

## **EFFECTS OF EGGSHELL POWDER AS PARTIAL REPLACEMENT OF CEMENT ON FLEXURAL BEHAVIOR OF ONE-WAY CONCRETE SLABS**

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### **Abstract**

This research investigated the effect of eggshell powder as a partial replacement of cement on flexural behaviour of a one-way concrete slab. First cement was partially replaced with eggshell powder at these percentage 0%, 3 %, 5 %, 8%, 10%, 13% and 15% (by weight of cement). The resulting concrete was compared for mechanical properties (density, compressive and flexural strength). The best three percentages of replacement that improved mechanical properties compared to reference mix without replacement were adopted to cast one-way slabs, which were tested under four-point flexural test to investigate the behaviour of concrete slabs contain eggshell powder. The Scanning Electron Microscope (SEM) test was made to study the microstructure of concrete and also explain the results. The obtaining results indicated the advantage of incorporation of eggshell powder in concrete. The concrete unit weight has not obviously affected by eggshell powder content. The 3% eggshell powder gives the highest compressive and flexural strength of about 51% and 4.9% respectively than the reference one. The Scanning Electron Microscope analysis shows that the structure of samples incorporating eggshell powder is more dense than the microstructure of the reference sample. For one-way slab specimens, at 3% and 5% ESP, the specimens fails at larger loads and smaller deflection compared to reference one. While concrete containing 8% ESP showed a gradual increase in the deformation capacity for a given load and its behaviour was closed to reference one.

Keywords: Eggshell powder, Maximum deflection, Maximum load at failure, Microstructure, One-way slabs.

## 1. Introduction

Eggs are one of the most widely used food, which results in several daily tons of eggshell waste. According to Verma et al. [1] about 250000 tons of eggshell waste is produced annually worldwide. Using of eggshell waste as a powder instead of natural lime as partial replacement of cement in concrete have benefits like minimize using of cement and consume the waste material. Hama [2] study effect of eggshell powder (ESP) on the properties of lightweight concrete. From the results of the study, she concluded that 5% ESP gave compressive strength closed to that for reference one. Gowsika et al. [3] used ESP obtaining from industrial in various ratios for cement replacement and it was found that no reduction in compressive strength and flexural strength in case of replacement of 5% ESP + 20% Microsilica. Ing and Choo [4] investigated using ESP as filler in concrete. In this study, particles passing through 2.36 mm sieve will be used as filler in concrete. Five percentages of ESP; 0% (reference), 5%, 10% 15% and 20% (by cement weight) were adopted. Based on this investigation water/cement ratio of 0.4 produces medium workability and using ESP as filler in concrete had improved the compressive strength of concrete because of and the maximum value was obtained at 10% replacement. Flexural strength of concrete was increasing from 2.36 to 3.50 MPa with the addition of ESP from 0 to 20% compared to the reference mix. Also, the addition of ESP to concrete had reduced water absorption and penetration. Yerramala [5] found that up to 10% ESP replacement as a powder in concrete gave a splitting tensile strength and sorptivity values comparable with control concrete. While 5% ESP replacement was given higher compressive strength than control mix, after both 7 and 28 days of curing ages. Gajera and Shah [6] presented a review paper about the utilization of the eggshell waste in concrete. They concluded that using ESP up to 10% keep strength without reduction. For 20% ESP replacement, the problem of bleeding and microcracking will appear. Dhanalakshmi et al. [7] study effect of ESP as a partial replacement of cement and various properties like workability, compressive strength, and density were determined. Fly ash was added to optimum ESP content. Based on the experimental investigation the following conclusion is drawn

- Addition of ESP to cement concrete was led to a reduction in workability, density and compressive strength of concrete
- Increasing in workability, density and compressive were found with the addition of fly ash to optimum percentages of ESP.

Binici et al. [8] evaluated the possibility of using eggshell waste powder for the protection of buildings against external radiation effects. mortars of cement, sand and ESP was made to study radiation-absorbing property. Test results showed that mortars with ESP had low radioactive permeability. Also, they found that using ESP as an additive decreased both of the compressive and flexural strengths of the mortars for all the samples with different percentages of ESP for all ages. However, the mixes satisfied the minimum compressive strength requirements of the Turkish standards.

Mohamad et al. [9] partially replaced Ordinary Portland cement with palm oil fuel ash (POFA) and eggshell powder. She found that the optimum mix proportion of concrete is 6% POFA: 4% ESP achieved a compressive strength of 38.60 N/mm<sup>2</sup> at 28 days.

## 2. Aim of Present Work

Since now the researches focused on the effect of ESP on mechanical properties of concrete and Binici et al. [8] showed the importance of ESP to produce a concrete has ability radiation-absorbing property. No study found on the effect of ESP on the microstructure of concrete and structural behaviour, i.e., load-deflection of structural elements. The influence of ESP as a partial replacement of cement on hardened properties, microstructure and load-deflection relation for one one-way slab have been investigated in this work to provide information in this field.

## 3. Materials, Mix Proportions and Tests

Eggshell material used in this work was collected from local sources. The shells were cleaned in normal water and sun-dried. The shells have been crushed, grinded to powder and passed through 75  $\mu\text{m}$  sieve (see Fig. 1). The specific gravity and the fineness of the used powder were 2.08 and 382  $\text{m}^2/\text{kg}$ , respectively. Chemical compositions of the ESP were presented in Table 1. Type I Ordinary Portland cement with a specific gravity of 3.15  $\text{g}/\text{cm}^3$  and Blaine fineness of 326  $\text{m}^2/\text{kg}$  was used in this research. The X-ray fluorescence spectrometry results were given in Table 1.



**Fig. 1. Procedure to produce eggshell powder.**

**Table 1. Chemical content of cement and eggshell powder.**

<b>Chemical compound</b>	<b>Cement</b>	<b>Eggshell powder</b>
<b>CaO</b>	64.02	52.8
<b>SiO<sub>2</sub></b>	22.15	0.08
<b>Al<sub>2</sub>O<sub>3</sub></b>	5.40	0.04
<b>Fe<sub>2</sub>O<sub>3</sub></b>	4.08	0.01
<b>MgO</b>	2.80	0.01
<b>SO<sub>3</sub></b>	2.48	0.44
<b>K<sub>2</sub>O</b>	0.95	-
<b>Na<sub>2</sub>O</b>	0.20	0.20
<b>L.O.I</b>	3.80	40.80

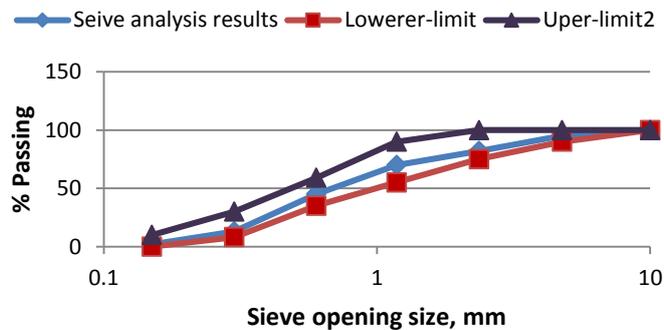
River gravel was used as coarse aggregate with a maximum size of 12.5 mm and a specific gravity 2.65. Fine aggregate was natural sand with a maximum size of 4.75 mm with a specific gravity of 2.43. Glenium 51 with a specific gravity of 1.1 was used as a superplasticizer. Sieve analysis for both fine and coarse aggregate are shown in Figs. 2 and 3 respectively with the upper and lower limits according to I.O.S. No. 45 [10].

Concrete mixtures details are shown in Table 2. ESP were replaced with cement at seventh contents of 0% (reference), 3%, 5%, 8%, 10%, 13% and 15% by weight of cement.

Compression test was made according to BS EN 12390-3 [11] with an average of three (100×100×100) cubics specimens. Flexural tensile strength was made according to ASTM C78/C78M [12], using (100×100×500 mm) prisms at the 28-day age for average three prisms for each mix. Microstructural image analysis was conducted as complied with ASTM C1723 [13] by the mean of Scanning Electron Microscope (SEM). procedure. Four one-way R.C. slabs specimens were casting and testing under bending for the 0%, 3%, 5% and 8% ESP (see Fig. 4). The dimensions and reinforcement details are shown in Fig. 5. Reinforcing steel bars of diameter (4 mm) were used. The yield stress of steel bars was (720 MPa). The details of the slabs are shown in Fig. 5.

**Table 2. Mixes proportions.**

Mixes	Cement (kg/m <sup>3</sup> )	ESP (kg/m <sup>3</sup> ) (%weight of cement)	Gravel (kg/m <sup>3</sup> )	Sand (kg/m <sup>3</sup> )	w/b ratio	Sp (% weight of cement)
Reference	435.00	0 (0%)	1305	652.5	0.28	1.15%
ESP-3%	421.95	13.05(3%)	1305	652.5	0.28	1.15%
ESP-5%	413.25	21.75(5%)	1305	652.5	0.3	1.15%
ESP-8%	400.20	34.80(8%)	1305	652.5	0.32	1.15%
ESP-10%	391.50	43.50(10%)	1305	652.5	0.33	1.15%
ESP-13%	378.45	56.55(13%)	1305	652.5	0.35	1.15%
ESP-15%	369.75	65.25(15%)	1305	652.5	0.38	1.15%



**Fig. 2. Sieve analysis of fine aggregate.**

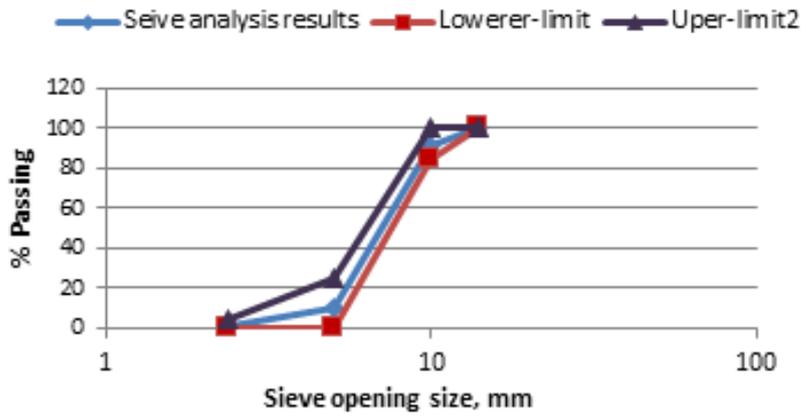


Fig. 3. Sieve analysis of coarse aggregate.



Fig. 4. Slabs reinforcing and casting.

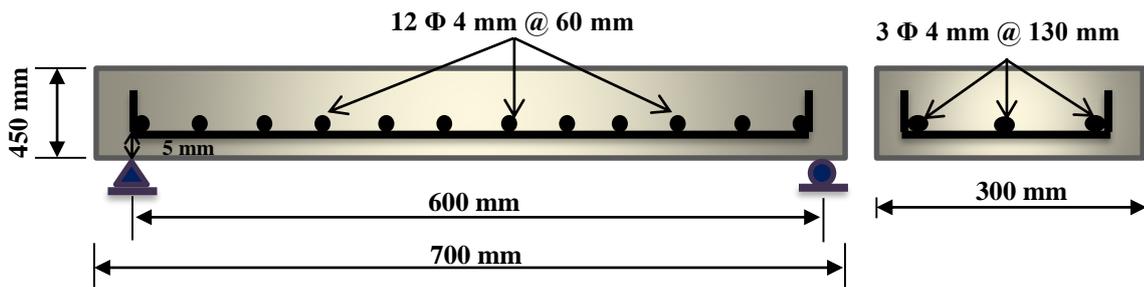


Fig. 5. Details of slab reinforcement.

## 4. Experimental Results

### 4.1. Compression and flexural strengths of ESP concrete

Figure 6 represents the variation of the compressive strength of concrete with partial replacement of cement by ESP at 28 day age. The compressive strength of ESP concrete was higher to that of reference mixes with ESP up to 8% by 51%, 28.9% and 8.9% for 3%, 5% and 8% ESP respectively. then began to decrease by 15.6%, 28.9% and 42.2% for 10%, 13% and 15% ESP respectively. The decreasing in compressive strength for 10%, 13% and 15% of substitution, which is essentially due to the formation of pores as observed by results of water absorption test. In the same manner, flexural strength increase slightly with increasing of ESP percentage up to 8% by 4.9%, 3.1% and 2.9% for 3%, 5% and 8% ESP respectively. Then began to decrease by 8.2%, 14.7% and 22.4% for 10%, 13% and 15% ESP respectively (see Fig. 7).

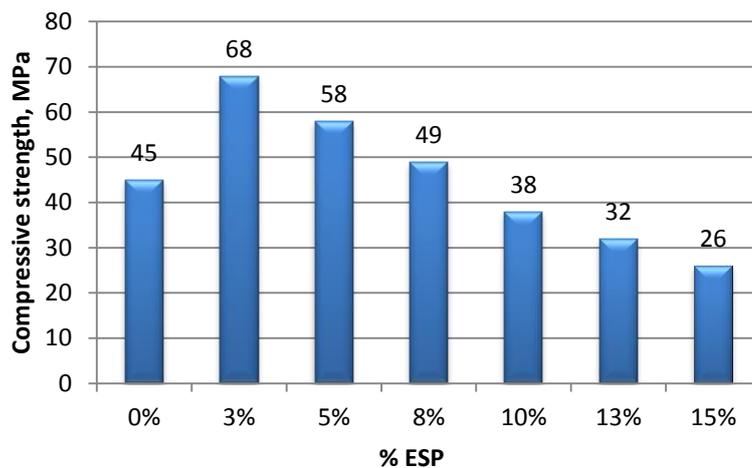


Fig. 6. Variation of compressive strength with % ESP.

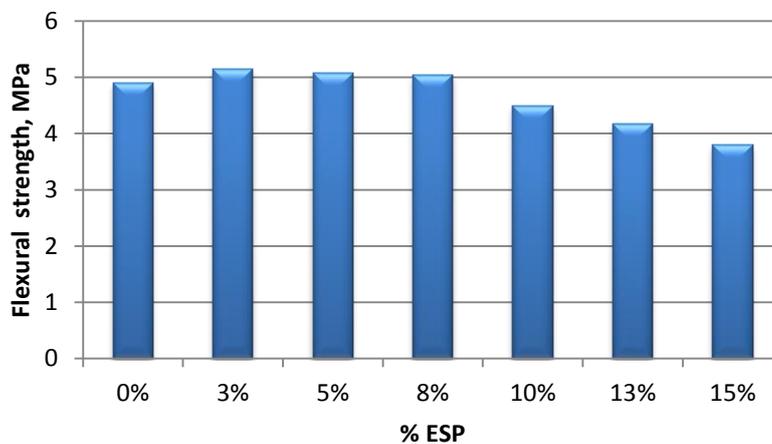


Fig. 7. Variation of flexural strength with % ESP.

#### 4.2. Density of ESP concrete

The density of concrete was calculated by dividing the mass by volume of a cube. Figure 8 represents the variation of the dry density of concrete mixtures with the percentage of ESP. It is observed that density increases slightly with increases ESP ratio up to 5% by 1.0%, 0.5% and 0.1% for 3% , 5% and 8% ESP respectively. The increasing ratio can be neglected since it is very small. For ESP dosages higher than 8% the density began to decrease slightly by 1.3%, 2.5% and 3.0%. This is due to the lower specific gravity of ESP (2.08) comparing with a specific gravity of cement (3.15).

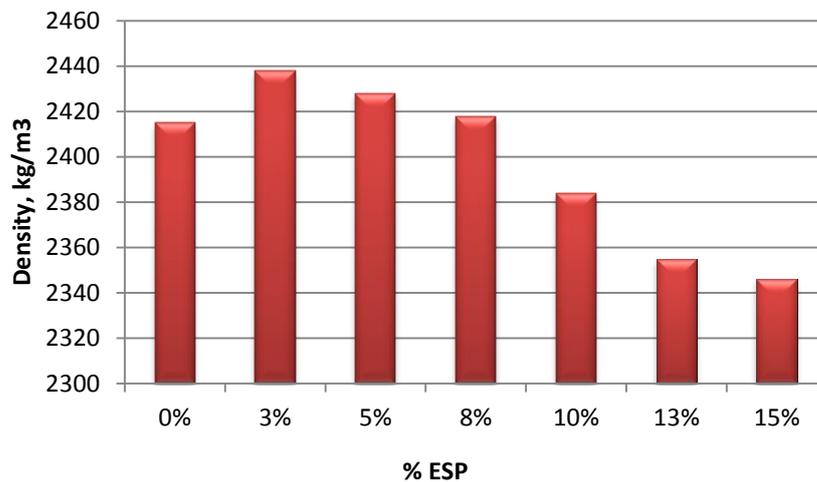


Fig. 8. Variation of density with % ESP.

#### 4.3. Load-deflection relationship of one-way slabs

One-way slabs concrete of 700 mm × 300 mm × 40 mm dimensions were cast and subjected to four-point loading system (see Fig. 9). The load and flexural response of specimen due to the concentrated load at the centre was obtained by recording deflection with the corresponding load at the mid-span of the slab.

Results were represented as load versus deflection. At a constant rate of loading the loading and, deformation was measured until the final failure of the specimen. load to deflection relationships are shown in Fig. 10.

Figure 11 shows the variation of load-deflection with different percentages of ESP. Concrete containing ESP demonstrated an increased in strength with increased ESP content up to 8%. At 3% and 5% ESP, the specimens fails at larger loads and smaller deflection compared to reference one.

While concrete containing 8% ESP showed a gradual increase in the deformation capacity for a given load and its behaviour was closed to reference one. From Fig. 10, one can notice that area under the curve for the slab of 3%. ESP content is smaller than others, which refers to more brittle behaviour.



Fig. 9. Four-point loading system for flexural test of slab.

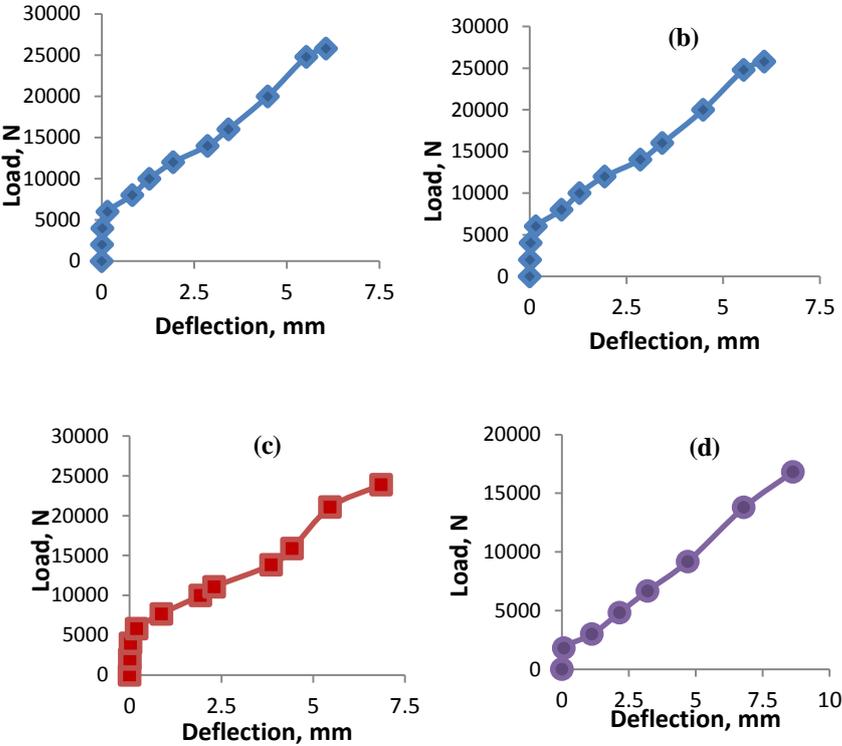


Fig. 10. Load verse deflection of: (a) Reference concrete, (b) Concrete with 3% ESP, (c) Concrete with 5% ESP, (d) Concrete with 8% ESP.

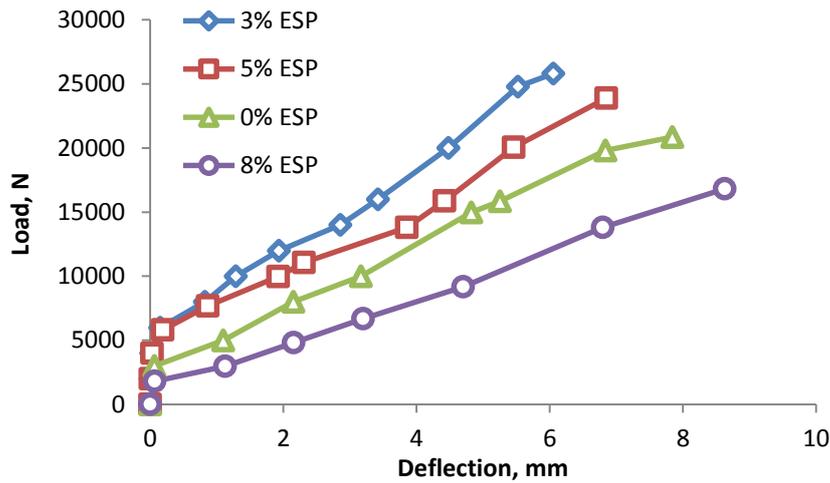


Fig. 11. Load verse deflection of one-way slabs specimens for different percentage of % ESP.

**4.4. Variation of maximum deflection and maximum load of slabs at failure with ESP content**

The maximum deflection at failure is increasing with increasing of ESP content. The slabs, which incorporated 3% and 5% ESP showed smaller deflection than reference slab without ESP. While the slab that incorporated 8% ESP showed larger deflection than reference one (see Fig. 12). The maximum load at failure decreased with increasing of ESP content. The load at failure for slabs, which incorporated 3% and 5% ESP were higher than reference slab without ESP. While load at failure for 8% ESP was smaller than for reference slab (see Fig. 13).

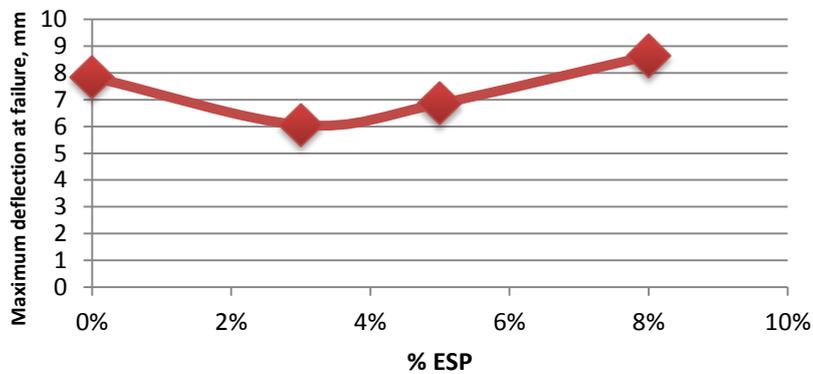


Fig. 12. Variation of maximum deflection at failure with percentage of ESP.

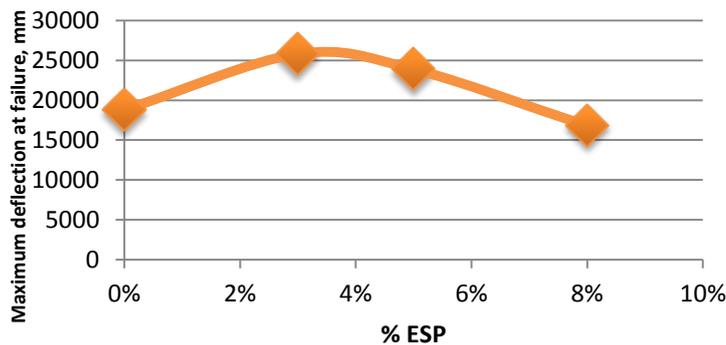
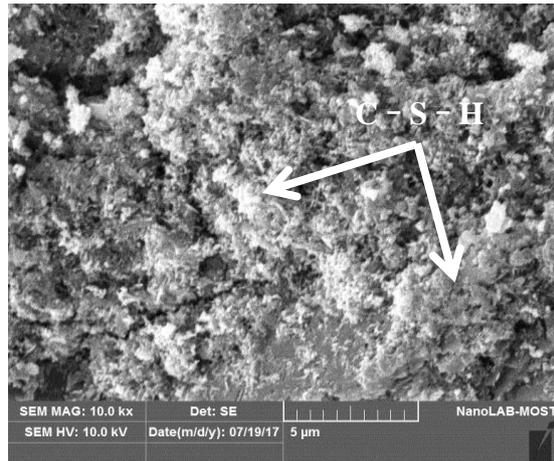


Fig. 13. Variation of maximum load at failure with the percentage of ESP.

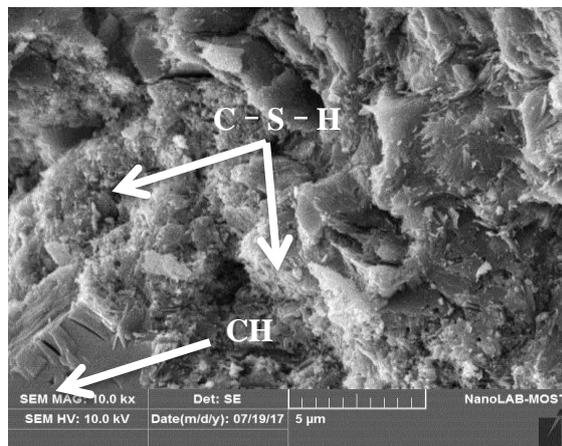
## 5. Discussion of Results

Figures 14(a) to (c) present the microstructural images with of 10 kx magnifications for 3 %, 5% and 8% of ESP respectively. The structure of 3% ESP look more uniform and more porous but the voids are tiny and disconnected. According to Escalante-Garcia and Sharp [14], C-S-H gel is generated by the interaction of the added material (such as ESP used in this study) to the cement with the CH liberated during the hydration of the  $C_3S$  and  $C_2S$  present in the cement. As soon as the C-S-H and CH start forming, further hydration will be influenced by the microstructural characteristics of the C-S-H and CH. The irregularity and geometrical complexity of many CH particles in the cement system reflect the tortuous character of the capillary pore space in the hydrated cement. The deposition of the C-S-H and CH phases in the microstructure of the hydrated cement is quite distinct; C-S-H is deposited mainly around the cement grains, while CH is precipitated in the water-filled pores [15, 16]. To show the porous phases of C-S-H settings of contrast and brightness are made in images as shown in Figs. 5(a) to (d). Richardson [17, 18] argued that low-density C-S-H within the hydration shells might appear dark in SEM images. The inert eggshell powder will help in filling up the pores within concrete, as shown in Fig. 14, which in turn results in a less porous microstructure, which leads to an increase in the compressive strength of concrete.

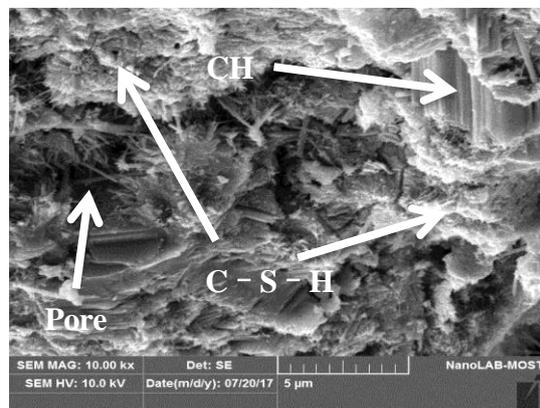
CaO is the main chemical composition of the eggshell powder (see Table 1). The reaction between CaO with the main compounds of cement in the presence of water is responsible for the decrease in setting time and development of strength due to dilution of  $C_3S$  and  $C_3A$  content in the cement [19]. For more explanation In presence of ESP, the structure of concrete will be strengthened due to a more homogeneous distribution of smaller calcium silicate hydrates (C-S-H crystals), finer pore structure, and accelerated hydration of cement [20]. When the amount of powder beyond the optimal, which determined at 8% replacement in the present research, the amount of fine powder increases much than the ability of compounds of cement to react with all ESP, so drop in the reactive cement component results in significant physical modifications of the material [21]. This cause a weak bond between the cement and aggregate, which result in loss in compressive strength for higher ESP replacement amounts than the optimal one.



(a)



(b)



(c)

**Fig. 14. Microstructure of: (a) Concrete with 3% ESP, (b) Concrete with 5%ESP, (c) Concrete with 8% ESP.**

## 6. Conclusions

From this research, results one can conclude that the incorporation of ESP into concrete has the following effects:

- A slight difference in the density was noticed for all ESP mixes compared with reference mix maximum about 3%, which can be neglected.
- An increase in the compressive was noticed for ESP up to 8% by about 51%, 28.9% and 8.9% for 3%, 5% and 8% ESP respectively. For ESP content more than 8% a decrease in the compressive was noticed with increasing of ESP content by 15.6%, 28.9 and 42.2% for 10%, 13% and 15% ESP respectively.
- In addition, an increase in flexural strength was noticed for the replacement of ESP up to 8% by 4.9%, 3.1% and 2.9% for 3%, 5% and 8% ESP respectively. While the ESP content of more than 8% caused a decrease in the flexural strength by 8.2%, 14.7% and 22.4% for 10%, 13% and 15% ESP respectively.
- The maximum load recorded from slab test under bending at failure decreased with increasing of ESP content.
- The maximum deflection at failure is increasing with increasing of ESP content.
- Also because of the high content of calcium carbonate in ESP, which can act as inert filler within the concrete, the concrete with ESP has less porous microstructure for ESP up to 8%.

### Abbreviations

ASTM	American Society for Testing and Materials
ESP	Eggshell Powder
SEM	Scanning Electron Microscope
SP	Superplasticiser
w/b	water/binder

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