ARTICLE
JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلـة جـــامعة بـــــابـل للعلـــــوم الهندسية
Vol. 33, No.6. \ 2025 ISSN: 2616 - 9916

Mechanical Properties of Self-curing Concrete Containing Recycled Materials

Nadiya Sadeek Alsaffar

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

Nadiya.alsaffar@uomosul.edu.iq

Received:	13/11/2025	Accepted:	29/12//2025	Published:	31/12/2025

Abstract

This study is examined the combined effects of using recycled ceramic powder as cement substitute and the accumulation of polyethylene glycol 4000 (PEG-4000) as a self-internal curing agent on the mechanical features of concrete. Compressive strength, tensile splitting strength, unit weight and Flexural strength were studied as well as fresh property such as slump. By using less quantities of cement, the primary goal is to enhance sustainability and lower CO2 effluents. PEG-4000's was added at 0%, 0.5%, 1%, 1.5%, and 2% as a percentage of total weight of cement, while recycled ceramic was employed at replacement percentage of 0%, 10%, 15%, 20%, and 25%. Results illustrate that for mixtures that use ceramic powder as a partial cement substitute, a PEG-4000 dosage of about 1% would be the best way to retain a workable consistency. Generally, using ceramic powder as cement replacement along with PEG-4000 lowers the self-curing concrete's unit weight. The optimal compressive strength is found to be at 10% cement replacement with 0.5% curing agent. Generally, the obtained split tensile strength designate that the splitting tensile strength of concrete is significantly impacted when recycled ceramic powder is added as a partial cement substitute. 10% ceramic replacement with 1.0–1.5% PEG 4000 is the ideal combination, as the beneficial self-curing effect makes up for the lower cement concentration and creates a more durable and finer microstructure. The complementary advantages of self-curing and pozzolanic reaction cause increased flexural strength at intermediate ceramic replacement (10–20%) with combination of 1% PEG-4000. There was a growth in flexural strength by (12%) as compared to the baseline mix with 15% ceramic and 1% PEG.

Keywords: Cement replacement, Polyethylene Glycol PEG4000, Self-curing Concrete, Recycled Ceramic Powder.

1.Introduction

One of the biggest sources of carbon dioxide emissions globally is the building sector; the manufacturing of ordinary Portland cement (OPC) is the reason of around eight percentage of worldwide CO2 releases [1, 2]. Developing substitute materials that can partially replace cement while preserving or improving the performance of concrete is becoming more and more important as sustainability becomes a top issue [3].

An appropriate substitute for cement is recycled ceramic debris, which is produced from building and demolition projects, broken ceramic items, and industrial byproducts. Milled ceramic waste has pozzolanic characteristics that allow it to react with calcium hydroxide when water is present, enhancing the strength and durability of concrete [4]. In addition to eliminating a significant amount of material from landfills, using ceramic waste in place of some cement reduces the demand for virgin natural resources, which sequentially drops climate pollutants related to the manufacture of cement [5]. In order to give the cement time to hydrate, curing is the procedure of reducing the amount and rate of moisture loss from concrete throughout cement hydration mechanisms [6]. Conventional moist curing techniques, including as fogging, wet coating, and water spraying, have been widely employed to keep concrete's temperature and moisture levels stable. However, because of the dense microstructure and low w/b, the additional water that is provided remains on the outside of the concrete without significantly penetrating its pores [7,8,9].

The hydrated cement paste incorporates water as part of the self-curing procedure, which keeps the internal relative humidity steady. By adding a limited amount of water to the concrete, internal curing is achieved. Water can fill the voids created during shrinkage through the hydrated cement paste and contribute more water to the structure of the hydrated cement paste. By keeping them wet, it delays the essential pore size reduction [10]. By enabling constant hydration throughout the concrete matrix, internal curing compensates for surface moisture loss, lowers labor costs, and expedites curing time, according to the American Concrete Institute (ACI 308) [11].

Elemam et al. [12] made an investigation in order to examine the possibility of use ceramic waste as a hydraulic binder and fine aggregate in the concrete production. The efficiency of concrete mixtures that substituted 10–30% ceramic waste powder for cement and 20 to 100% ceramic waste particles as fine aggregate. The main parameters involved in this study were workability, mechanical properties, durability and the ability to resist elevated temperature. The results established that concrete workability declines when ceramic waste powder and ceramic waste fine replacement levels rise. As the replacement ratios reached` up to 50% and 10% for cement and sand replacements, respectively, the compression and flexural strengths increased. At twenty-eight days, the enhancement in flexural and compressive strength was 8.14% and 5.33%, respectively. When concrete mixtures containing ceramic particles as fine aggregate and ceramic waste powder were exposed to 2000C, 4000C, 6000C, and 8000C, their remaining compressive strengths increased to 95.02%, 89.66%, 74.33%, and 51.34%, respectively, in comparison to reference mixes, which attained 84.25%, 76.03%, 59.36%, and 35.84% of their original strength.

Alnour and Mansour [13] investigated substituting ceramic waste powder for OPC cement at weight percentages of 0%, 10%, 15%, and 20% of concrete with grade 30. The typical mixture and concrete's mechanical properties, like compressive and tensile strength, were examined. For seven and twenty-eight days, these tests were conducted to assess the mechanical characteristics. At 5% ceramic waste powder

(CWP) concrete mix, the highest values of tensile strength and compressive strengths at seven and twenty-eight days were attained. The development of compressive strength was retarded by CWP, especially in the initial phases. At twenty-eight days, every mix including CWP demonstrated good strength development. All CWP replacement ratios were found to have higher compressive strengths than conventional compressive strengths, with the exception of the 20% replacement ratio, which produced somewhat lower results than the reference mix.

Mokhtar and Younis [14] examined using powdered ceramic waste as an alternative to cement. According to Egyptian code, five mixes containing varying percentages of ceramic waste powder CWP by cement weight (0%, 5%, 10%, 15%, and 20%) were made and evaluated. Compressive strength, and flexural strength were investigated. Compared to the baseline concrete, The main findings were that the concrete with 10% CWP had a 9.85% increase in compressive strength. The ceramic mortar was found to have a bending strength of 3.85 MPa, which is around 12% higher than that of the cement mortar. At 10% replacement ratio, the best flexural tensile strength was achieved.

The effectiveness of using self-curing technique in concrete by Polyethylene Glycol (PEG 4000) as a chemical admixture to maintain internal moisture during hydration is investigated by Dr. Vimala et al. [15]. Concrete grades M20, M30, and M40 were tested using various PEG percentages (0.5%, 1%, 1.5%, and 2%) to determine the ideal dosage for each grade. Several specimens were created, including prisms (100 mm × 100 mm × 500 mm) for flexural strength evaluations, cubes (150 mm × 150 mm × 150 mm) for determining the optimal PEG dosage, cylinders (150 mm × 300 mm) for split tensile strength tests, and beams (1500 mm × 150 mm × 230 mm) for load-deflection studies. According to the findings, PEG enhanced the mechanical characteristics at the best concentrations of 0.5% for M40, 1% for M30, and 2% for M20. In comparison to traditionally cured concrete, self-curing concrete had greater compressive and flexural strengths; improvements for M20, M30, and M40 were 7.0%, 8.3%, and 5.8%, respectively.

Jyoti and KARALE [16] attempted to use the advantages of self-compaction and self-curing. The self-healing ingredient polyethylene glycol (PEG-4000) is used at quantities varying from 0.1 to 1% by cement weight. Polyethylene glycol PEG4000 is added to the concrete at weight percentages of 0.1%, 0.5%, and 1% in order to test the strength of internal curing, self-compacting concrete. At 7 and 28 days, a compressive strength test was performed. To assess water absorption capacity, the weight of cubes was determined at 3, 7, 14, 21, 28, and 56 days after the date of demolding. Two distinct concrete mixes with 28-day cube compressive strengths—70 MPa and 50 MPa—were targeted. For the experimental program, 90 cubes in all were cast. When PEG-4000 is added, the compressive strength of self-compacting concrete with a lower water- to -cement ratio increases and is nearly equal to wet curing. For larger w/c ratios, the decrease of weight is decreased when the percentage dosage of PEG-4000 is increased.

The effect of internal-curing chemicals like, Poly Vinyl Alcohol (PVA), Poly Ethylene Glycol and Super Absorbent Polymer (SAP) on the concrete with grade 25 (control mix) concrete mix was the main topic of a study conducted by Sastry and Kumar [17]. When comparing the effect of different chemicals on concrete strengths (whether compressive, tensile, or flexural), PEG-4000 stood out as the most effective of all of them.

Comparative evaluation of various chemicals effect on the compressive strength, split tensile strength, and flexural strength, it was found that PEG-4000 was the most effective of all of them.

The effectiveness of self-curing concrete is examined by G. Vimala et al. [18] utilizing Polyethylene Glycol (PEG 4000) as a chemical additive to preserve internal moisture during hydration. To determine the ideal dosage for each grade, concrete grades M20, M30, and M40 were examined using different PEG concentrations (0.5%, 1%, 1.5%, and 2%). According to the findings, PEG enhanced mechanical qualities in concrete at the best concentrations of 2% for M20, 1% for M30, and 0.5% for M40. In comparison to conventionally cured concrete, self-curing concrete had greater compressive and flexural strengths; improvements for M20, M30, and M40 were 7.0%, 8.3%, and 5.8%, respectively. The study comes to the conclusion that by enhancing workability, compressive strength, and durability, self-curing concrete can offer useful advantages in regions with limited water supplies.

2. Research Objective

Using polyethylene glycol PEG4000 as a curing agent, this study investigates the viability of partially substituting recycled ceramic waste for cement in concrete using the self-internal curing technique. In order to determine if ceramic-based substitutes may encourage greater sustainability, the researcher studies the mechanical properties of such mixes, which consist of compressive strength, unit weight, tensile splitting strength, and flexural strength, as well as their environmental advantages.

3. Experimentals

3.1 Materials

Ethylene glycol repeating units make up the polymer known as Polyethylene Glycol 4000 (PEG 4000) as shown in Figure (1). It is extensively utilized in industrial, cosmetic, and pharmaceutical applications. The standard formula for polyethylene glycol is $HO–CH_2CH_2–O–CH_2CH_2–…–OH$, usually extending from 4 to roughly 180. The average molecular weight is indicated by the combination of the acronym (PEG) and a numerical suffix. The fact that PEG is water soluble seems to be one of its common characteristics. Table (1) represents the properties of it. Ordinary Portland cement was manufactured locally. Cement's chemical and physical characteristics are shown in Tables (2) and (3), respectively, and they meet Iraqi specification I.Q. No. 5/2019 [18]. The cement’s chemical properties were evaluated at the Environmental Engineering Department Laboratory, College of Engineering, University of Mosul. The physical tests were carried out in the Materials Testing Laboratory at Civil Engineering

Department /College of Engineering / University of Mosul. Locally available river sand was used. The sieve analysis of the used aggregate satisfies I.Q.S. No. 45/1984 [20], as shown in Table (4). Bulk Specific gravity is 2.63 and Absorption Capacity about 2.3%. According to Iraqi requirements I.Q.S. No. 45/1984 [18], coarse aggregates with a maximum aggregate size of 20 mm were graded its Bulk -Specific Gravity (S.S.D) 2.67 and absorption capacity 0.62%. The sieve analysis is presented in Table (5). Ceramics were ground to the proper fineness using a specialized machine as shown in Figure (1), the physical and chemical properties of ceramic are listed in Table (6) and Table (7) respectively. PC-175 is a high-range water-reducing additive built on polycarboxylate ether (PCE) is used to increase workability, lower water content, and boost concrete's strength and performance which conform with ASTM C494 Type F & G, EN 934-2 [21]. Figure (1) shows the Ceramic Powder and self-curing agent PEG-4000.

c. Recycled Ceramic b. Ceramic Powder a. PEG-4000

Figure (1) a. Recycled Ceramic. b. Ceramic Powder. C. Self-Curing Agent PEG-4000.

Table (1) Properties of Polyethylene Glycol PEG (4000) [28].

Item	Specification	Test Result
Product Name	PEG-4000	
Hydroxyl Value (as KOH)	25.5 – 31	28.10
Average Molecular Weight	3619 – 4400	4030.17
Appearance (25°C)	White Powder	White Powder
pH (5% Aqueous Solution)	5 – 7	5.90
Executive Standard	Company Standard	

Table (3) physical properties of cement

No.	Test	Value	Specification Limits
1	Standard ductility (w/c)	0.265	---------
2	Initial Setting Time (min.)	150.00	45≤
3	Final Setting Time (hr.)	3.30	10≥
4	Compressive Strength at 3 days (MPa)	16.7	10≤
5	Compressive Strength at 28 days (MPa)	24.4	32.5≤
6	Fineness at sieve No. 170 (%)	4.7	10≥

Table (2) Cement 's Chemical Characteristics

Composition of Chemicals	Value %	Limits %		Chemical Composition	Value %	Limits %
Sio_2	21.00	----		C_3S	38.68	----
Al_2O_3	4.16	----		C_2S	31.03	----
Fe_2O_3	2.01	----		C_3A	7.64	----
CaO	59.10	----		C_4AF	6.10	----
MgO	2.95	**≤ 5**		L.S. F	89.10	----
SO_3	1.57	**≤ 2.8**		Solid Solution	12.16	----
Free Lime	1.72	----				
Loss on ignition	0.80	**≤ 4**				
Insoluble residue	0.95	**≤ 1.5**				

Table (4) Sieve Analysis of Fine Aggregate according to Iraqi Specification [20]

Sieve size(mm)	Passing %	Iraqi Specification
10	100	100
5	100	90-100
2.36	100	75-100
1.18	86	55-90
0.6	49	35-59
0.3	18	8-30
0.15	7	0-10

Table (5) Sieve Analysis of Coarse Aggregate according to Iraqi Specification [20]

Sieve size(mm)	Passing %	Iraqi Specification
37.5	100	100
20	100	95-100
10	55	30-60
5	8	0-10

Table (6) Physical properties of Ceramic Powder

Properties	Recycled Ceramic
Fineness (Blaine) gm/cm2	6936
Initial Setting Time (min.)	571
Final Setting Time (hrs.)	5.0
Bulk -specify Gravity (S.S.D)	2.4
Absorption Capacity %	12.8
Unit Weight Kg/m3	1381

Table (7) Chemical Properties of Ceramic Powder

Oxide composition		Content %
Silica oxide	SiO_2	64.92
Alumina oxide	Al_2O_3	16.1
Ferro oxide	Fe_2O_3	3.88
Lime	CaO	9.2
Magnesia oxide	MgO	0.41
Sulphate	SO_3	0.01
Sodium oxide	Na_2O	1.43
Potash oxide	K_2O	1.15
Titanium dioxide	TiO_2	0.60
Phosphorus pent oxide	P_2O_5	0.15
Manganous oxide	MnO	0.08
Loss of ignition	L.O.I	2.0

Vol. 33, No.6. \ 2025 ISSN: 2616 - 9916

3.2 Mix Proportions

In this investigation, the mixing proportions were designed according to [22] and it is found to be 1:1.65:2.55/0.45. These ratios were utilized with one dosage of superplasticizer to guarantee workability with a slump rate from 75mm to 100mm. The required compressive strength is 35MPa. Using an electronic balance each ingredient was weighed. Cement and fine ceramic dust were first suitably combined in a dry state, and then sand and coarse aggregate were added. The specific amount of PEG-4000 was carefully dissolved in the mixing water for ten to twenty minutes before adding the dry components. As soon as the concrete had been homogenously mixed, it was instantaneously molded and compacted for one to two minutes. Following the molds' casting a full cover with plastic wrap was performed for 24 hours as shown in Figure (2). Table (8) demonstrates the details of overall mixes that are achieved in this study.

Figure (2) Mixing Process

Table (8) Mix proportions in Kg per m^3

No.	Mix	Cement	Fine aggregate	Coarse Aggregate	Ceramic	Water	PEG-4000
1	M**1**-P0C0	411	680	1050	0	185	0
2	M2-P0C10	369.9	680	1050	41.1	185	0
3	M3-P0.5C10	369.9	680	1050	41.1	185	1.8495
4	M4-P1.0C10	369.9	680	1050	41.1	185	3.696
5	M5-P1.5C10	369.9	680	1050	41.1	185	5.544
6	M6-P2.0C10	369.9	680	1050	41.1	185	7.392
7	M7-P0C15	349.4	680	1050	61.6	185	0
8	M8-P0.5C15	349.4	680	1050	61.6	185	1.7475
9	M9-P1.0C15	349.4	680	1050	61.6	185	3.494
10	M10-P1.5C15	349.4	680	1050	61.6	185	5.241
11	M11-P2.0C15	349.4	680	1050	61.6	185	6.988
12	M12-P0C20	328.8	680	1050	82.2	185	0
13	M13-P0.5C20	328.8	680	1050	82.2	185	1.644
14	M14-P1.0C20	328.8	680	1050	82.2	185	3.288
15	M15-P1.5C20	328.8	680	1050	82.2	185	4.932
16	M16-P2.0C20	328.8	680	1050	82.2	185	6.576
17	M17-P0C25	308.25	680	1050	102.75	185	0
18	M18-P0.5C25	308.25	680	1050	102.75	185	1.54125
19	M19-P1.0C25	308.25	680	1050	102.75	185	3.0825
20	M20-P1.5C25	308.25	680	1050	102.75	185	4.62375
21	M21-P2.0C25	308.25	680	1050	102.75	185	6.165

M- Mix P- (PEG-4000) percentage of weight of cement C- Ceramic percentage of weight of cement

ARTICLE
JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلـة جـــــامعة بـــــابـل للعلـــــوم الهندسية
Vol. 33, No.6. \ 2025 ISSN: 2616 - 9916

4. Results and Discussion

4.1 Slump

According to ASTM C143/C143M-2020 [23], the slump cone assessment was used to assess the workability of fresh concrete as shown in Figure (2). The workability (slump test) results of both traditional concrete and concrete containing recycled ceramic powder for all mixes are obtained as illustrated in Figure (3).

Figure (2) Slump Test.

The relation between slump (mm) and PEG-4000 percentage for varying levels of ceramic waste replacement in concrete mixes is depicted in Figure (3). According to the slump behavior, PEG-4000 improves workability up to an ideal dose (~1% by weight of cement), after which its advantages decrease, perhaps as a result of excessive internal curing action or water retention that lowers the surface water needed for slump. On the other hand, because of its greater surface area and water absorption, slump is regularly decreased when ceramic powder is used. Workability and ceramic powder content are inversely correlated. Only at moderate dosage ranges can PEG-4000 partially counteract the negative effects of ceramic powder on slump. In order to maintain workable consistency, a PEG-4000 dosage of roughly 1% may be ideal for combinations that include ceramic powder as a partial cement substitute. The slump test result for mix MP0C0 was 100mm.

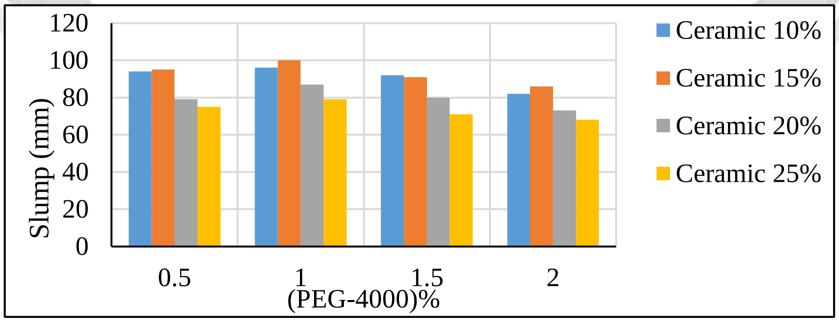

Figure (3) The relationship between PEG-4000 percentage with Slump.

4.2 Unit Weight

For each PEG-4000 ratio, Figure (4) displays the dry unit weight of concrete along with the proportions of ceramic powder replacement. The concrete dry unit weight shows a slight decrease when PEG-4000 is added as a self-curing admixture (at dosages of 0.5–2.0% by weight of cement). This is mainly because of increased internal water retention, potential formation of additional porosity, and decreased packing efficiency. However, as ceramic waste powder (CWP) has a lower specific gravity (2.4) than OPC (3.10-3.15) [24] and may increase porosity, replacing cement by ceramic powder at a rate of 10–25% results in observable declines in the dry density of concrete.

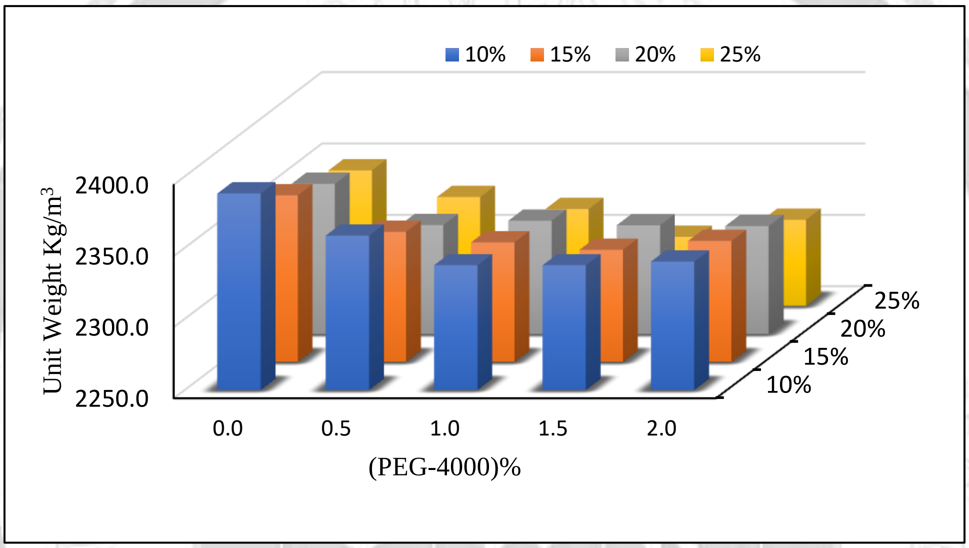

Figure (4) The relationship between unit weight of concrete with PEG-4000 for each ceramic Replacement Ratio.

4.2 Compressive Strength

Using different dosages of PEG-4000 as a self-curing agent and recycled ceramic powder (RCP) as a partial substitution for ordinary Portland cement (OPC), the concrete compressive strength was experimentally evaluated using three 150 mm x150mm x 150mm for each mix at a curing age of twenty eight days according to BS EN 12390-3-2019 [25] as shown in Figure (5). Compressive strength varies as ceramic replacement ratio increases (0%, 10%, 15%, 20%, and 25%) with respect to four PEG-4000 self-curing agent (10%, 15%, 20%, and 25% by weight of cement), based on the findings, which are presented Figure (6). The ten-percentage ceramic replacement ratio using traditional curing process gives higher compressive strength with approximately 8% increase compared to the reference mix that is because the ceramic can behave as pozzolanic material and can create more cementitious chemicals by reacting with calcium hydroxide when water is present. The fine and reactive ceramic powder can partially make up for the lost cement hydration by taking part in secondary hydration reactions (pozzolanic reaction) to produce more calcium silicate hydrate (C–S–H). However, when replacement rises, strength is lost due to a decrease in cement availability, an increase in porosity and weaker interfacial transition zones. This reactivity is slower than that of Portland cement but there is no loss in strength or slightly increase. As the replacement ratio of cement increase up to 25% the reduction in strength is noted due to the dilution effect and the dry density reduction because of the specific gravity of ceramic is lower than cement. Although the strength slightly decreased, it was still within allowable bounds for structural applications. Using 0.5% PEG-4000 the compressive strength has a slight increase about (6%). This strength gain is attributed to internal curing which endorses continuous hydration of cement even without external water. The optimum PEG -4000 ratio for 0% cement replacement is (1%) because of adequate retained water without reduction in workability. Excess PEG-4000 ratios i.e. (1.5% and 2 %) may increase porosity and affect hydration. Reducing bonding with cement paste. Compressive strength may remain stable or decrease slightly. However, the combined effect of replacing cement with ceramic powder using PEG -4000 as internal -curing agent is that the optimum compressive strength is found to be at 10% cement replacement with 0.5% curing agent.

Figure (5) Compressive strength casting and Test (3 Cubes for each

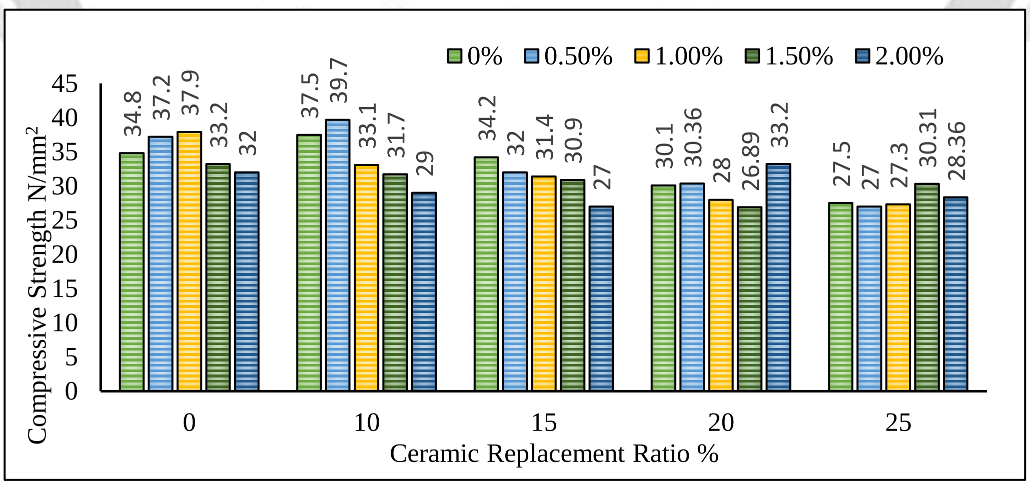

Figure (6) The Compressive Strength of concrete Versus Ceramic

4.3 Splitting Tensile Strength

For each mix, three 150 x 300 mm cylinders are utilized to test the concrete's splitting tensile strength according to ASTM C496/C496M-04e1 [26]. Figure (7) illustrates samples, casting and testing process.

Figure (7) Test and Specimens casting of Split Tensile Strength (Three Cylinders for each Mix)

The test outcomes presented in Figure (8) proved that the concrete's split tensile strength was significantly impacted once recycled ceramic powder was added as a part of cement content. The reference mix, which had no replacement, had the maximum tensile strength, ranging from 3.63 to 3.75 MPa. Tensile strength gradually decreased as the percentage of ceramic substitution grew from 10% to 25%, suggesting a dilution effect brought on by the ceramic particles' weaker reactivity in comparison to Portland cement. Even so, this strength loss was somewhat reduced by adding of PEG 4000 as an internal curing agent. Increased tensile performance was demonstrated by mixes with 0.5% to 1.5% PEG-4000, especially at 10% replacement. At 3.41 MPa, 1.5% PEG-4000 indicated increased internal curing and extended hydration. The tensile strength deteriorated at greater PEG contents (2%), most likely as a result of lower matrix density and excessive water retaining. Generally, the findings indicate that 10% ceramic replacement with 1.0–1.5% PEG 4000 is the ideal combination, as the beneficial self-curing effect makes up for the lower cement concentration and creates a more durable and finer microstructure.

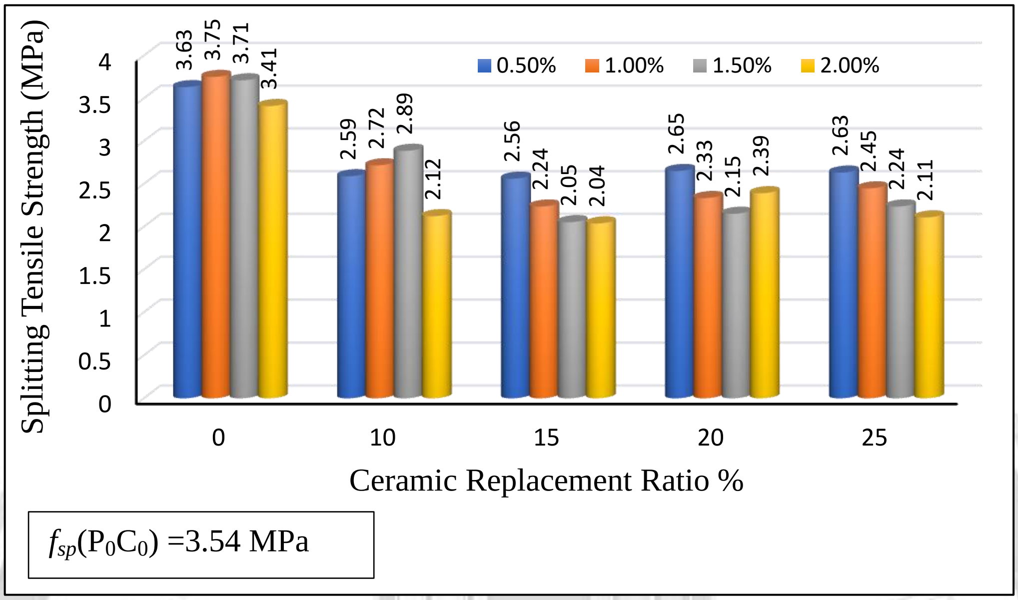

Figure (8) The Split Tensile Strength of concrete Versus the Ceramic Replacement Ratio Relationship for each PEG-4000 Ratio.

4.4 Modulus of Rupture

The concrete's flexural strength was obtained using testing prism specimens under third-point loading. For each mix proportion, three prisms of dimensions 100 mm × 100 mm × 500 mm were prepared. The samples were tested using a three-point bending arrangement on a universal testing machine until failure at 28 days of curing. The technique was conducted in compliance with the specifications of ASTM C293/C293M [27] Standard Test Method for Flexural Strength of Concrete as shown in Figure (9). The following equation represents modulus of rupture:

$$f_r = \frac{P.L}{bd^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Figure (9) Modulus of Rupture Testing and Samples after Test.

ARTICLE
JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلــة جـــامعة بـــــابـل للعلـــــوم الهندسية
Vol. 33, No.6. \ 2025 ISSN: 2616 - 9916

The results demonstrated in Figure (10) illustrate how the PEG-4000 dosage and the ratio of ceramic powder replacement affect the flexural strength of concrete. For all levels of replacement, the addition of PEG-4000 can enhance the flexural strength compared to the reference mix, validating its efficiency as an internal self-curing agent that improves interior moistness retaining and cement hydration. This behavior can be attributed to enhancing internal cohesion and reducing shrinkage microcracks which is in agreement with Gopala et al. [17] and Vimala et al. [15] findings. At 10% ceramic powder replacement, the flexural strength increased significantly to 4.53 MPa at 1.0% PEG-4000, indicating that the cement replacement is enhancing the microstructure by pozzolanic action and filler effects. A similar behavior was reported by reference [28]. The complementary advantages of self-curing and pozzolanic reaction cause increased flexural strength at intermediate ceramic replacement (10–20%) with a combination of 1% PEG-4000. The optimal flexural strength found to be 4.62 MPa at replacement ratio 15% with 1.0% PEG with 12% increase as compared to the reference mix.

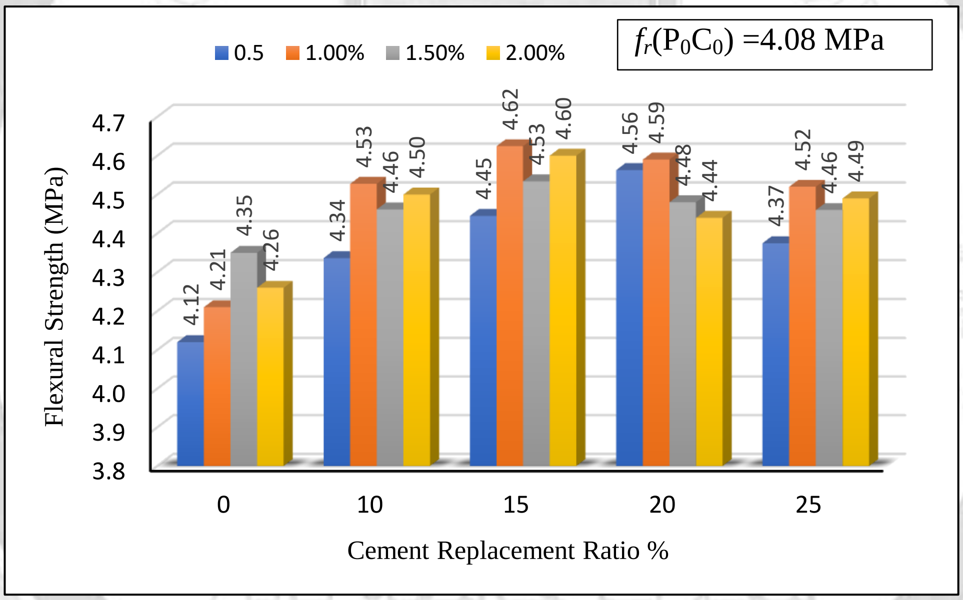

Figure (10) The Flexural Strength of concrete Versus the Ceramic Replacement Ratio Relationship for each PEG-4000 Ratio.

5. Conclusions

1- By lubricating the cement and aggregate particles, PEG-4000 increases the workability of concrete by up to 1%. By binding water and changing the viscosity of the liquid, higher dosages lessen slump.

2- To maintain satisfactory workability, 1% PEG-4000 is recommended, even when using a mild ceramic powder content of 10–15%. However, slump values may decrease if the PEG-4000 dosage or the ceramic powder content is significantly increased.

3- When PEG-4000 is applied as a self-curing additive, the dry unit weight of the concrete decreases slightly (at dosages of 0.5–2.0% by weight of cement). This is mostly due to decreased packing efficiency, possible creation of extra porosity, and higher internal water retention.

4- The optimal compressive strength is found to be at 10% cement replacement with 0.5% curing agent.

5- By keeping water in the mixture, PEG4000 improves early-age hydration and somewhat mitigates the strength defect caused by ceramic powder.5- The 10% ceramic replacement with 1.0–1.5% PEG 4000 is the optimal combination, as the advantageous self-curing effect makes up for the lower cement concentration and creates a more durable and finer microstructure.

6- In general, the obtained splitting tensile strength designate that 10% ceramic replacement with 1.0–1.5% PEG 4000 is the ideal combination, as the beneficial self-curing effect makes up for the lower cement concentration and creates a more durable and finer microstructure.

7- The complementary advantages of self-curing and pozzolanic reaction cause increased flexural strength at intermediate ceramic replacement (10–20%) with a combination of 1% PEG-4000 by approximately (12%).

References

[1]Agwa, I. S., Omar, O. M., Tayeh, B. A., & Abdelsalam, B. A. Effects of using rice straw and cotton stalk ashes on the properties of lightweight self-compacting concrete. *Construction and Building Materials*, 235, 117541, 2020. https://doi.org/10.1016/j.conbuildmat.2019.117541

[2]Tahwia, A. M., Hamido, M. A., & Elemam, W. E.. Using mixture design method for developing and optimizing eco-friendly ultra-high performance concrete characteristics. *Case Studies in Construction Materials*, 18, e01807, 2023. https://doi.org/10.1016/j.cscm.2023.e01807

[3]Lothenbach, B., Scrivener, K., & Hooton, R. D. . Supplementary cementitious materials. *Cement and Concrete Research*, 41(12), 1244–1256, 2011. https://doi.org/10.1016/j.cemconres.2010.12.001

[4]Torgal, F. P., & Jalali, S. . Compressive strength and durability properties of ceramic wastes-based concrete. *Materials and Structures*, 44, 155–167, 2011 . https://doi.org/10.1617/s11527-010-9616-6

[5]Jwaida, Z., Dulaimi, A., & Bernardo, L. F. A. The use of waste ceramic in concrete: A review. *CivilEng*, 5(2), 482–500, 2024. https://doi.org/10.3390/civileng5020024

[6]Pamnani, N. J., Verma, A. K., & Bhatt, D. R. Comparison of compressive strength of medium strength self-compacted concrete by different curing techniques. *International Journal of Engineering Trends and Technology (IJETT)*, 4(5), 2013 .

[7]Neville, A. M., & Brooks, J. J. . *Concrete technology*. Longman Group UK Limited, Pearson, 2010.

[8]Kosmatka, S. H., Panarese, W. C., & Kerkhoff, B. . *Design and control of concrete mixtures* (Vol. 5420). Portland Cement Association, Skokie, 2002.

[9]Olonade, K. A., Fitriani, H., & Kola, O. T. . Regression models for compressive strength of concrete under different curing conditions. In *MATEC Web of Conferences* (Vol. 120). EDP Sciences, 2017. https://doi.org/10.1051/matecconf/20171200123

[10]Yang, L., Shi, C., Liu, J., & Wu, Z. . Factors affecting the effectiveness of internal curing: A review. *Construction and Building Materials*, 267, 121017, 2021. https://doi.org/10.1016/j.conbuildmat.2020.121017

[11]Patel, M. K. D., & Pitroda, J. K. R. . Introducing the self-curing concrete in construction industry. *International Journal of Engineering Research and Technology*, 3(3), 2014.

[12]Elemam, W. E., Agwa, I. S., & Tahwia, A. M. (2023). Reusing ceramic waste as a fine aggregate and supplemental cementitious material in the manufacture of sustainable concrete. *Buildings*, 13, 2726. https://doi.org/10.3390/buildings13112726

[13]Alnour, M. A. A., Kambal, M. E. M., & Mansour, M. I. Study the effect of using ceramic waste powder as partial replacement for cement on concrete properties. *Journal of Karary University for Engineering and Science (JKUES)*, 1(1), 2021. https://doi.org/10.54388/jkues.v1i1.125

[14]Mokhtar, G., & Younis, S. Improve the characteristics of concrete using waste ceramic as a cement replacement ingredient. *Journal of Advanced Engineering Trends*, 44(2). ISSN 2682-2091, 2025.

[15]Vimala, G., SriLakshmi, K., Srinu, B., Bandi, S., Radhika, G., & Nagaveni, S. Performance evaluation of self-curing concrete using polyethylene glycol for enhanced strength and durability. *International Journal of Environmental Sciences*, 11(13s), 2025. https://theaspd.com/index.php

[16]Shelke, J., & Karale, S. S. , An experimental investigation on internal sealing of self-curing & self-compacting concrete using higher molecular weight polyethylene glycol (PEG). *International Journal of Creative Research Thoughts (IJCRT)*, 6(2), 2018. http://www.ijcrt.org

[17]Gopala Krishna Sastry, K. V. S., & Manoj Kumar, P. . Self-curing concrete with different self-curing agents. *IOP Conference Series: Materials Science and Engineering*, 330, 012120. https://doi.org/10.1088/1757-899X/330/1/012120

[18]Vimala, G., SriLakshmi, K., Srinu, B., Bandi, S., Radhika, G., & Nagaveni, S. (2025). Performance evaluation of self-curing concrete using polyethylene glycol for enhanced strength and durability. *International Journal of Environmental Sciences*, 11(13s), 2018. https://theaspd.com/index.php

[19]Iraqi Standard Institution. *I.Q. Standard No. 45: Portland cement.* Baghdad, Iraq.

[20]Central Organization for Standardization and Quality Control. (1984). *Iraqi Specification No. 45: Aggregates from natural sources for concrete and building construction.* Baghdad, Iraq, 2019.

[21]ASTM International. *ASTM C494/C494M-19: Standard specification for chemical admixtures for concrete.* West Conshohocken, PA: ASTM International, 2019.

[22]American Concrete Institute. *ACI 211.1-91: Standard practice for selecting proportions for normal, heavyweight, and mass concrete (Reapproved 2009).* Farmington Hills, MI: American Concrete Institute, 2009.

[23]ASTM International. *ASTM C143/C143M: Standard test method for slump of hydraulic-cement concrete.* West Conshohocken, PA: ASTM International, 2020.

[24]Portland Cement Association. *Design and control of concrete mixtures* (14th ed.). Skokie, IL: PCA, 1988.

[25]British Standards Institution. *BS EN 12390-3: Testing hardened concrete—Part 3: Compressive strength of test specimens.* London, UK: BSI, 2019.

[26]ASTM International. *ASTM C496/C496M-04e1: Standard test method for splitting tensile strength of cylindrical concrete specimens.* West Conshohocken, PA: ASTM International, 2011.

[27]ASTM International. *ASTM C293/C293M-20: Standard test method for flexural strength of concrete (using simple beam with center-point loading).* West Conshohocken, PA: ASTM International. https://doi.org/10.1520/C0293_C0293M-20Torgal, F. P., & Jalali, S. (2011). *Eco-efficient Construction and Building Materials*. Springer. ISBN 978-0-85729-891-1. DOI: 10.1007/978-0-85729-892-8, 2020.

[28]Simel Chemical Industry Co., Ltd., & Hebei Simel Import & Export Trading Co., Ltd. (n.d.). *Technical data and specifications of polyethylene glycol (PEG-4000).* Shijiazhuang, Hebei Province, China: Simel Chemical Industry Co., Ltd. https://www.simelchem.com

ARTICLE
JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلـة جـــامعة بــــابـل للعلـــــوم الهندسية
Vol. 33, No.6. \ 2025 ISSN: 2616 - 9916

الخواص الميكانيكية للخرسانة ذاتية المعالجة والحاوية على مواد معاد تدويرها

نادية صديق إسماعيل الصفار

قسم الهندسة المدنية، كلية الهندسة، جامعة الموصل، الموصل، العراق

Nadiya.alsaffar@uomosul.edu.iq

الخلاصة:

تهدف هذه الدراسة إلى استكشاف التأثيرات المشتركة لاستخدام مسحوق السيراميك المعاد تدويره (RCP) كبديل جزئي للإسمنت، وإضافة بولي إيثيلين جلايكول (PEG-4000) كمادة للمعالجة الذاتية، على خصائص الخرسانة من حيث القوة واللدونة. شمل البرنامج العملي اختبارات مقاومة الانضغاط، مقاومة الشد بالانشطار، مقاومة الانحناء، الكثافة، إضافةً إلى قياس قابلية التشغيل (الهبوط).

لزيادة الاستدامة وتقليل انبعاثات ثاني أكسيد الكربون، تم استبدال جزء من الإسمنت بمسحوق السيراميك بنسب 10%، 15%، 20%، و25%، بينما أضيف PEG-4000 بنسب 0%، 0.5%، 1%، 1.5%، و2% من وزن الإسمنت.

أظهرت النتائج أن الجرعة المثلى من PEG-4000 للحفاظ على قابلية التشغيل الجيدة في الخلطات المحتوية على مسحوق السيراميك تبلغ حوالي 1%. كما لوحظ أن استخدام مسحوق السيراميك كبديل جزئي يقلل من كثافة الخرسانة بشكل عام. فيما يخص المقاومة، حققت أعلى مقاومة ضغط عند استبدال 10% من الإسمنت مع إضافة PEG-4000 بنسبة 0.5%.

أما مقاومة الشد بالانشطار، فقد تأثرت بشكل ملحوظ بإضافة مسحوق السيراميك، حيث تم تحقيق الأداء الأمثل عند استبدال 10% من الإسمنت بالسيراميك مع (1.0 –1.5) % من PEG-4000، إذ ساعدت المعالجة الذاتية في تعويض نقص محتوى الإسمنت وتكوين بنية مجهرية أكثر كثافة وقوة. كما لوحظت زيادة في مقاومة الانحناء عند نسب الاستبدال المتوسطة (10–20%) مع 1% من PEG-4000، نتيجة للتفاعل الإيجابي بين المعالجة الذاتية والنشاط البوزولاني. وبلغت أعلى زيادة في مقاومة الانحناء حوالي 12% عند 15% من مسحوق السيراميك و1% من PEG-4000 مقارنة بالخلطة المرجعية.

الكلمات الدالة: بديل الأسمنت، بولي إيثيلين جلايكول PEG4000، الخرسانة ذاتية المعالجة، مسحوق السيراميك المعاد تدويره.