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Effect of Eggshell Powder Application on the Early and Hardened Properties of Concrete

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ABSTRACT

In this study, the role of eggshell powder and its effect on concrete's mechanical properties and to achieve the optimum percentage of eggshell utilization for higher strength and durability were investigated. The eggshell was grounded and heated to 950°C for 2 hours, and by XRD test, the chemical analyses were carried out and compared with Portland cement. Experimental tests including water absorption percentage, the specific gravity of concrete, electrical resistance test (indicating corrosion and permeability), flexural strength, and compression strength were performed on samples with 0, 10, and 20 wt% cement replacement eggshell. The tests were carried out at 3, 7, and 28 day age on 15 cm cube specimens. Flexural tests were carried out on prisms 100x100x500mm. The results of tests on concrete showed that replacement of 10% eggshell causes 12% slump reduction, 1% increase in compressive strength, 21% decrease in water absorption, 2% increase in concrete, specific weight, and 90% increase the electrical resistance in comparison with 0% eggshell (control specimen). 20% cement replacement eggshell causes 24% decrease in a slump, a 17% decrease in compressive strength, and 4% enhanced in water absorption, a 1% increase in specific gravity, and a 90% increase in electrical resistance in comparison with control specimen. Corrosion in the control specimen is fairly certain, while with 10% and 20% eggshell in both mixes, corrosion is less possible. The results of the compression test are compared to other research work in order to present the different %eggshell on concrete strength. The results of this study suggest that the use of eggshell substitutes an appropriate proportion replaced cement gives a suitable quality and also causes a safer environment.

Keywords: Compressive strength, Eggshell powder, Water absorption percentage, Specific gravity, Concrete electrical resistance.

1. INTRODUCTION

Nowadays, the use of by-product materials in concrete is of great importance due to the reduction of environmental hazards and the prevention of wastage of primary resources, and cost reduction. The design and production of various cement-based products have led to various additives to the mix design of this product. In the concrete sustainable development industry, those materials can be used to produce cement-based products that have a little environmental impact. Based on the rare properties of concrete, it has been widely used throughout the world in the present century, and the demand for concrete is in progress. What is certain is that concrete research and development must be done to meet the needs of the industrial community [1,2]. The research presents by AlaaJaber et al. [3] is presented an experimental investigation of eggshell powder (ESP) addition influence on the Portland cement mortar performance. Two different eggshell powders states were prepared. These include untreated eggshell powder (UESP) and treated eggshell powder (TESP). The TESP consists of heating the ESP to 750 °C for one hour in an electric furnace. Cement mortar of ordinary Portland cement with [4, 5], (cement to sand) ratio, were mixed with each of two ESP states (UESP and TESP) at different percentages ranged from (0 to 20) wt. % of the total weight of the cement mortar mixture. They concluded that the better thermal insulation of mortar samples was obtained from the addition of UESP, reaching the rate of reduction in the thermal conductivity to 40% than the control mortar [3]. Egg consumption in Iran is over 930000 tons per year; eggshell weight is more than 10% of the weight of one egg. In this study, the use of eggshell scraps containing more than 80% calcium carbonate (CaCO3) as limestone is replaced as a part of cement in concrete was studied and tested. For this purpose, the eggshell was heated after grinding and powdered (passing a sieve score of 200, that is, smaller than 0.076 mm in diameter) for 2 hours in the oven at 950 °C to CaCO3 calcium carbonate converted to CaO or lived lime. The resulting product was replaced by part of the cement in concrete and tested for evaluation of the concrete properties, including compressive strength, flexural strength, water absorption, specific gravity, electrical resistivity, and durability of the new concrete [2]. A paper describes research carried out into the use of poultry waste in concrete through the development of concrete incorporating eggshell powder (ESP). Different ESP concretes were developed by replacing 5-15% of ESP for cement [4]. The results indicated that ESP could successfully be used as a partial replacement of cement in concrete production. The data presented cover strength development and transport properties. Concerning the results, at 5% ESP replacement, the strengths were higher than control concrete and indicate that 5% ESP is optimum for maximum strength. In addition, the performance of ESP concretes was comparable up to 10% ESP replacement in terms of transport properties with control concrete. The results further show that the addition of fly ash and ESP is beneficial for improved concretes' performance. Compressive strength was higher than control concrete for 5 % ESP replacement at 7 and 28 days of curing ages. ESP replacements greater than 10 % had lower strength than control concrete. The addition of fly ash improved the compressive strength of ESP concrete. Split tensile strengths of ESP concretes were comparable with control concrete up to 10 %. However, concrete with 15 % ESP had lower split tensile strength than control concrete. As in compressive strength, the addition of fly ash improved the split tensile strength of 15 % ESP concrete. ESP performance was nearly the same as that of the limestone filler in concrete. The results demonstrated that irrespective of ESP percentage replacement, there was a good relationship between compressive strength and split tensile strength. Absorption characteristics show that the initial 30 min absorption values for all the concretes were lower than limits commonly associated with good quality concrete [5]. The maximum absorption observed was 1.87 % for 15 % ESP and 15 % fly ash concrete. The absorption decreased with a decrease in permeable voids. The Sorptivity of the concretes was comparable with control concrete up to 10 % ESP replacement. However, 15 % ESP concrete and 15 % ESP and 15 % fly ash concrete were higher than control concrete. The maximum sorptivity was for ESP, and fly ash replaced concrete with 0.17 mm/s0.5. Sorptivity decreased with strength and increased with water absorption. D.Gowsika et al. [6] Experimentally investigated the Egg Shell Powder as Partial Replacement with Cement in Concrete. This paper reports the result, so experiments evaluating the use of eggshell powder from the egg production industry as a partial replacement for ordinary Portland cement in cement mortar. The chemical composition of the eggshell powder and the compressive strength of the cement mortar was determined. The cement mortar of mix proportion1:3 in which cement is partially replaced with egg shell powder as 5%, 10%, 15%, 20%, 25%, 30% by weight of cement. The compressive strength was determined at curing ages 28 days. The sharp decrease in compressive strength beyond 5% eggshell powder substitution. The admixtures used are Sawdust ash, Fly Ash, and Micro silica to enhance the strength of the concrete mix with 5% eggshell powder as a partial replacement for cement. In this direction, an experimental investigation of compressive strength, split tensile strength, and Flexural strength was undertaken to use eggshell powder and admixtures as a partial replacement for cement in concrete [6]. Shiferaw et al. [7] illustrated that the utilization of eggshell powder in cement helps to reduce the carbon dioxide emissions from cement factories in producing clinker. In their study, the effect of eggshell powder on the hydration of cement products was investigated using X-ray diffraction (XRD), thermogravimetric analysis (TGA), Fourier-transform infrared spectroscopy (FT-IR), and scanning electron microscopy (SEM). Pastes were made with 10% and 20% eggshell powder and examined for 1, 14, and 28 days of hydration. The addition of eggshell powder transformed ettringite to mono-sulfoaluminate and to mono-carboaluminate. In 20% eggshell powder, the formation of mono-carboaluminate was detected in the early stages and accelerated the hydration reaction. The CaCO3 from the eggshells reacted with the C3A and changed the hydration products of the pastes. The addition of eggshell powder provided nucleation sites in the hydration products and accelerated cement hydration. Eggshell powder is not only a filler material but also participates in the hydration product of cement. From the point of solid waste recycling, the utilization of eggshells is one of the sustainable, feasible, and cost-effective methods. Eggshells can easily be found in households, chicken factories, and egg breaking factories; thus, from the point of using cheaper materials for cement, eggshells can be an alternative material. It also helps to reduce the emission of CO2 from cement factories by reducing the amount of clinker produced and the energy generated in the production of Portland cement [7]. As a result of this investigation, the addition of eggshell powder to Portland cement accelerates the hydration reaction by reacting with tri-calcium silicate (C3S) and influences cement's hydration product paste by providing nucleation sites. The precipitation of CSH is also promoted by the nucleation effect of ESP. Cement with ESP addition shows a great increase in the degree of hydration starting from the early stages. Nisar Ahmed Gabol et al. [8] carried out a research using ESP with various percentages as a partial replacement in concrete mixes. The main objective of the study was to determine the workability and reinforcing properties, including compression, tensile and flexural strength of concrete using various percentages (0, 2.5, 5, 7.5 & 10) of ESP by weight replaced cement. A total of 120 concrete samples were cast (60 cubic meters, 30 cylinders, and 30 prisms) with a target strength of 28 N/mm2. The compressive strength of a cube sample (100 × 100 × 100 mm) was tested after 3, 7, and 28 days, while tensile strength was also measured for 3 days, 7 days and 28 days using a cylindrical specimen (200 × 100 mm). The bending strength of the specimen (100 x 100 x 500 mm), cast during 3, 7, and 28 days of curing. Results showed, the percentage of ESP increased, the workability of fresh concrete decreased. Also, results show that compressive and tensile strength using eggshell powder reduced, the flexural strength increased by 7.5%, permeability decreased over a long period, and eggshell increased carbonation process in concrete. Sugirtha and Sargunan [9], in their paper, summarizes the various research papers that deal with the investigations on cement concrete proportioned with eggshell powder as a substitute. This paper briefly reveals the investigations endured on strength and structural characteristics of conventional cement concrete that are evenly proportioned with calcium-rich eggshell powder.

Chandrasekaran [10] carried out a fairly comprehensive experimental test research on using eggshell as partial replacement of cement of M20 concrete. He concluded that outstanding performance was obtained with eggshell ash. It was found that eggshell ash can partially substitute cement in the concrete mix at 30 to 40%, thereby increasing its strength characteristics. Incorporation of eggshell ash into concrete improved compressive, flexural, and split tensile strengths and durability of the concrete. The experimental results further indicated other advantages of such partial substitution at 30 or 40%, including enhanced concrete performance and structural resistance against seismic events.

2. MATERIALS AND METHODS

The sand used is normal washed rivers, and the aggregate is irregularly fractured in both 9.5 and 19 mm, where the requirements of ASTM C330 [11] are met. The physical properties of the aggregates consumed are presented in Table (1).

Table 1. Physical characteristics of aggregates used in the fabrication of samples

aggregate	Max. size of aggregate(mm)	Specific density gr/cm3	% absorb water	Specific weight (gr/ cm3)In SSD
Large aggregate	19	2.64	0.48	2.63
Small aggregate	9.5	2.62	0.91	2.61
sand	4.75	2.59	1.67	2.58

2.1. Sand-aggregate Grading Chart

Sand-aggregate Grading chart is presented based on the standard is shown in Figure 1. As it can be seen, the grading sand- aggregate used in this work (red line) is mostly within the limit presented in Figure 1.

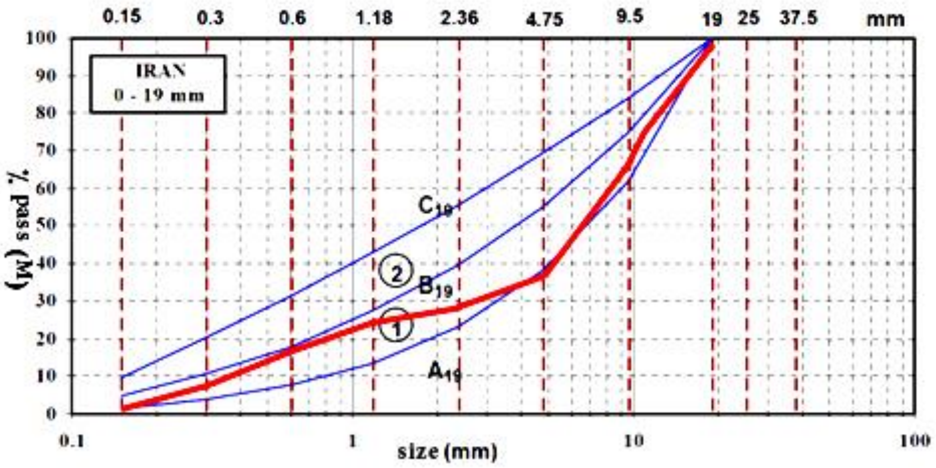

Figure 1. Grain diagram used in the construction design (National Concrete Mix Design Method Diagram [12])

In this research, consuming cement in all types of mixing designs was Portland cement type II of Khuzestan Cement Company with ASTM C150-84 [13] standard was used. Table 2 presents the elemental analysis specifications of Type 2 cement. Table 3 shows the average composition of Portland cement type 2 and their comparison with the Iranian standard.

Table 2. Elemental Cement Specifications of Type 2 Cement Based on Elemental Analysis and Comparison with Iranian Standard

Composition	Blaine (cm2/gr)	SiO2 %	Al2O3 %	Fe2O3 %	CaO %	MgO %	SO %	LIO %
OPC type II	3150	20.03	3.72	3.38	64.4	1.54	2.23	2.76
ISIRI-389	≥2800	≥20	≤6	≤6	-	≤5	≤3/5	≤3

Table 3. Average of Major Composition of Portland cement Type 2 [12] and Comparison with Catalog of Khuzestan Cement Company and Iranian Standard

	C4AF	C3A	C2S	C3S
OPC type II (Khuzestan)	9.8	7.8	27.9	46.9
OPC type II	11.9	7.1	16.2	58.00
ISIRI-389	---	8>	---	---

2.2. Eggshell powder

Eggshell scraps can be made from incubators or pastries. The eggshell color at the time of milling is white as in (2a), but after heating the new egg shell is as gray as (2b).

Figure (2a). Eggshell powder

Figure (2b). Heated egg shell powder

Eggshell, after grinding and powdering (by passing a sieve score of 200, that is, (smaller than 0.076 mm in diameter) for 2 hours at the oven to 950 ° C, to convert $CaCO_3$ calcium carbonate to CaO lime. Elemental analysis, according to the XRD experiment, is presented in Tables 4. Flexural strength is carried out based on ASTM C293-02 [14]: with a loading rate of 0.5 kN/s curing regime on the flexural strength of eggshell concrete prism. Evidently, water curing is the most suitable type of curing in order to obtain a better flexural strength of the eggshell concrete beams. The satisfactory performance of the water-cured eggshell concrete is due to the improvement in the pore structure; the concrete may have lower porosity as a result of the high degree to which the hydration process takes place without any moisture being evaporated into the air.

2.3. SCAN ELECTRON MICROSCOPE (SEM) IMAGES

The SEM analysis of ordinary Portland cement (OPC) and the sample containing eggshell powder (ESP) is shown in Figure 3. In both samples, portlandite (plate-like shape) and CSH (sheet-like structure) are the major hydration products. In OPC (Figure 3a), a needle-like structure is visible, which indicates the presence of ettringite. In samples containing ESP (Figure 3b), ettringite is not shown because of the presence of calcium carbonate in the sample; instead, mono-carboaluminate is visible, which is a crystalline structure. Baquerizo et al. [15] also found a crystalline morphology of mono-carboaluminate in studies. In the presence of calcium carbonate, the stability of ettringite is very low.

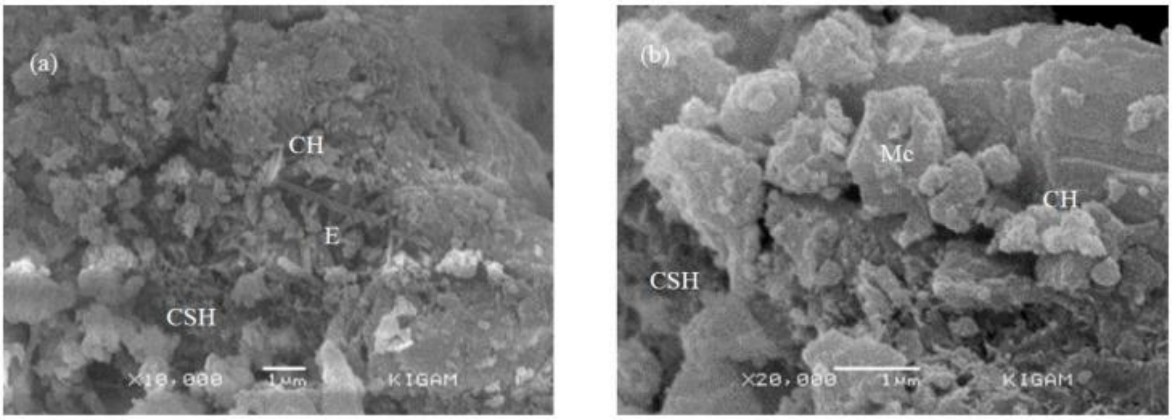

Figure 3. SEM image of (a) ordinary Portland cement (OPC) and (b) samples containing eggshell powder [16].

The XRD analysis was carried out on eggshell used in this work and compared with type II cement and presented in Table 4. The Blaine and CaO are approximately had similar values in both materials.

Table 4. Elemental Analysis Properties of Eggshell and cement

Material	Blaine (cm2/gr)	SiO2 (%)	Al2O3 (%)	CaO (%)	MgO (%)	SO3 (%)	LIO (%)
eggshell	≥ 3150	0.07	0.06	54.92	0.66	0.23	43.14
Type II cement	3150	20.03	3.72	64.4	1.54	2.23	2.76

The effect of eggshell as partially cement replacement in concrete is investigated and compared with cement.

2.4. PROPERTIES OF MIXING DESIGNS

The mixing design used in the construction of the control concrete in this study is in accordance with ACI-211-89 [16]. In this study, 3 mixing designs were used, one of them as control concrete and the other two designs with a constant water-to-cement ratio of 0.5 and variation in cement content with percentages of eggshells with values of 0, 10%, and 20% replacement of cement samples were made. The general specifications of these schemes are presented in Table 5.

Table 5. Mixing scheme specifications

Material	Control specimen 0% eggshell	sample 10% eggshell	sample 20% eggshell
Sand (kg/m3)	750	750	750
9mm agg.(kg/m3)	345	345	345
20mm agg.(kg/m3)	695	695	695
Water (lit)	185	185	185
Cement (kg/m3)	370	333	296
Egg shell powder (kg/m3)	0	37	74
Water / (cement + eggshell powder)	0.5	0.5	0.5

2.4.1. Mechanical Properties Analysis

The compression strength test was carried out using a testing machine with a loading rate of 2.4 kN/s, while the flexural strength test employed a U-test machine with a loading rate of 0.5 kN/s. The samples were tested at room temperature after full water curing. Both compressive and flexural strength tests consisted of five specimens at each composition and were averaged, respectively. Subsequently, a compression test was performed according to BS 1881: Part 116 [17], while a flexural strength test was performed according to BS1881: Part112 [18]. In this study, different laboratory tests were performed on conventional concrete as control concrete and with (0,10 and 20) percent egg replacement cement consumed at 3, 7, and 28 days of age and individually on 15 * 15 * 15 cm cubic specimens and prism 100 x 100 x 500mm. After molding, the specimens were applied with a damp cloth to prevent evaporation, and after 24 hours, immersed in wet conditions. Then some samples were treated for up to 3 days, 7 days, and others for up to 28 days according to the type of test and standard. After 3, 7, and 28 days of water treatment, the samples were removed from the water in order to schedule the experiments.

2.5. WATER ABSORPTION

The results of the rate of water absorption for water-cured specimens, referring to Figure 9. It can be seen that the permeability of the eggshell concrete for water-cured concrete specimens was greatly reduced. The rate of penetration measured by the rate of water absorption for water-cured specimens was reduced. Thus, the eggshell powder may be a good filler for concrete as it provides extra calcium to produce more secondary C–S–H gel [19].

2.6. FLEXURAL TEST

Figure 4 shows the method to exert flexural load to a prism that is used in this research. The test was carried out under one point flexural loading (3 point bending) based on ASTM C293-02 or BS1881: Part112 [18, 20].

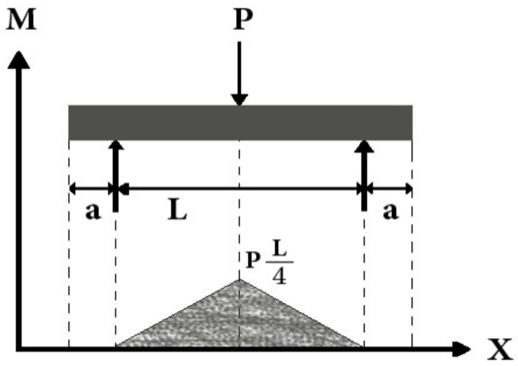

Figure 4. Schematic of flexural loading system

3. RESULTS AND DISCUSSION

3.1. SLUMP TEST

The eggshell absorbs more water than the cement because its particles are slightly smaller, and this reduces the slump of the concrete. The results of experiments conducted in this study, according to ASTM C143 [21], showed that the liquidity and workability changes of concrete contain different percentages of eggshell are more varied than control concrete. The results of this experiment are presented in Figure (5). Slump and workability are reduced by replacing eggshell replacement cement.

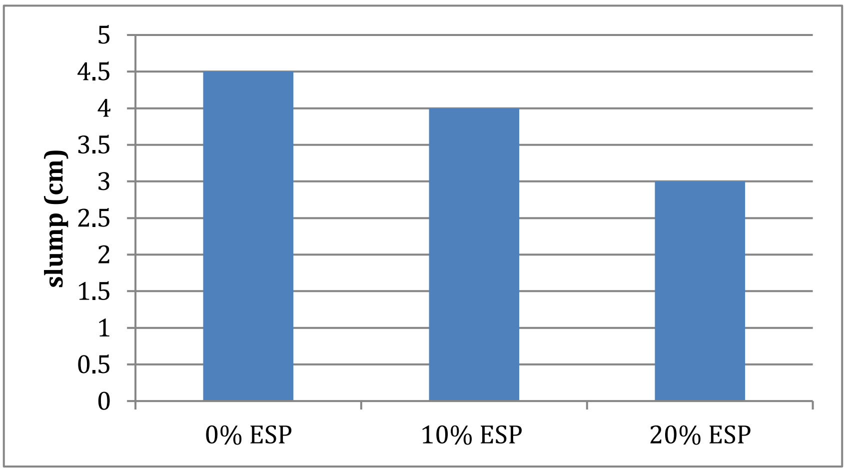

Figure 5. Slump rate diagram of the mixes

3.2. SPECIFIC WEIGHT OF FRESH AND HARDENED CONCRETE

The results of this experiment, which are in accordance with BS EN 12390-1: 2012, are shown in Figures (6) and (7).

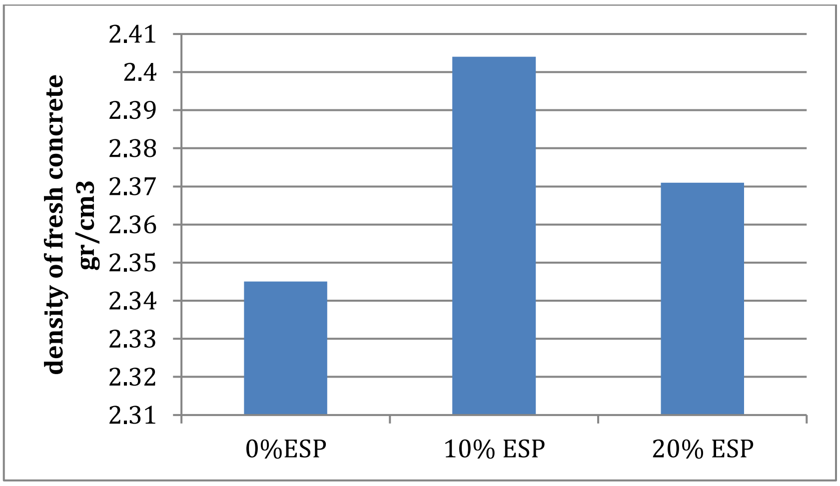

Figure 6. Specific weight for fresh concrete designs

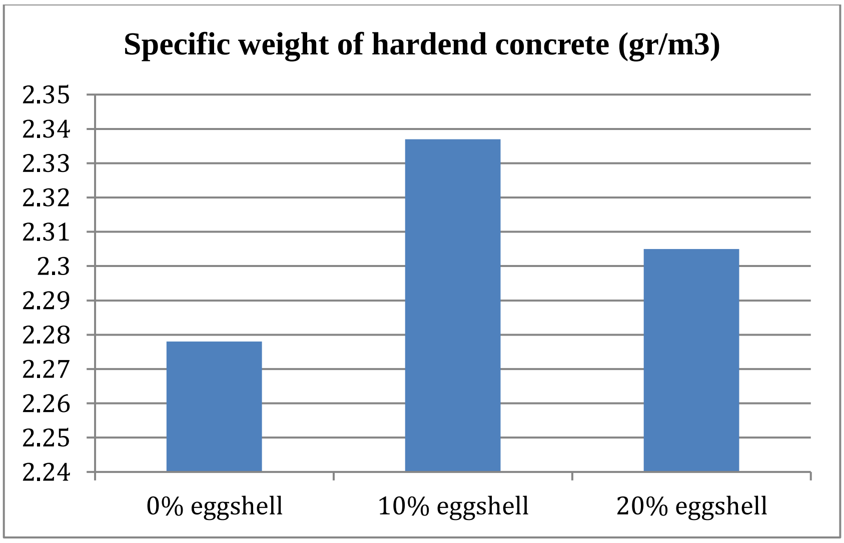

Figure 7. 28-day specific gravity chart of hardened concrete designs

The results of this experiment showed an increase in specific density of concrete by 10% eggshell replaced of cement is 0.059 g /cm3 greater compared to the control concrete, but by an increase of eggshell to 20% the gravity concrete is 0.032 g /cm3 and decreased in respect to 10% the eggshell, but its specific gravity still was higher than that of the control specimens. Subsequently, by replacing the eggshell with cement, it can be seen an increase in the specific gravity of hardened concrete in the eggshell specimens, which continues to increase until the 10% eggshell and decreased in the 20% eggshell specimens. The same can be expected to be seen in the results obtained from the specific gravity of fresh concrete due to the greater hydration rate at an early age.

3.3. WATER ABSORPTION RATE

This test was performed according to BS 1881 - Part122 [22]. Concrete specimens can be visualized by coring Taken from cube specimen according to Figure 8.

Figure 8. Core taken from cube specimens

The results of the coring sample taken from cubes had shown the percentage of water absorption, which can be seen in Table 6 and Figure 9.

Table 6. Water absorption rate of samples at 28 days of age

characteristic	Height of specimen (mm)	Weight of dry specimen (gr)	Weight of wet specimen (gr)	Water absorption (gr)	Modify Water absorption (%)
Eggshell 0%	150	965.86	1009.82	43.96	4.55
Eggshell 10%	150	990.42	1027.41	36.98	3.60
Eggshell 20%	150	977.16	1023.65	46.49	4.76

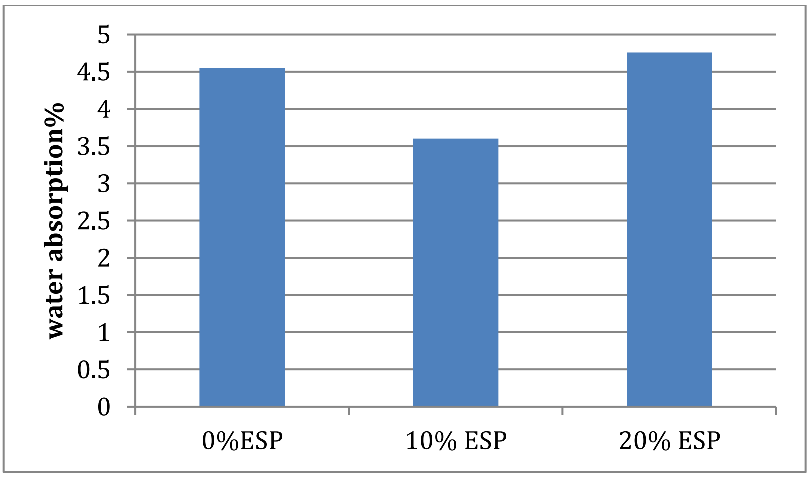

Figure 9. 28-day water absorption for design mixes

According to the results of this study, for the eggshell 10%, the percentage of water absorption in the samples decreased. So, the lowest percentage of water absorption is related to concrete containing 10% eggshell (i.e. 3.6gr). As can be seen from the results, water absorption increased by 32% in concrete with 20% eggshell compared to concrete with 10% eggshell. Therefore, the replacement of 10% eggshell with cement is considered as the optimum percentage for water absorption. Also, by comparing the results obtained in this experiment with Table (7) [22], it can be seen that the positive results (2-4%) on the positive effects of eggshell on the production of low permeable and durable concrete for severe environmental conditions.

Table 7. Permissible values determined from permeability tests on reinforced concrete for indicating durability under environmental conditions in the region [23]

Experiment	The permissible limit		
	Condition A	**Condition B and C**	**Condition D and E**
Half hour water absorption BS 1881 – Part122	Max 4 %	Max 3 %	Max 2 %
Water immersion in 28 days BS EN 12390-8:2000	Max 50 mm	Max 30 mm	Max 10 mm
Chloride immersion in 28 days ASTM C 1202,1994	Max 3000 Coulombs	Max 3000 Coulombs	Max 1500 -2000 Coulombs for D and E

Note that 2000-4000 coulombs indicate moderate permeability due to chloride immersion

3.4. Electrical resistance of concrete and its relation with corrosion

In this study, electrical resistivity tests were performed on 28-day-old cubic specimens according to ASTM Standard C1202-10 [23]. The method of reading the numbers in this experiment was that three readings were made on three sides of each sample, and the results and mean values of electrical resistance of the three samples in 28 days are presented in Table (8). Also, for comparison and growth of electrical resistance changes of each design mix's samples at 28 days, their results are plotted in Figure (11). Correlation of electrical resistance of concrete with corrosion rate according to Standard C1202-10 [23] is given and compared the results. Overall, concrete's electrical resistivity can be described as the ability of concrete to withstand the transfer of ions subjected to an electrical field. In this context, resistivity measurement can be used to assess the size and extent of pores' interconnectivity. Corrosion is an electro-chemical process. The rate of flow of the ions between the anode and cathode areas, and therefore the rate at which corrosion can occur, is affected by the resistivity of the concrete [20, 24]. To measure the concrete's electrical resistivity, a current is applied to the two outer probes, and the potential difference is measured between the two inner probes. Empirical tests have arrived at the following threshold values, which can be used to determine the likelihood of corrosion.

- When $\rho \geq 120$ Ω-m corrosion is unlikely
- When $\rho = 80$ to 120 Ω-m corrosion is possible
- When $\rho \leq 80$ Ω-m corrosion is fairly certain

These values have to be used cautiously, as there is strong evidence that chloride diffusion and surface electrical resistivity is dependent on other factors such as mix composition and age [25]. The electrical resistivity of the concrete cover layer decreases due to [26]:

- Increasing concrete water content
- Increasing concrete porosity
- Increasing temperature
- Increasing chloride content

When the electrical resistivity of the concrete is low, the rate of corrosion increases. When the electrical resistivity is high, e.g. in case of dry and carbonated concrete, the rate of corrosion decreases.

3.4.1. Four Probs

On-site electrical resistivity of concrete is commonly measured using four probes in a Wenner array. The reason for using four probes is the same, as in the laboratory method - to overcome contact errors. In this method, which is used in this study (Figure 10) four equally spaced probes are applied to the specimen in a line. The two outer probes induce the current to the specimen and the two inner electrodes measure the resulting potential drop. The probes are all applied to the same surface of the specimen, and the method is consequently suitable for measuring the resistivity of bulk concrete in situ.

The resistivity is given by:

$$\rho = 2\pi a \frac{V}{I} \tag{1}$$

V is the voltage measured between the inner two probes (measured in volts, V)

I is the current injected in the two outer probes (measured in amps, A)

a is the equal distance of the probes (measured in meters, m) [20, 23].

Figure 10. Apparatus of resisto-meter and the method used the electrical resistance of specimen

The results of electrical resistance tests on the mix are presented in Table 8 and Figure 11.

Table 8. Average electrical resistance of designs (Ω. m)

% mix	Eggshell 0%	Eggshell 10%	Eggshell 20%
Electric resistance 28 days Ω-m	52	99	99

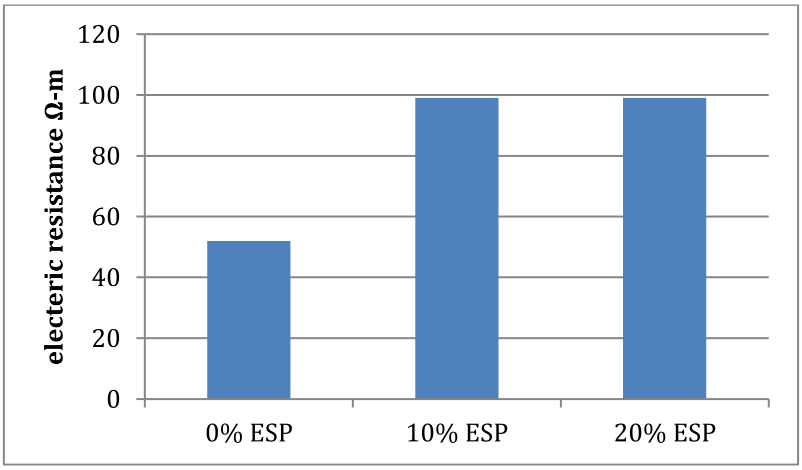

Figure 11. Graph of the average electrical resistance (Ω-m) of the designs mixes

The results of this study show that by adding eggshell, electrical resistivity in all designs mix increased, which could be due to reduced porosity and permeability of concrete. Therefore, 10 and 20 percent designs exhibit the highest resistance growth in the hardened state, so that for concrete containing 10 and 20 percent eggshell approximately 1.9 times higher than the electrical resistance of concrete with zero percent eggshells, there is an increase in electrical resistance. Therefore, in this experiment, the highest amount of electrical resistance was observed in the design containing 10 and 20% eggshell, and it seems that with more than 20% eggshell growth, we will continue to experience electrical resistance in concrete. Also, by comparing the numbers obtained in this experiment with the data given by ASTM C1202-10 [25], we can see the positive results of the eggshell effect on durable concrete construction with low permeability and corrosion rate lesser than control specimen.

3.5. COMPRESSIVE STRENGTH

The most important characteristic expressed as a mechanical property of concrete is compressive strength. This test was performed in accordance with BS EN 12390-3: 2009 on 150mm cubic meters at 3, 7, and 28 days of age, and the mean results are given in Table 9. Also, to compare and increase each design's compressive strength changes at 3, 7, and 28 days of age, their results are plotted in Figure 12. The composite graph of the compressive strength of the average concrete designs is drawn

Table 9. Average compressive strength of construction designs

% mix	Eggshell 0%	Eggshell 10%	Eggshell 20%	Variance (SD)	Testing Temp.	RH%
Compressive strength 3 days (kg/cm2)	183	187	156	4	25	19
Compressive strength 7 days (kg/cm2)	222	233	196	3	25	19
Compressive strength 28 days (kg/cm2)	365	370	306	3	25	19

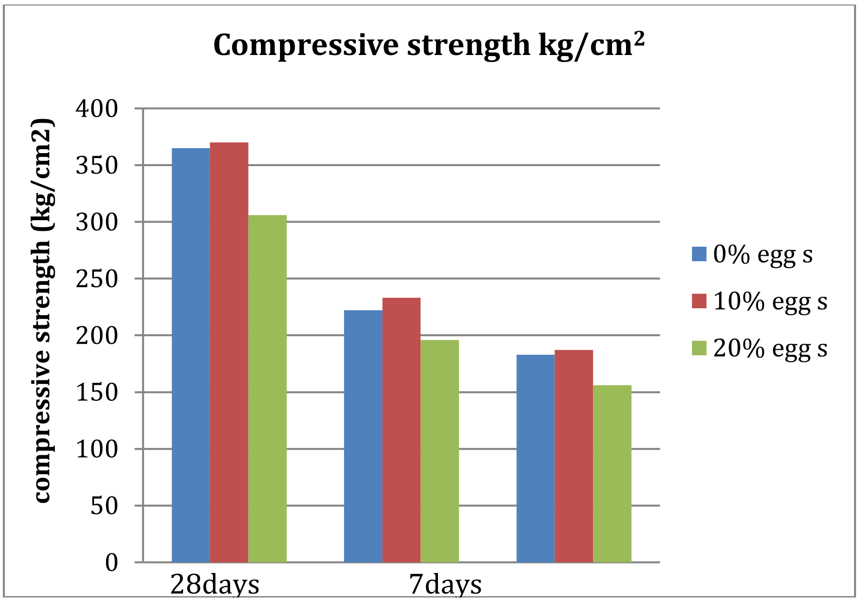

Figure 12. Composite graph of average compressive strength of concrete with (0-10-20) percent eggshell

Figure 13 represents the comparison between the compression strength of eggshell powder replacement cement using the results from this research (0, 10, and 20%) eggshell and other research (0, 6, 12, 18, and 24%) [27, 28].

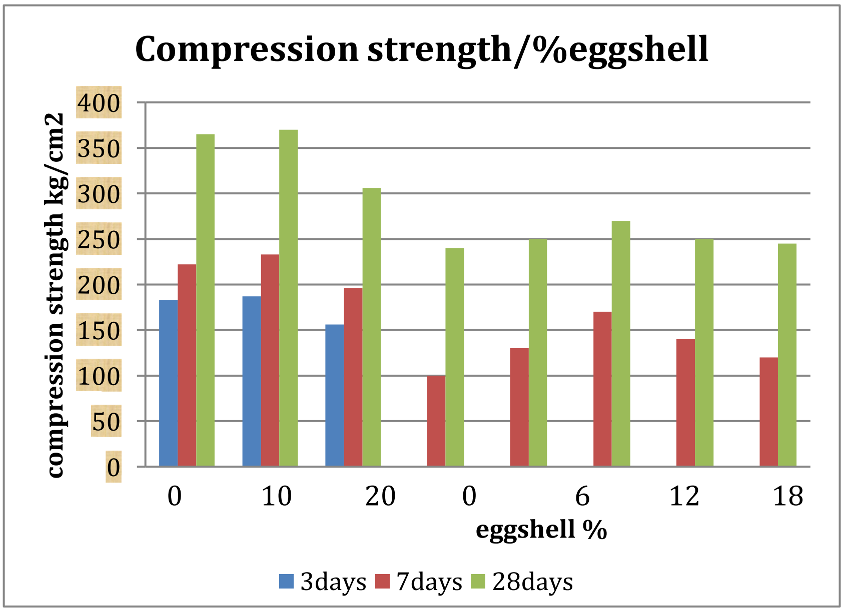

Figure 13. results of compressive test at different eggshell replacement cement

From Figure 13, at 7 days strength for 6%, 10%, 12%, 18%, 20% and 24% eggshell replaced cement the strength increased or decreased by about 20%, 5%, 17%, 14%, -0.12% and 15%, of control specimen respectively. From Figure 13, at 28 days strength for 6%, 10%, 12%, 18%, 20% and 24% eggshell the strength increased or decreased by about 6.4%, 0.14%, 21%, 4%, -0.16% and 0%, in respect with control specimen respectively. Therefore according to the above result, at 7 days strength 6% eggshell and for 28 days strength 12% eggshell gives higher strength than control specimen. This variation in strength may contribute to the procedure of providing eggshell, filling capacity, microstructures of eggshell particles, and the porosity in concrete. However, the highest strength at 28days is at 12% eggshell replaced cement. The comparison of the results shown the replacing eggshell at various eggshell replacements at 7 days mainly has a positive effect on concrete strength development.

3.6. Flexural strength

The results of the flexural strength shown in Figure 14 highest flexural is obtained for 10% eggshell at both 7 and 28 days in comparison with 0% and 20%.

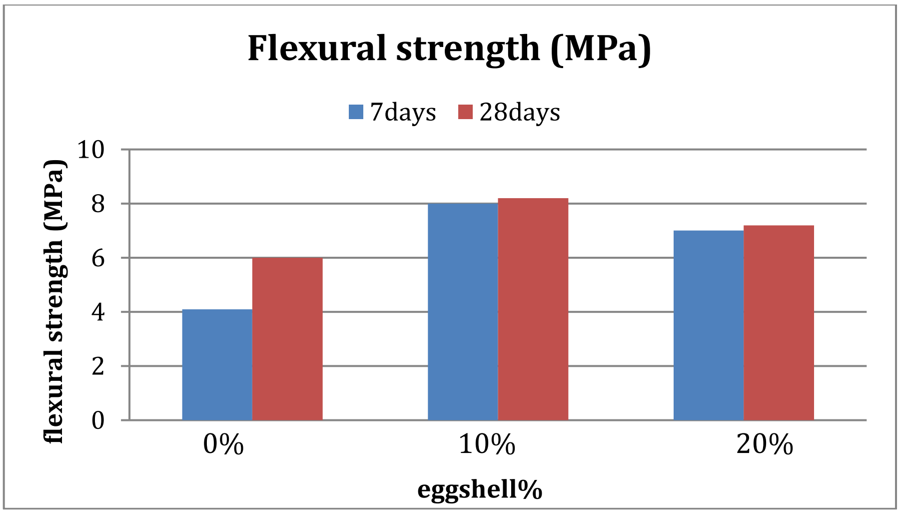

Figure 14 results of flexural test at 0, 10, 20% eggshell replacement cement

3.7. COMPRESSIVE STRENGTH

The results of the compressive strength test of the designs, as can be seen from Fig. 8, indicate the improvement and growth rate of compressive strength in all Pozzolanic designs compared to the control concrete, which increased slightly in the early age (7 days). Compared to control concrete, it is more intuitive in the hardened state (28 days). Increasing the percentage of eggshell replacement by cement increases the compressive strength of concrete by 10%. Therefore, the highest increase in compressive strength was related to the 10% eggshell design of replacement cement with 4 kg /cm2 at 3 days and 11 kg/cm2 at 7 days and with 5 kg/cm2 at 28 days compared to control concrete. It was also observed that by adding 20% eggshell to cement, the compressive strength of concrete decreased, and its amount was lower than the compressive strength obtained from control concrete. So, it can be said that in the pozzolanic design, 10% eggshell is used to improve the compressive strength of the concrete. However, using 20% eggshell instead of cement in concrete decreases the strength of control concrete. Therefore, the replacement of 10% eggshell with cement as the optimum percentage is considered to be the highest compressive strength.

4. CONCLUSION

The following results are obtained from this research are divided into the early and hardened state of concrete with eggshell.

4.1. PROPERTIES OF EARLY AGE CONCRETE BY REPLACING PARTIALLY CEMENT BY THE EGGSHELL

The liquidity content of concrete is lower than that of control concrete but exceeds the minimum recommended in the standard. Workability depends on the amount of concrete slump made. The slump rate is controlled according to the standard recommended in Issue 55 [22], and the contractors are required to produce the required concrete based on the slump requested in the specifications and performance criteria. Concretes that do not meet the required specifications when casting should be rejected and should be discarded and removed from the workshop. In this study, the slump for 20% eggshell was only 3 cm, which shows low workability, during the slump for 10% eggshell 4cm and control 4.5 cm. This shows by adding eggshell, and a stiffer mix is obtained.

- Specific gravity of fresh concrete with eggshell increased compared to that of control concrete; this increase in specific gravity in concrete with 10% eggshell more than other samples.

- Cement with the addition of ESP eggshell powder can have a great increase in the degree of hydration starting from the early stages. The setting time in the concrete samples with eggshell is reduced compared to the control concrete. The temperature of concrete due to cement and water reactions, especially in bulk concrete, causes thermal stress and eventually crack in the concrete. By adding eggshell or replacing it with cement, the increase in the initial temperature of the concrete significantly decreases and increases the initial and final setting time of the concrete. Therefore, the use of eggshells, especially in bulk cementing, reduces surface cracking.

4.2. PROPERTIES OF HARDENED CONCRETE IN THE EGGSHELL REPLACED CEMENT IN CONCRETE

According to the experiments conducted in this study to investigate the properties of hardened concrete, the following results were obtained:

- Compressive strength of concrete increased by adding eggshell to 10% instead of cement, but by adding eggshell by 20% we saw a decrease in compressive strength of concrete compared to the control sample.

- Specific gravity of concrete increased by 10% of the replacement of eggshell.
- The water absorption percentage test on 28-day samples showed that replacement of eggshell instead of cement reduced the percentage of absorption in concrete, which was higher in 10% eggshell design than 20% design mix.
- The results of this study show that the electrical resistivity of the eggshell has increased in eggshell design mixes in comparison with control specimen; this increase is such that the possibility of corrosion of the reinforcement in concrete with the eggshell is less possible.
- Fracture due to breaking of concrete specimens in the laboratory is the same as a satisfactory fracture of cubic specimens according to BS standard. Therefore, it can be concluded that the replacement percentage of 10% eggshell has the best performance. Although concrete slump with 20% eggshell replacement was higher slump than the concrete sample with 10% eggshells, still the efficiency of concrete with 10% eggshells is within the permissible performance limit of Journal 55 [29].
- Based on the investigation carried out in this research on compressive strength at the variation of eggshell replacement cement at 7 days and 28day shows that the highest strength at 6% and 12% respectively.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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