

Research Article:

A Review Study of Eggshell Powder as Cement Replacement in Concrete

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Abstract

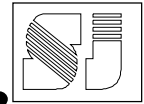
The extensive usage of cement concrete leads to a 5% to 7% release of Carbon Dioxide (CO₂) gas into the atmosphere resulting in increased global warming. Also, the increase in world population and industry has led to the generation of by-product waste materials such as eggshells. Landfilling non-treated eggshells sometimes cause environmental and health matters due to their odor. The use of eggshell powder as partial cement replacement is a considerable solution for recycling the waste eggshells and decreasing the cement. It is believed that eggshells powder (ESP) are rich in calcium oxide and can enhance the strength and durability of concrete. The objective of this study is to analytically review the currently available experimental studies on the effectiveness of partial replacement of ordinary Portland cement by some percentage of eggshell powders ranging between 0-25% in concrete mixes. The database was created for the concrete mixes containing eggshell powder with corresponding concrete properties such as compressive strength, flexural strength, split tensile strength, slump, and density based on nine different research groups. The results from the previous works were analyzed and discussed. The model for predicting compressive strength was established according to multilinear regression analysis using curing time, water-cement ratio, and ESP content for 92 tested data. It was concluded that eggshell powder has less strength reduction than curing time and water-cement ratio.

1. Introduction

Concrete is an artificial building material that usually consists of cement, aggregates, and water. It has been estimated that the concrete industry uses 1.5 billion tons of cement each year [1]. Cement is a vital component in manufacturing concrete as it acts as a binder, joining the components to produce a solid, strong, and durable composite material. The demand for concrete has risen over the years, increasing the demand for cement. Though cement plays a vital role in manufacturing concrete, it has raised environmental concerns. Benhelal et al. [2] reported

that the cement industry contributed to more than 6% of the total global Carbon Dioxide (CO₂) gas emissions.

Moreover, the manufacture of one ton of cement releases a nearly equal amount of CO₂. Another concern is the number of raw materials required to produce cement. According to Naik and Moriconi [3], to produce 1.6 billion tons of cement, 2.5 billion tons of raw natural resources such as limestone and clay are required. Each year, the demand for concrete has



increased; consequently, cement production is also rising. The non-stop production of cement is consuming natural resources at an alarming rate. Therefore, to reduce the dependency on cement as a binder in the manufacturing of concrete, researches have been done to find an alternative binder material that can substitute cement and reduce the depletion of natural resources. The waste materials can be possible additional cementitious materials (CM). Eggshell is one of the waste materials which could be utilized as partial cement replacement. Though total replacement of cement cannot be done at present, replacing 15% of cement worldwide can significantly reduce the CO₂ emissions up to 250 million tons [3].

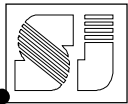
Eggshell is one of the waste materials generated in abundance across the world. Eggshell amount is approximately 11% of the total weight of an average medium size chicken egg, which weighs 55 grams [4]. The eggshells are generally thrown into the garbage, resulting in landfills. Without proper treatment, this solid waste possesses significant environmental pollution due to its availability and chemical composition [4]. The continuous disposal of waste materials such as eggshells increases the landfilling and cause a serious environmental issue all over the world. To achieve sustainability in the construction industry and at the same time reduce the waste materials that are being generated, researchers have tried to utilize waste materials as cement replacements. As such, previous research on eggshell's chemical composition has found that it contains an almost similar amount of Calcium Oxide (CaO) as cement [5]. CaO plays a significant role in cement, as a precise amount is required to achieve strength. The high amount of CaO means that it can be potentially utilized as supplementary cementitious material (SCM). Several types of research have been carried out to investigate concrete's fresh and hardened properties on the partial replacement of cement with ESP contents.

Yerramala [5] used different ESP contents in concrete by substituting 5-15% of cement with ESP. The results showed that ESP could positively be utilized to replace cement in concrete partially. The strengths were higher than control concrete at 5% ESP replacement, indicating that 5% ESP is the optimum content for maximal strength. They suggested that the ESP with other cementitious materials such as fly ash improved the performance of concretes. Parthasarathi [6] investigated the work using eggshell powder and silica fume as a limited cement replacement. Eggshell powder is replaced by 5%, 10%, and 15% with silica fume by 2.5%, 5%, and 7.5% of the weight of cement. Split tensile strength, compressive strength, and flexural strength concrete were studied. It was found that the strength of the concrete increased with the addition of ESP content and silica fume. Jhatial et al.

[7] experimentally replaced the cement with three different ESP contents of 5%, 10%, and 15% by weight of cement in M40 grade concrete. ESP was ground into two fineness (50 μ m and 100 μ m) and considered supplementary cementitious material. It was reported that partial cement replacement using ESP successfully achieved higher strength than the control sample. It was determined that 10% ESP was optimum, where the highest compressive strength was achieved. Furthermore, the fineness of ESP also influenced the compressive strength, the ESP, which passed 50 μ m, resulted in improved strength. The optimum ESP to be employed was determined to be 10% in both fineness.

Yu Tan et al. [8] used different ESP content of 5, 10, 15, and 20% by volume of cement in concrete for different curing conditions. Eggshell concrete greatly increased the compressive and flexural strength of concrete by up to 51.1 and 57.8 percent, respectively, according to the findings. However, Because the eggshell includes a large amount of calcium, which reacts rapidly with acid and alkali liquids, the compressive strength of the eggshell concrete falls gradually as the amount of eggshell powder increases during immersion in alkali and acid liquids. The reduction of compressive strength during immersion in sulphur and sodium sulfate solutions was 27.5% and 31.2%, respectively, when 20% of eggshell powder was used to replace cement. It was concluded that the optimum percentage of oven-dried eggshell powder as a partial cement replacement is 15%. Langah et al. [9] partially utilized ESP as the cement in the concrete made with a proportion ratio of 1:2:4 with 0.5 w/c ratios. The density, workability and compressive strength were examined. They tested 84 cubic specimens for compressive strength at different curing periods of 1, 3, 7, and 28 days. The results showed that the increase in ESP contents decreased the concrete workability and density compared to the control concrete mix. Compressive strength increases sufficiently with the starter of eggshell powder content up to a certain level of dosage.

These days the construction industry has been forced to achieve sustainability. Reducing the consumption of natural resources and energy and reducing greenhouse gas emissions has become an environmental requirement as cement and concrete production is expected to increase over the years. The eggshell shell is made of carbonate, which contains both carbon and oxygen atoms [5]. One of the possible methods of reducing environmental effects is utilizing waste in other products as applicable as in concrete manufacturing. Recycling waste is the technique of processing the waste material to make new products. The use of eggshell powder in concrete can be convenient for environmental defense and economic construction.



This research aims to analyze the previous studies done on the effect of different ESP contents on some mechanical properties of concrete and the workability of concrete. The data from the literature were collected as a database, and the statistical model will be performed to predict compressive strength for the concrete mixes containing eggshell contents between 0 to 25%.

2. Significance of Research

Eggshell is one of the waste materials being generated worldwide, especially in Iraq, where the poultry sector is one of the vibrant parts of the livestock sector, and a considerable amount of eggs is frequently imported from neighboring countries. According to United Nations Food and Agricultural Organization FAO [10], Iraqi people continuously consumed eggs from 1960 to 2017, as shown in Fig. 1. The annual egg consumption per capita has significantly increased with some fluctuations. For instance, each Iraqi person used an average egg mass of 9.44 kg in 2017. Regarding the total citizen population, thousands of ton eggshells are thrown as a waste material into landfilling without recycling. Eggshell solid waste has significant environmental concerns because of its chemical composition and odor. The continuous disposal of waste materials such as eggshells leads to an increase in the number of landfills and results in serious environmental matters in the world. In terms of sustainability in the construction industry, recently, scholars have tried to utilize waste materials as cement replacements to reduce the high rate of carbon dioxide in the atmosphere. On the other hand, the landfilling of waste materials such as eggshells is being solved simultaneously.

3. Methodology

3.1. Data Collection

This paper analytically investigates the mechanical properties of concrete containing eggshell powder as a partial replacement of ordinary Portland cement. The data were collected from nine experimental studies done by different research groups worldwide, as shown in Table 2. Nearly fifty mixes were tested with the use of eggshell powder. The studies were tested normal concrete with 100% cement called control mixes. The control mixes were used to evaluate the effect of eggshell powder contents on the concrete. The eggshell powder contents were used in the studies in the range of 0 to 25% by mass.. Several mechanical and physical properties of concrete were evaluated concerning the eggshell contents. The mechanical properties commonly used for concrete, such as compressive strength, split tensile strength,

and flexural strength, have been studied here for different curing ages. The compressive strength has been considered at the 7 and 28 days curing age. Also, a few studies tested the concrete samples at ages of 1, 3, and 14 days. The results for physical properties of concrete such as workability and densities of concrete measured by some researchers are also presented in Table 1. Concerning the test results of control samples, the corresponding ratios were calculated for compressive strength, flexural strength, split tensile strength, slump, and density.

3.2. Modelling

Figure 2 shows the flow chart where the independent and dependent variables are illustrated in detail. This paper will present the collected data in two ways. Firstly, the effects of eggshell powder on the properties of concrete are analytically discussed in terms of slump, density, flexural, split tensile strength, and compressive strength according to the control samples for the studies. Secondly, the statistical modeling analysis is done for the compressive strength because there is enough data to perform and predict a model.

Ninety-two experimental data were used to model compressive strength in this paper as listed in Table 2. The input data set involves the water-cement ratio (w/c), the curing period (t, days), and the eggshell powder content (ESP, %), while the tested compressive strength of concrete (fc, MPa) was used as a target. The multivariable linear approach model was used to suggest the model for the impact of the input parameters on the concrete compressive strength as given in Eq. 1.

$$f_c = a - b(ESP) - c \left(\frac{W}{C} \right) + d(t) \dots \dots \dots (1)$$

where t is curing period in (days), and ESP is percent eggshell powder content. a, b, c, and d are the model coefficients in compliance with Eq. 2. All the variables seem to be modified with linear modelling.

4. Results and Discussions

4.1. Slump

Among nine cited papers in Table 1, slump values were reported in only four studies concerning the eggshell powder content shown in Fig. 3. Langhah et al. [9] reported that slump decreased with increasing the eggshell powder. The slump value was 34 mm at 0% eggshell powder, reduced to 6 mm at a 25% replacement ratio. However, according to Hordofa [13], the amount of slump slightly increased with increasing the eggshell powder content. At 0% replacement, the slump was 32 mm, and it increased to 40 mm at 15% replacement contents. The available data is not enough to create a model for this property of concrete, as the values' dispersion can be seen in



Table 1. It is suggested to do more research to investigate the effect of eggshells on the workability of concrete. However, to make the slump values meaningful for this analytical study, slump ratios were calculated as the proportion of slump for the mixes divided by the corresponding control mix in each research. Figure 3 shows the slump ratios for 21 mixes. It can be seen that the slump slightly decreases with increasing eggshell contents. The slump loss may be attributed to the high water absorption of eggshell powder which consumes the water and limits the concrete flowability.

4.2. Compressive Strength

The average compressive strength testing was conducted in guidelines for the samples cured for specified ages (3, 7, 14, and 28) days as given in Tables 1 and 2. The data were used in this review covers those mixtures containing eggshell powder without other cementitious materials such as fly ash or silica fume. The curing time has a high impact on concrete compressive strength, and the compressive strength at 28 days increased concerning seven days curing period. Figure 4 shows the compressive strength ratios at 7 and 28 days. The compressive strength ratios were calculated independently for each study according to the control mixes. It was noted that the compressive strength ratio ranged (0.578 -1.511) at 28 days and (0.722 -1.864) at 7 days. It was found that the majority of the researcher observed that up to 10% cement replacement results in the increase of compressive strength, and beyond this value, the compressive strength decreases.

4.3. Split Tensile Strength

Split tensile of concrete were reported at the age of 7 and 28 days. The majority of data were given at the age of 28 days, while a few data were available for the age 7 days. The split tensile strength decreased with increasing the eggshell contents corresponding to the control mixes. Figure 5 shows the effect of curing time on the increase of split tensile strength, where at 28 days, the strength is higher than those tested at 7 days.

4.4. Flexural Tensile Strength

The flexural strength of concrete was measured at 7 and 28 days, as shown in Fig. 6. In general, the flexural strength increased with increasing the eggshell powder in some limited percentage up to 15%. The flexural strength was significantly increased with curing periods. The values of flexural strength for specimens tested at 28 days were higher

than those at 7 days.

4.5. Density

A few researchers [5, 12, and 14] reported eggshell powder's effects on the density of concrete in Table 1. It was found that concrete density was reduced by increasing eggshell powder contents. Yerramala [5] experimentally stated that concrete density decreased from 2364 to 2305 kg/m³ at 0 and 15% cement replacement, respectively. These reductions in concrete density were also observed in the studies [12 and 14]. Fig. 7 shows the relationship between density ratio and eggshell powder contents up to 15%. The density ratio reached 0.97 at 15% cement replacement with eggshell powder. The density reduction may be due to the eggshell's specific gravity being less than that of cement.

4.6. Modelling For Compressive Strength

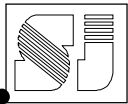
The model equation proposed is based on the multivariable linear analysis for 92 tested data as given in Eq. 2. Table 3 summarizes model coefficients, standard errors. The relationships between tested compressive strength ($f_{c,t}$) and predicted compressive strength ($f_{c,p}$) of the concrete are given in Eq. 3 with $R^2 = 0.67$. Figure 8 shows the relation between both predicted and experimental results of compressive strength. From model coefficients in Eq. (2), it can be inferred that the ESP content has less impact on the compression strength of other w/c and curing time. The model parameter observed that the w/c significantly decreased compressive strength of concrete compared to both eggshell powder content and curing time, while it seems that eggshell powder contents have the lowest impact on the compressive strength concrete than w/c ratio and curing time.

$$f_c = 61.51 - 0.16(ESP) - 82.82 \left(\frac{w}{c}\right) + 0.43 (t) \quad (2)$$

$$f_{c,p} = 0.6661(f_{c,t}) + 8.8764 \quad (3)$$

5. Conclusions

This study has analyzed some mechanical and physical properties of concrete by partially replacing ordinary Portland cement with eggshell powder contents up to 25%. The experimental data have been obtained from different previous works done to statistically investigated the suitability of eggshell waste powder as partial cement replacement cement for concrete production. The model has been proposed

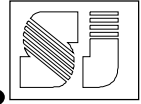


to predict the compressive strength of concrete based on 92 data. The following conclusions from this paper can be drawn:

1. Various outcomes were reported in the previous papers with increasing eggshell powder contents. The effect of eggshell contents has fluctuated between the results achieved in the literature. According to the slump ratios calculated for the slump results, the workability of concretes slightly decreased with increasing eggshell powder.
2. In some reported data, the replacement of cement with eggshell powder increased the compressive strength at the curing ages of 7 and 28 days compared to the corresponding control mix up to 10% replacement, and then the trend declined. However, the linear regression analysis expected that compressive strength slightly decreased with increasing eggshell contents at different curing ages.
3. Split tensile strengths of ESP concrete were nearly the same as that control concrete. However, split tensile decreased with increasing eggshell powder contents, and the reduction was predicted about 1 MPa from 0 to 15% cement replacement.
4. To some extent, The flexural strength of concrete increased with increasing eggshell content compared to control specimens at both curing ages of 7 and 28 days up to 15% cement substitution, according to the findings.
5. Concrete density decreased with increasing eggshell contents. The amount of the reduction in density was dependent on specific gravities of both cement and eggshell contents.
6. The multivariable linear regression analysis was used to predict the concrete strength using 92 experimental data, including variables w/c ratio, eggshell powder content, and curing time. The model predicted the compression strength of the testing data with a reliable coefficient of correlation (R 0.67). It was concluded that both water content and curing time have a higher effect on the compressive strength than eggshell contents. The model predicted a minor reduction occurs in concrete compressive strength up to 25% cement replacement.

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مراجعة خصائص الخرسانة والنمذجة العددية لقوة الانضغاط

مسحوق قشر البيض كبديل جزئي للأسمنت

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المستخلص

يؤدي الاستخدام المكثف للخرسانة الأسمنتية إلى إطلاق ٥٪ إلى ٧٪ من غاز ثاني أكسيد الكربون (CO₂) في الغلاف الجوي مما يؤدي إلى زيادة الاحتباس الحراري. كما أدت الزيادة في عدد سكان العالم والصناعة إلى توليد النفايات كمنتج ثانوي مثل قشور البيض التي يتم التخلص منها في مدافن النفايات مما يتسبب في مشاكل بيئية وصحية. يعد استخدام مسحوق قشر البيض كبديل جزئي للأسمنت حلاً مهماً لإعادة تدوير مخلفات قشر البيض وتقليل الأسمنت. يُعتقد أن مسحوق قشر البيض (ESP) غني بأكسيد الكالسيوم ويمكن أن يعزز قوة ومتانة الخرسانة بسبب تفاعلاتها البوزولانية. الهدف من هذه الدراسة هو المراجعة التحليلية للدراسات التجريبية المتوفرة حالياً والتي أجريت على فعالية الاستبدال الجزئي للأسمنت البورتلاندي العادي بنسبة معينة من قشر البيض تتراوح بين ٠-٢٥٪ في الخلطات الخرسانية. و من ثم إنشاء قاعدة البيانات للخلطات الخرسانية التي تحتوي على مسحوق قشر البيض مع خصائص الخرسانة المقابلة مثل مقاومة الانضغاط وقوة الانثناء وقوة الشد والانقسام والكثافة بناءً على تسع مجموعات بحثية مختلفة. تم تحليل ومناقشة نتائج الأعمال السابقة. تم إنشاء نموذج التنبؤ بمقاومة الانضغاط وفقاً لتحليل الانحدار متعدد الخطوط باستخدام وقت المعالجة ونسبة الماء إلى الأسمنت ومحتوى مسحوق قشر البيض لـ ٩٢ بيانات تم اختبارها. استنتج أن مسحوق قشر البيض لديه انخفاض أقل في القوة مقارنة بوقت المعالجة ونسبة الماء إلى الأسمنت.

الكلمات المفتاحية:

مسحوق قشر البيض؛ قوة ملموسة؛ ركدكثافة الخرسانة؛ تحليل احصائي؛ النمذجة

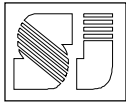
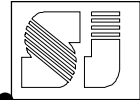


Table 1 Experimental database

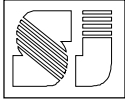
Ref.	Mix ID	ESP, %	Compressive strength, MPa				Split tensile strength, MPa				Flexural strength, MPa				Workability (slump), mm	Density (kg/m ³)
			7 day	28 day	fc ratio, 7 day	fc ratio, 28 days	7 day	fst ratio 7 day	28 day	fst ratio 28	7 day	fr, ratio 7 days	28 day	fr, ratio 28 days		
[5]	control	0	11.1	22.3	1.000	1.000	0.8	1.000	2.4	1.000						2364
	M2	5	14.4	24	1.297	1.076	1.3	1.625	2.4	1.000						2347
	M3	10	10.7	18.9	0.964	0.848	1	1.250	2.3	0.958						2323
	M4	15	9.8	16.1	0.883	0.722	1.4	1.750	1.6	0.667						2305
[6]	control	0	17	31.8	1.000	1.000	2.12	1.000	3.13	1.000	3.06	1.000	4.5	1.000		
	E5S0	5	18	35	1.059	1.101	2.13	1.005	3.24	1.035	3.22	1.052	4.78	1.062		
	E10S0	10	17.5	34	1.029	1.069	2.16	1.019	3.22	1.029	3.25	1.062	4.65	1.033		
	E15S0	15	17.4	31	1.024	0.975	2.19	1.033	3.2	1.022	3.15	1.029	4.55	1.011		
[8]	control	0	22	32	1.000	1.000					4.8	1.000	6.5	1.000	75	
	O 5	5	31	42	1.409	1.313					7.7	1.604	7.6	1.169	70	
	O 10	10	38	45.5	1.727	1.422					8.4	1.750	8.8	1.354	71	
	O 15	15	41	48	1.864	1.500					7.2	1.500	7.4	1.138	73	
	O 20	20	32.5	33	1.477	1.031					7.2	1.500	7	1.077	84	
[11]	control	0	20.29	30.57	1.000	1.000										
	C95-E5	5	23.49	33.54	1.158	1.097										
	C90-E10	10	23.55	35.15	1.161	1.150										
	C85-E15	15	22.71	30.11	1.119	0.985										
	C80-E20	20	21	28.35	1.035	0.927										
	C75-E25	25	17.17	21.58	0.846	0.706										
[7]	control	0	27.66	44.73	1.000	1.000									57	
	5	5	27.31	45.07	0.987	1.008									50.8	
	10	10	28.36	45.88	1.025	1.026									44.5	
	15	15	26.13	38.94	0.945	0.871									38	
[12]	control	0		45		1.000							4.9	1.000		2415
	3	3		68		1.511							5.1	1.041		2438
	5	5		58		1.289							5.05	1.031		2428
	8	8		49		1.089							5.03	1.027		2418
	10	10		38		0.844							4.6	0.939		2385
	13	13		32		0.711							4.2	0.857		2355
	15	15		26		0.578							3.8	0.776		2345
[13]	control	0	27	38.9	1.000	1.000	2.51	1.000	3.5	1.000			3.64	1.000	32	
	ESP3	3	24.125	40.07	0.894	1.030	2.612	1.041	3.515	1.004			3.71	1.019	33	
	ESP7	7	26.1	40.36	0.967	1.038	2.899	1.155	3.79	1.083			3.87	1.063	35	
	ESP11	11	22.35	38.565	0.828	0.991	2.45	0.976	3.41	0.974			4.48	1.231	38	
	ESP15	15	19.5	36	0.722	0.925	2.38	0.948	2.068	0.591			4.24	1.165	40	
[14]	control	0	25.7	30.98	1.000	1.000									34	2515
	ESPC1	2.5	25.97	29.23	1.011	0.944									29	2500
	ESPC2	5	26.88	28.31	1.046	0.914									24	2490
	ESPC3	7.5	24.57	32.71	0.956	1.056									20	2485
	ESPC4	10	27.89	34.22	1.085	1.105									15	2480
	ESPC5	12.5	23.14	28.15	0.900	0.909									11	2475
	ESPC6	15	22.09	27.51	0.860	0.888									6	2470



[15]	control	0	18	26	1.000	1.000					1.5	1.000	2.1	1.000		
	5	5	22	26.6	1.222	1.023					2	1.333	2.5	1.190		
	10	10	24.8	28	1.378	1.077					2.2	1.467	2.7	1.286		
	15	15	27.5	36	1.528	1.385					2.7	1.800	3.1	1.476		
	20	20	19	27	1.056	1.038					1.6	1.067	2	0.952		

Table 2 Experimental and predicted compressive strength with their variables

Ref.	Data No.	ESP (%)	w/c ratio	curing time (day)	fc, exp (MPa)	fc, predict (MPa)	Residuals (MPa)
[5]	1	0	0.6	1	6.8	12.3	-5.5
	2	5	0.6	1	4.9	11.5	-6.6
	3	10	0.6	1	7.7	10.6	-2.9
	4	15	0.6	1	6.9	9.8	-2.9
	5	0	0.6	7	11.1	14.8	-3.7
	6	5	0.6	7	14.4	14.0	0.4
	7	10	0.6	7	10.7	13.2	-2.5
	8	15	0.6	7	9.8	12.4	-2.6
	9	0	0.6	28	22.3	23.8	-1.5
	10	5	0.6	28	24	23.0	1.0
	11	10	0.6	28	18.9	22.2	-3.3
	12	15	0.6	28	16.1	21.4	-5.3
[6]	13	0	0.5	7	17	23.1	-6.1
	14	5	0.5	7	18	22.3	-4.3
	15	10	0.5	7	17.5	21.5	-4.0
	16	15	0.5	7	17.4	20.7	-3.3
	17	0	0.5	28	31.8	32.1	-0.3
	18	5	0.5	28	35	31.3	3.7
	19	10	0.5	28	34	30.5	3.5
	20	15	0.5	28	31	29.7	1.3
[8]	21	0	0.45	1	13	24.7	-11.7
	22	5	0.45	1	27	23.9	3.1
	23	10	0.45	1	36	23.1	12.9
	24	15	0.45	1	37	22.3	14.7
	25	20	0.45	1	26.5	21.5	5.0
	26	0	0.45	7	22	27.3	-5.3
	27	5	0.45	7	31	26.4	4.6
	28	10	0.45	7	38	25.6	12.4
	29	15	0.45	7	41	24.8	16.2
	30	20	0.45	7	32.5	24.0	8.5
	31	0	0.45	28	32	36.3	-4.3
	32	5	0.45	28	42	35.5	6.5
	33	10	0.45	28	45.5	34.7	10.8
	34	15	0.45	28	48	33.9	14.1
	35	20	0.45	28	33	33.1	-0.1
[14]	36	0	0.5	1	18.35	20.5	-2.2
	37	2.5	0.5	1	18.12	20.1	-2.0
	38	5	0.5	1	17.25	19.7	-2.5
	39	7.5	0.5	1	16.81	19.3	-2.5
	40	10	0.5	1	16.39	18.9	-2.5
	41	12.5	0.5	1	15.92	18.5	-2.6
	42	15	0.5	1	15.33	18.1	-2.8
	43	0	0.5	3	21.55	21.4	0.2
	44	2.5	0.5	3	21.61	21.0	0.6
	45	5	0.5	3	21.95	20.6	1.4
	46	7.5	0.5	3	20.39	20.2	0.2



Ref.	Data No.	ESP (%)	w/c ratio	curing time (day)	fc, exp (MPa)	fc, predict (MPa)	Residuals (MPa)
	47	10	0.5	3	20.11	19.8	0.3
	48	12.5	0.5	3	19.36	19.4	0.0
	49	15	0.5	3	19.15	19.0	0.2
	50	0	0.5	7	25.7	23.1	2.6
	51	2.5	0.5	7	25.97	22.7	3.3
	52	5	0.5	7	26.88	22.3	4.6
	53	7.5	0.5	7	24.57	21.9	2.7
	54	10	0.5	7	27.89	21.5	6.4
	55	12.5	0.5	7	23.14	21.1	2.0
	56	15	0.5	7	22.09	20.7	1.4
	57	0	0.5	28	30.98	32.1	-1.1
	58	2.5	0.5	28	29.23	31.7	-2.5
	59	5	0.5	28	28.31	31.3	-3.0
	60	7.5	0.5	28	32.71	30.9	1.8
	61	10	0.5	28	34.22	30.5	3.7
62	12.5	0.5	28	28.15	30.1	-2.0	
63	15	0.5	28	27.51	29.7	-2.2	
[12]	64	0	0.28	28	45	50.3	-5.3
	65	3	0.28	28	68	49.9	18.1
	66	5	0.28	28	58	49.5	8.5
	67	8	0.28	28	49	49.1	-0.1
	68	10	0.28	28	38	48.7	-10.7
	69	13	0.28	28	32	48.3	-16.3
	70	15	0.28	28	26	47.9	-21.9
[13]	71	0	0.48	7	27	24.8	2.2
	72	3	0.48	7	24.125	24.3	-0.2
	73	7	0.48	7	26.1	23.6	2.5
	74	11	0.48	7	22.35	23.0	-0.7
	75	15	0.48	7	19.5	22.4	-2.9
	76	0	0.48	28	38.9	33.8	5.1
	77	3	0.48	28	40.07	33.3	6.8
	78	7	0.48	28	40.36	32.7	7.7
	79	11	0.48	28	38.565	32.0	6.5
	80	15	0.48	28	36	31.4	4.6
[11]	81	0	0.45	7	20.29	27.3	-7.0
	82	5	0.45	7	23.49	26.4	-3.0
	83	10	0.45	7	23.55	25.6	-2.1
	84	15	0.45	7	22.71	24.8	-2.1
	85	20	0.45	7	21	24.0	-3.0
	86	25	0.45	7	17.17	23.2	-6.1
	87	0	0.45	28	30.57	36.3	-5.7
	88	5	0.45	28	33.54	35.5	-1.9
	89	10	0.45	28	35.15	34.7	0.5
	90	15	0.45	28	30.11	33.9	-3.7
	91	20	0.45	28	28.35	33.1	-4.7
	92	25	0.45	28	21.58	32.3	-10.7

Table 3 Summary of the proposed model

	Coefficients	Standard Error	t Stat	P-value
Intercept	61.51	5.23	11.76	0.00
ESP %	-0.16	0.11	-1.50	0.14
w/c ratio	-82.82	9.80	-8.45	0.00
curing time	0.43	0.06	7.01	0.00

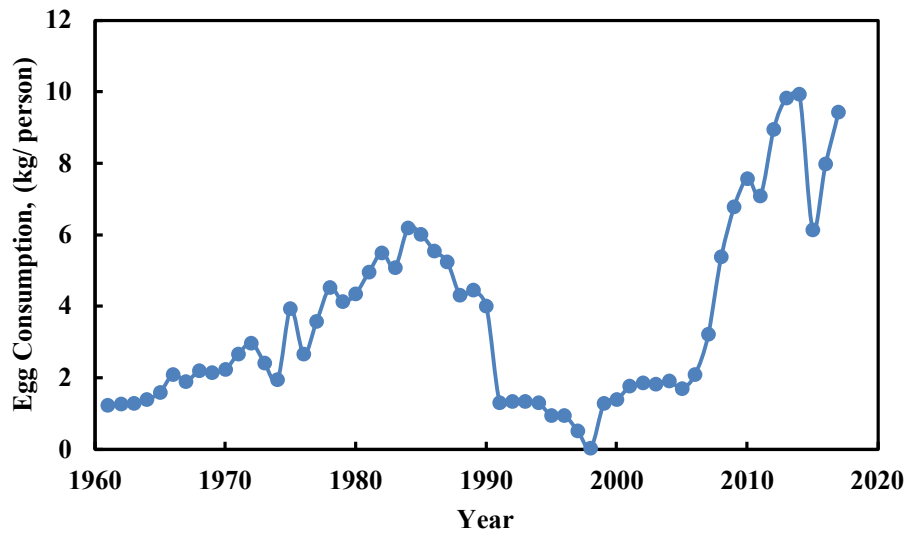
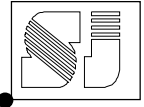


Fig. 1 Egg consumption in Iraq [10]

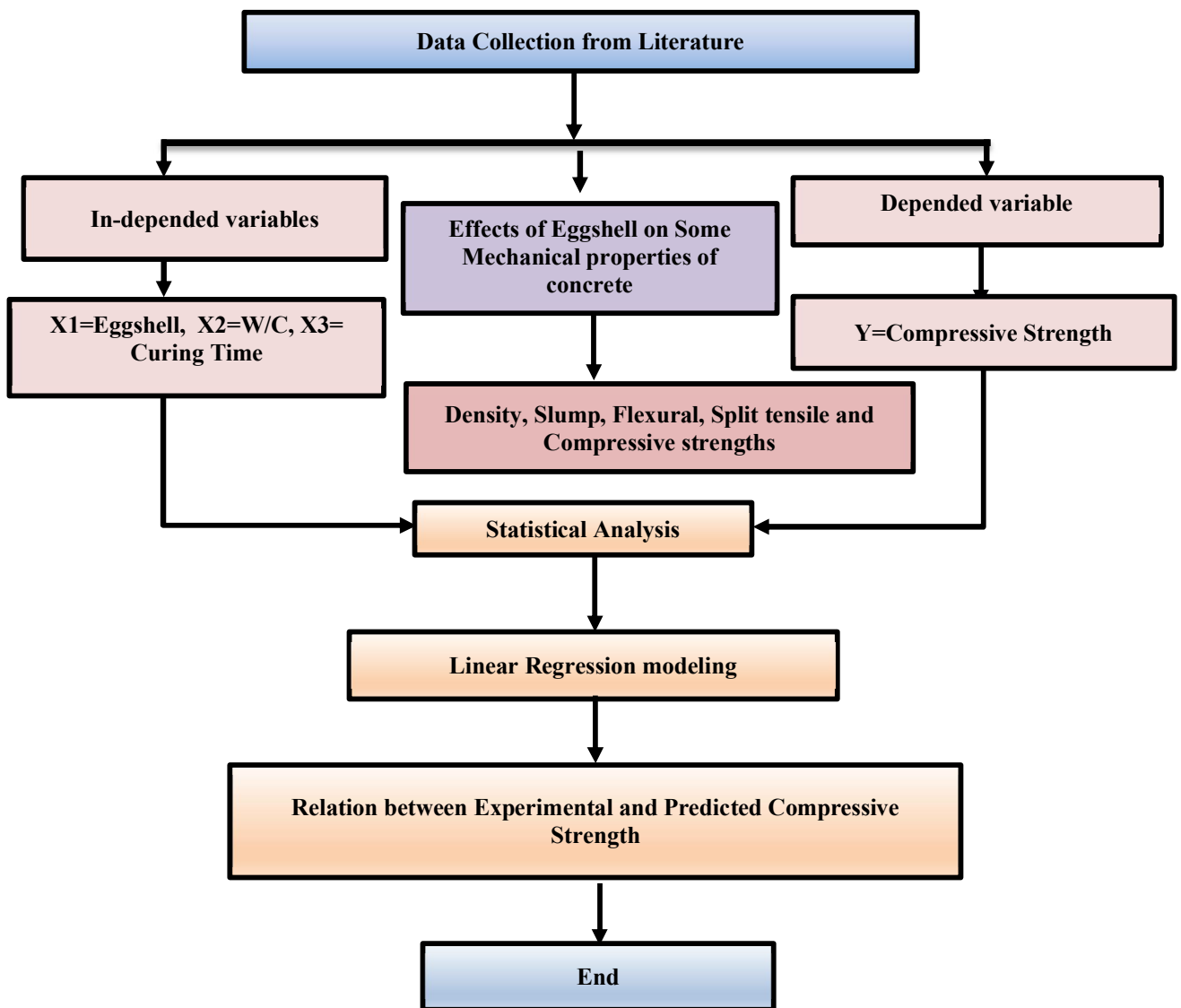
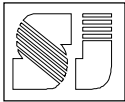


Fig. 2 Flow chart of the study

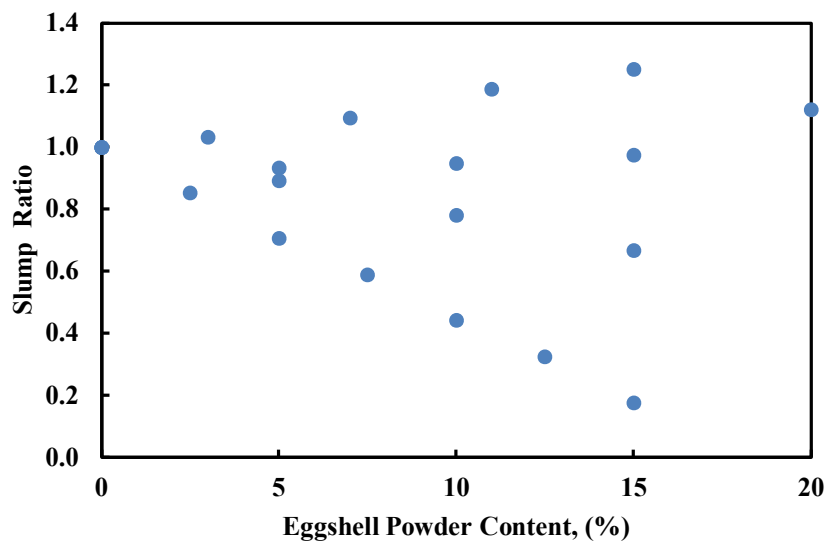


Fig. 3 ESP content vs slump ratio

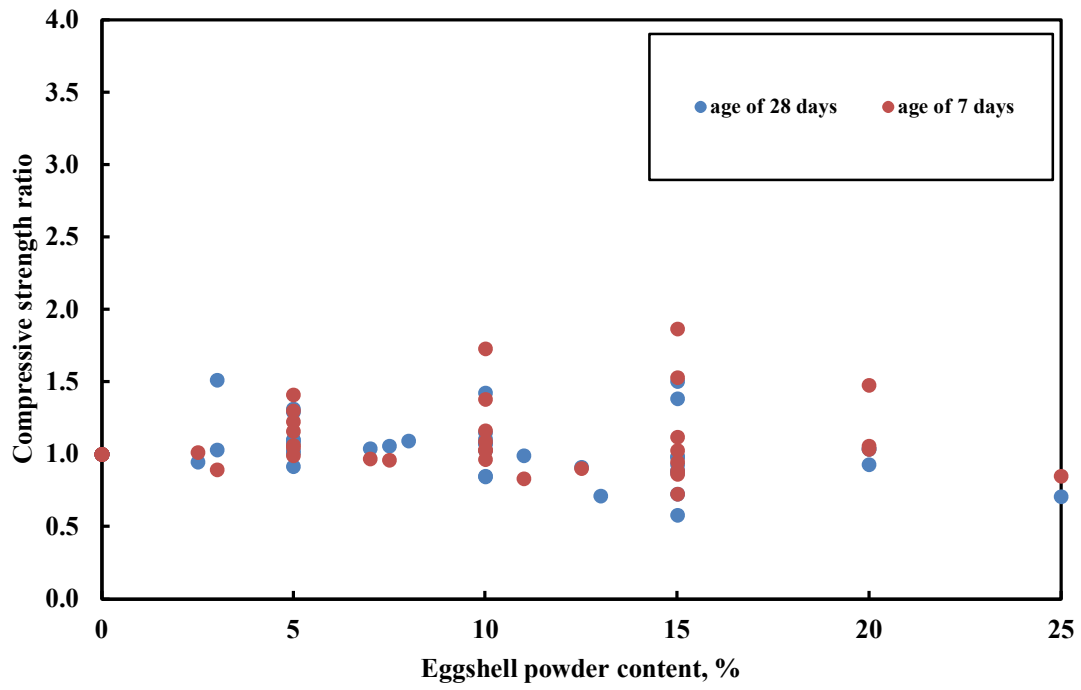
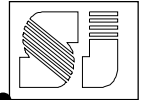


Fig. 4 Compressive strength ratio at 7 and 28 days curing

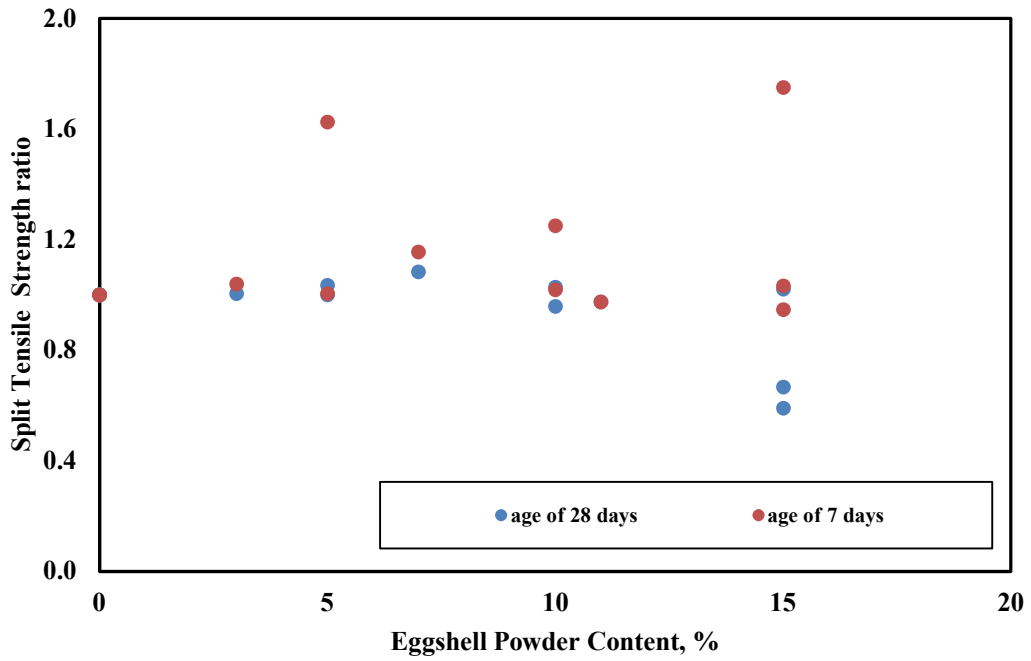
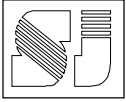


Fig. 5 Split tensile strength ratio at 7 and 28 days curing

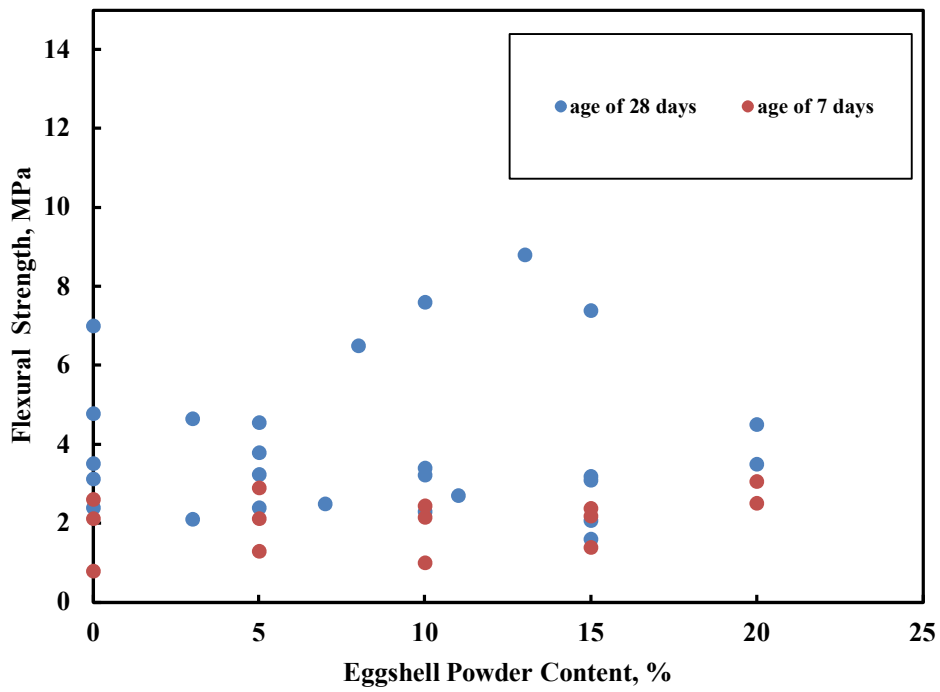


Fig. 6 Effect of ESP contents on flexural strength

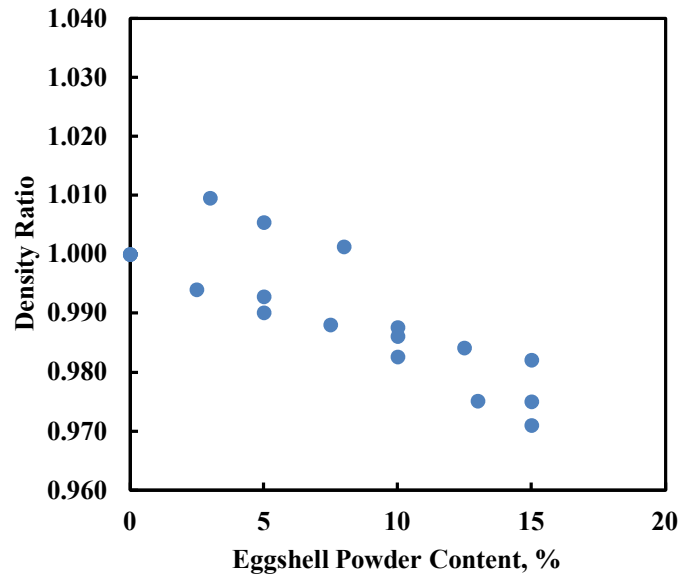
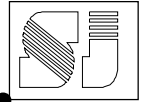


Fig. 7 Effect of ESP contents on density ratio

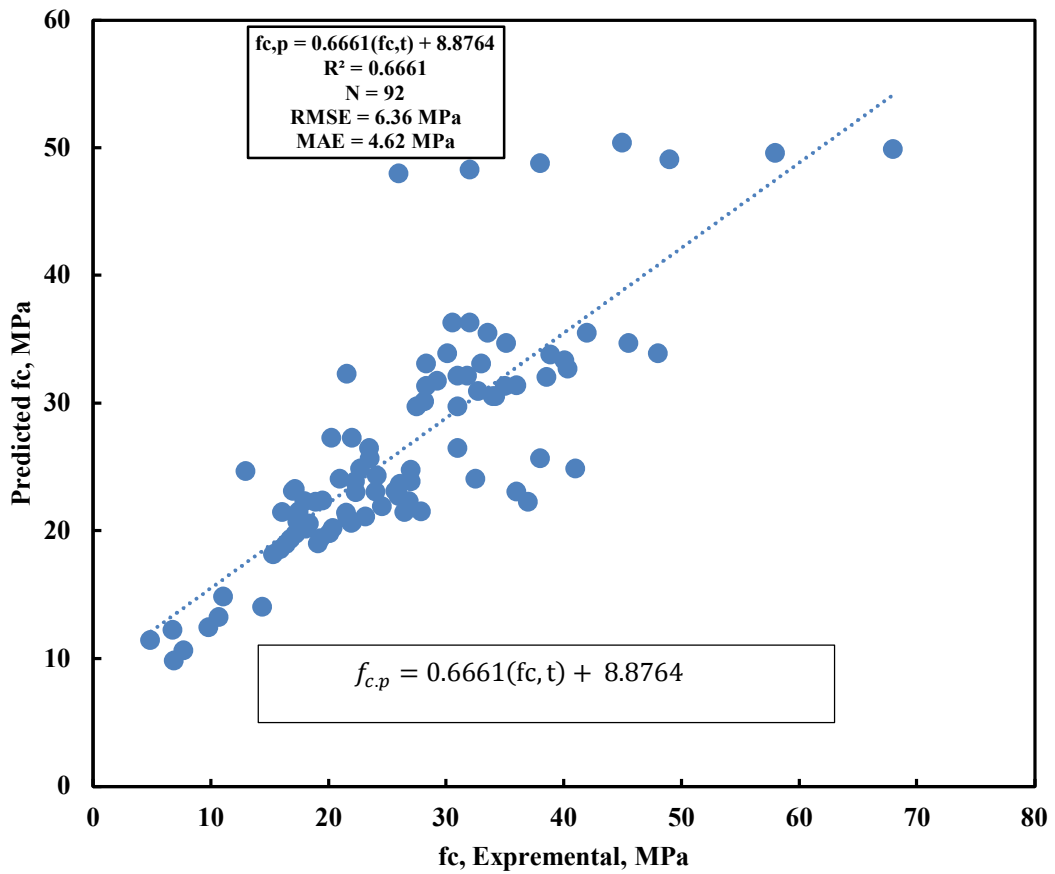


Fig. 8 Relation between predicted and experimental compressive strength