared to crushed dolomite. Many researchers confirmed this explanation [7,27].

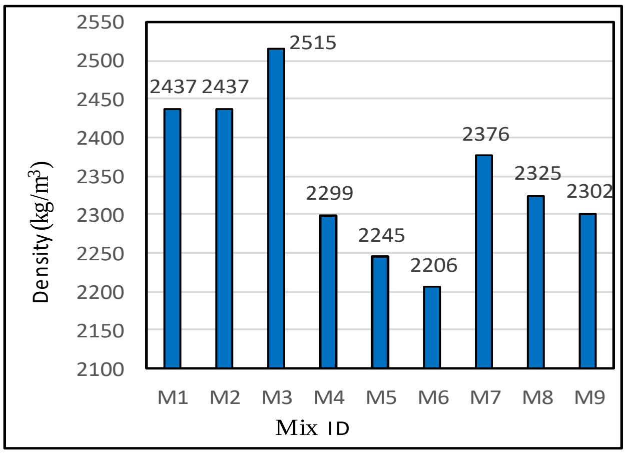

Figure 10: Density for different mixtures at 28 days

4.2.7. Water Sorptivity

The water sorptivity test was performed at 28 days. The effect of PEG 400 on the water sorptivity of concrete mixtures was investigated. The results of the water sorptivity test are presented in Figure (11). It was observed that the addition of PEG 400 decreased water sorptivity. The water sorptivity reduced until the replacement reached 40% of dolomite with CB and CW compared to M1. The water sorptivity of M1 is lower than that of M2 by 12.5%. The water sorptivity of M3 reduced by 8.1% compared to M1. This is because PEG 400 retains the moisture necessary for the hydration of cement, which reduces pores in the concrete matrix. The water sorptivity decreased by 3.73%, 0.62%, 5.6%, and 3.2% for M4, M5, M7, and M8, while it increased by 4.35%, 1.24% for M6, and M9, respectively, compared to M1. Water sorptivity reduced by 15.76%, 13.5%, 8.7%, 17.4%, 15.2%, and 11.4% for M4, M5, M6, M7, M8, and M9, respectively. with respect to M2. Consequently, the durability of concrete enhanced using PEG 400 as a self-curing agent. These results are in parallel with those of previous researchers [7,11].

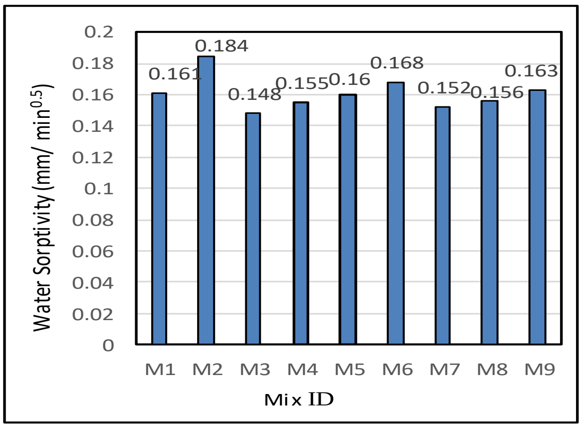

Figure 11: Results of water sorptivity for different mixtures at 28 days

4.3. Concrete Microstructure

The influence of PEG 400 on concrete microstructure was investigated by SEM at 28 days. Figure (12) shows SEM images of M1, M3, M4, and M8. It was observed that the reference mix (M1) has CSH gel, micro-pores, and micro-cracks. The pores decreased, and more crystals of CSH formed in mixtures M3, M4, and M8. The main reason is that PEG 400 reduces evaporating water, which enhances the hydration of cement, resulting in excess crystals of CSH. These crystals increased in M8 because of the presence of CW, which acts as a reservoir of water, which leads to improved curing of concrete. This agrees with other studies [3,7,10]. SEM images could clearly explain the mechanical and physical properties of concrete mixtures. The results of the tests show the feasibility of using CB and CW as a partial replacement of coarse aggregate along with PEG 400. CB and CW can be used in concrete mixtures to have low-cost sustainable concrete with acceptable mechanical and physical properties, maintain natural coarse aggregate, and protect the ecosystem from waste. Furthermore, self-curing concrete provides a solution for high-rise buildings and concrete poured in desert environments where water is scarce.

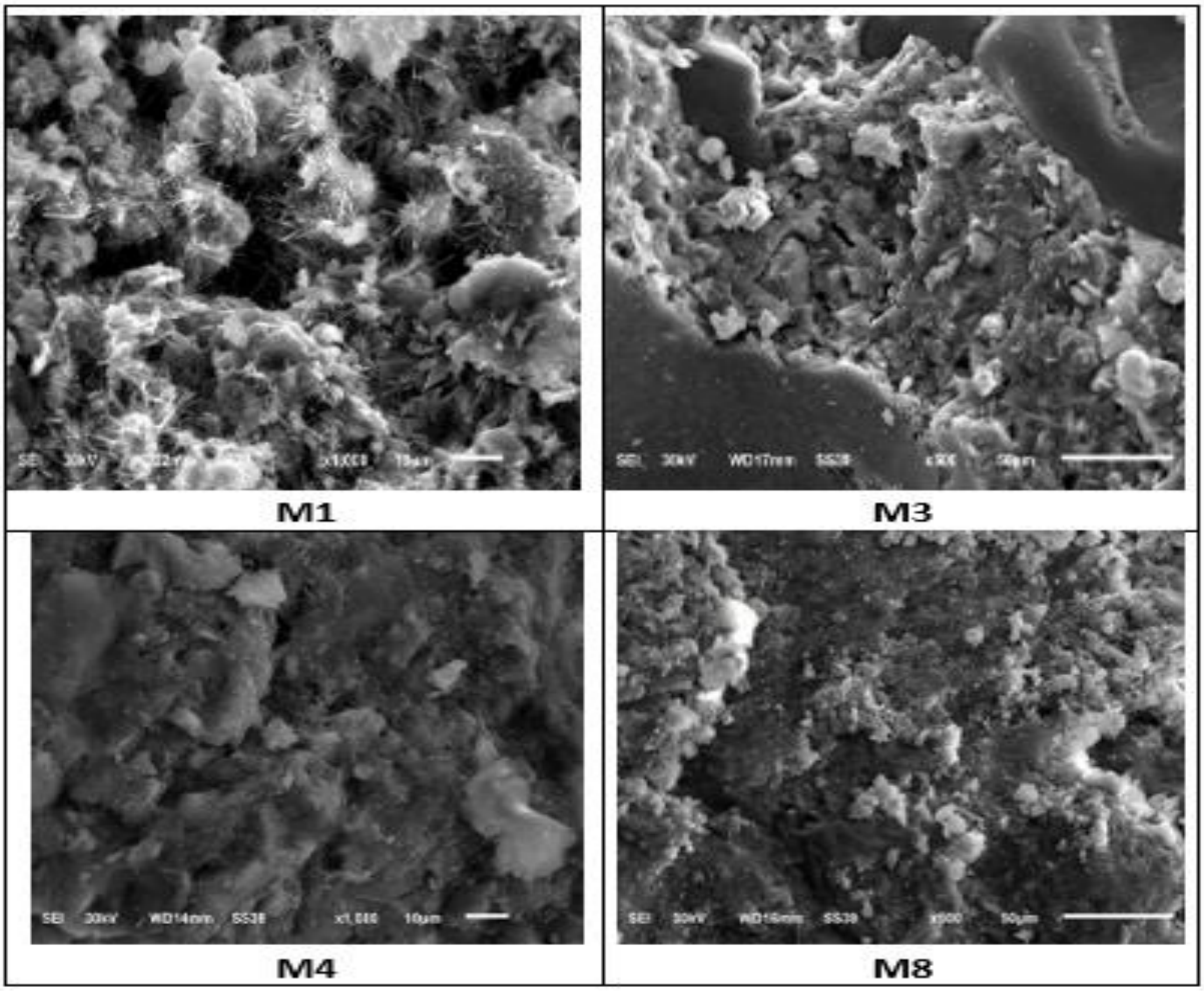

Figure 12: SEM images of M1, M3, M4, and M8 at 28 days

5. CONCLUSIONS

The effect of PEG 400, along with CB and CW, on the properties of concrete was investigated. From the previous findings of the practical program, it can be concluded that:

1. The compressive, flexural, and splitting tensile strengths of CW mixtures increased with respect to the reference mix cured in water. The mixture containing 40% CW achieved the highest compressive, flexural, and splitting tensile strength with respect to all mixtures. Contrarily, the compressive, flexural, and splitting tensile strengths of CB mixtures decreased compared to the reference mix cured in water.
2. The workability of CB and CW mixtures improved, and slump values increased with the increasing ratio of CB and CW.
3. The elastic modulus of CB mixtures decreased while it increased for mixtures containing CW with respect to the reference mix cured in water. The maximum value of elastic modulus was at a ratio replacement of 40% CW, while the minimum value of elastic modulus was at a mixture containing 60% CB.
4. The water absorption rate decreased for mixtures containing 20% CB, 20% CW, and 40% CW with respect to the reference mix cured in water.
5. Density of the CB and CW mixtures reduced compared to the control mix.
6. Water sorptivity decreased for mixtures containing 20% CB, 40% CB, 20% CW, and 40% CW while it increased for mixtures containing 60% CB and 60% CW compared to the reference mix cured in water.
7. SEM images showed that the pores decreased, and more crystals of CSH formed at mixtures with 20% CB and 40% CW with respect to the reference mix. SEM images could clearly explain the mechanical and physical properties of concrete mixtures.
8. CB and CW can be used in concrete mixtures to have low-cost sustainable concrete with acceptable mechanical and physical properties, maintain natural coarse aggregate, and protect the ecosystem from waste.

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Declaration of funding

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Declaration of competing Interest

The author states that he has no known conflicting financial interests or personal relationships that would have seemed to have an impact on the work presented in this publication.

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