Properties of concrete with eggshell powder as cement replacement

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This paper describes research into 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. The results indicated that ESP can successfully be used as partial replacement of cement in concrete production. The data presented cover strength development and transport properties. With respect to the results, at 5% ESP replacement the strengths were higher than control concrete and indicate that 5% ESP is an optimum content 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 addition of fly ash along with ESP is beneficial for improved performance of concretes.

1. INTRODUCTION

In 2004 ASTM International C150 allowed incorporation of up to a 5 % mass fraction of limestone in ordinary portland cement [1]. Hawkins et al (2003) reported that use of up to 5 % limestone does not affect performance of Portland cement [2]. Furthermore, Bentz et al (2009) reported that higher limestone percentage can also be used in concrete at lower w/c ratios [3]. Limestone powder substitution for cement makes sense in concretes saving money and energy and reducing carbon dioxide emissions [4]. However, as limestone is a natural mineral resource, quarrying and consequent prolonged use of limestone may again leads to problems associated with environment and sustainable development. Furthermore, lime production involves energy intensive process and consumes water. Therefore, identifying analogous material from waste and using the same in concrete production could be a wise idea.

Calcium rich egg shell is a poultry waste with chemical composition nearly same as that of limestone. Use of eggshell waste instead of natural lime to replace cement in concrete can have benefits like minimizing use of cement, conserving natural lime and utilizing waste material. According to a study eggshell waste generation in India, the United States and the United Kingdom is 190000, 150000 and 11000 tonnes per annum respectively. Eggshell waste can be used as fertilizer, animal feed ingredients and other such uses. However, majority of the eggshell waste is deposited as landfills. Eggshell waste in landfills attracts vermin due to attached membrane and causes problems associated with human health and environment. Few investigations were conducted to use eggshell waste in civil engineering applications. Amu et al., 2005 studied eggshell powder as a stabilizing material for improving soil properties [5]. A. J. Olarewaju et al, 2011 studied suitability of eggshell stabilized soil as subgrade material for road construction [6]. Apart from these studies, no other investigations were found in literature to use eggshells in civil engineering applications.

This study was aimed to use ESP in concrete. Although eggshell is calcium rich and analogous to limestone in chemical composition, it is a waste material. Therefore, to initiate use of eggshell waste for partial replacement of cement in concrete, there is a need to understand concrete properties made with eggshell powder. Thus, the primary objective of this study was to understand the possibilities of use of ESP in concrete. Investigations were systematically conducted on performance of ESP concretes in terms of strength properties like compressive strength and splitting tensile strength and transport properties like water absorption and sorption. The control and ESP replaced concretes were tested for 1, 7 and 28 days. Based on the test results, the influence of ESP replacement and the curing age on the concrete properties were discussed.

2. EXPERIMENTAL INVESTIGATIONS

2.1. Materials

Constituent materials used in this investigation were procured from local sources. Ordinary Portland cement of C53 grade conforming to both the requirements of IS: 12269 and ASTM C 642-82 type I was used [7, 8]. Broken egg shells collected from the local sources. The shells cleaned in normal water and air dried for five days approximately at a temperature range of 25 - 30°C. The shells then hand crushed, grinded and sieved through 90 µm. Material passed through 90 µm sieve was used for cement replacement and the retained material was discarded. Figure 1 shows processing of eggshell waste. Fly ash used in this investigation was procured from local suppliers. Chemical composition of the materials is presented in Table 1 along with specific gravities of the materials. Table 1 also shows chemical composition of lime stone [9]. From Table 1 it is clear that the chemical compositions of ESP and limestone are nearly same. Crushed blue granite of maximum size 20 mm was used as coarse aggregate. Well graded river sand finer than 2.36 mm was used as fine aggregate. The specific gravities of coarse and fine aggregates were 2.65 and 2.63 respectively.

Figure 1. Processing of eggshell waste (i) washing, (ii) air drying, (iii) grinding and (iv) sieving

2.2. Mix proportions

In order to investigate properties of ESP concretes, five mixes were employed. Before arriving at final mix proportions, several laboratory trial mixes were carried out with 300kg/m^3 cement. Water to cementitious ratio, coarse and fine aggregate quantities were arrived for concretes to be tested from the trial mixes. Visual observations were made on concrete mix homogeneity

Table 1. Chemical composition and specific gravity of the materials

	Cement	Fly ash	ESP	Lime stone filler [9]
SiO_2	21.8	58.3	0.08	0.58
Al_2O_3	6.6	31.7	0.03	0.06
Fe_2O_3	4.1	5.9	0.02	0.02
CaO	60.1	2	52.1	55.85
MgO	2.1	0.1	0.01	0.06
Na_2O	0.4	0.8	0.15	0.31
K_2O	0.4	0.8	-	0.25
SO_3	2.2	0.2	0.62	0.07
Others	-	-	0.62	-
LOI	2.4	0.3	45.42	43.58
Specific gravity	3.15	2.06	2.37	2.7

and workability in assessing final mixes. Control mix and ESP mixes were then selected for final investigations and another mix with both ESP and fly ash was also employed, in which, cement was replaced with both ESP (15%) and fly ash (15%) to investigate combined effect of both the materials. Water to cementitious ratio was maintained constant at 0.6 for all the concrete mixes. Details of the mixture proportions used for the concretes are given in Table 2.

2.3. Mixing, compaction, specimen preparation and curing

The concretes were mixed in a planetary mixer of 100l capacity. The mixing time kept to about 3 to 4 min. Mixing of the materials was in a sequence: (i) firstly coarse aggregate was placed into the mixer drum; (ii) portion of water quantity required for concrete mixes was poured into the mixture drum; (iii) cement and ESP were gently placed into the drum; and (iv) sand was spread over the powder and started mixing. During mixing, the remaining mix design water quantity was poured into the mixer drum for thorough mixing of constituents. Specimens were then prepared and left for 24 hours. The specimens were demoulded after 24 hours and immersed in normal water for curing until the test age.

3. TEST PROGRAM

Main objective of the present investigation was to study performance of ESP concretes in terms of strength with normal water curing and with no chemical admixtures in the mixes. Performance of the concretes was assessed through: compressive strength, split tensile strength, water absorption and sorption. The specimens were tested for 1, 7 and 28 days. Three specimens were tested for each mix and for each curing age, the mean values were reported.

Table 2. Mixture proportions

Concrete name	Cement, kg/m^3	ESP, kg/m^3	F, kg/m^3	CA, kg/m^3	FA, kg/m^3	w/cm*
M1	300	0	0	1170	750	0.6
M2	285	15	0	1170	750	0.6
M3	270	30	0	1170	750	0.6
M4	255	45	0	1170	750	0.6
M5	210	45	45	1170	750	0.6

ESP-Eggshell powder, f- fly ash, CA- coarse aggregate, FA-fine aggregate, cm-cementitious materials. * water was $180kg/m^3$

3.1. Compressive strength studies

Compressive loading tests on concretes were conducted on a compression testing machine of capacity 2000 kN. For the compressive strength test, a loading rate of 2.5 kN/s was applied as per IS: 516–1959 [10]. The test was conducted on 150mm cube specimens at 1, 7 and 28 days.

3.2. Split Tensile Strength

Split tensile strength test was conducted in accordance with ASTM C496 [11]. Cylinders of 100 x 200 mm size were used for this test. The test specimens were placed between the two platens with two pieces of 3 mm thick and approximately 25 mm wide plywood strips on the top and bottom of the specimens. The split tensile strength was conducted on the same machine on which the compressive strength test was performed.

3.3. Permeable voids and water absorption studies

Absorption study was conducted to understand the relative porosity permeable void space of the concretes, in accordance with ASTM C 642-82 [12]. Absorption and permeable voids tests were conducted on two 150 mm cubes. Saturated surface dry specimens were kept in a hot air oven at 105°C until a constant weight attained. Permeable voids in concretes were evaluated using the following formula.

$$\text{Permeable voids} = (A-B)/V*100$$

where A is the weight of surface dried saturated sample after 28 days immersion period. B is the weight of oven dried sample in air. V is the volume of sample.

The specimens removed from the oven were allowed to cool to room temperature. These specimens were then completely immersed in water and weight gain was measured until a constant weight reached. The absorption at 30 min (initial surface absorption) and final absorption (at a point when the difference between two consecutive weights was almost negligible) were reported to assess the concrete quality. The final absorption for all the concretes was observed to be at 72 h.

3.4. Sorption test

The sorption test was conducted on the concretes in order to characterize the rate of moisture migration of water into the concrete pores. Cubes of size 150x150 mm were marked on all four sides at 10 mm intervals to measure the moisture migration. As explained in the water absorption test, the specimens were oven-dried. They were then allowed to cool down to the room temperature. After cooling, the cubes were placed in water on the wedge supports to make sure that only the bottom surface of the specimens in contact with the water. A cotton cloth was covered on the top of the wedge supports to ensure that the specimens are in contact with the water throughout the test period. Moisture rise in the cubes was measured through weight gain of the specimens at regular intervals. Sorption of the concretes was then calculated using linear regression between the weight gain of the specimen per unit area of the concrete surface and square root of time for the suction periods.

4. RESULTS AND DISCUSSION

A comprehensive summary of the results of the properties of all the concretes are presented in Table 3.

4.1. Fresh state properties

Visual observations during mixing and compaction of all the concretes suggested that the concretes were homogeneous; there was no segregation and bleeding; and the mixes were compactable. The fresh state performance of the ESP concretes was comparable with control concrete. The concretes had very low slump, slump values of the concretes were between 5-12mm. ESP replaced concretes did not show any noticeable influence on fresh state behaviour when compared with control concrete. However, further through investigations are needed for complete understanding of ESP influence on fresh state properties of concrete.

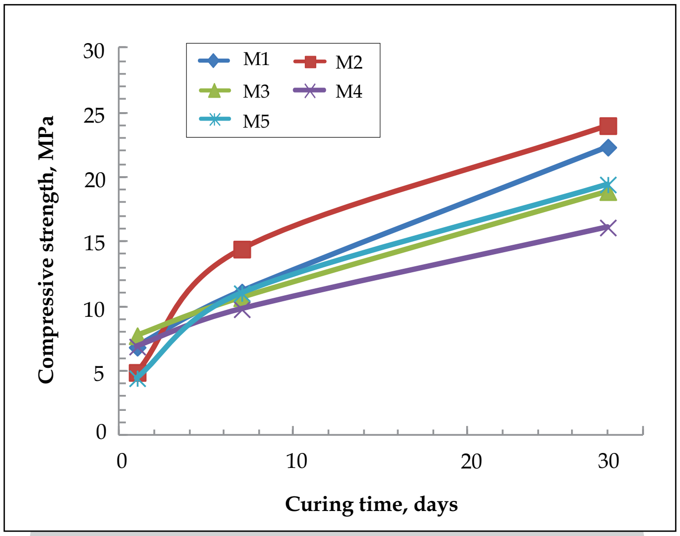

Figure 2. Compressive strength with age for control and ESP replaced concretes

From Table 3 it can be observed that the densities of ESP replaced concretes decreased with increase in ESP replacement. Decreased densities of the concretes can be attributed to the direct consequence of replacing the high density material (cement) with the low density material (ESP).

4.2. Compressive strength

Figure 2 shows change in compressive strengths for control (M1), ESP replaced (M2, M3 and M4) and both ESP and fly ash replaced concretes (M5) with age. From

Table 3. Properties of normal and eggshell powder concretes

Concrete name	Compressive strength, MPa			Split tensile strength, MPa			Density, kg/m^3	Absorption, %		Permeable voids	Sorption, $mm/s^{0.5}$
	1 day	7 day	28 day	1 day	7 day	28 day		30 min	72 hr		
M1	6.8	11.1	22.3	0.4	0.8	2.4	2364	1.38	4.39	7.7	0.12
M2	4.9	14.4	24	0	1.3	2.4	2347	1.02	2.94	7.7	0.106
M3	7.7	10.7	18.9	0.2	1	2.3	2323	1.39	3.41	8.89	0.11
M4	6.9	9.8	16.1	0	1.4	1.6	2305	1.67	4.38	8.3	0.16
M5	4.4	11	19.4	0.2	1.3	2.2	2317	1.88	5.13	9.48	0.17

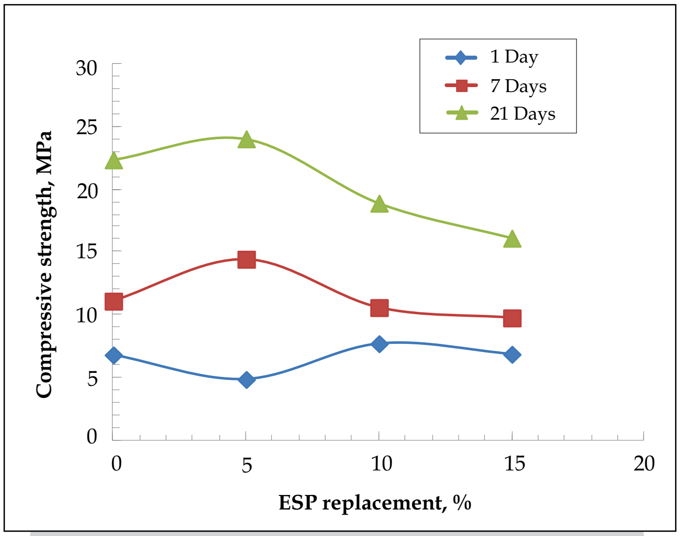

Figure 3. Change in compressive strength with different ESP replacements

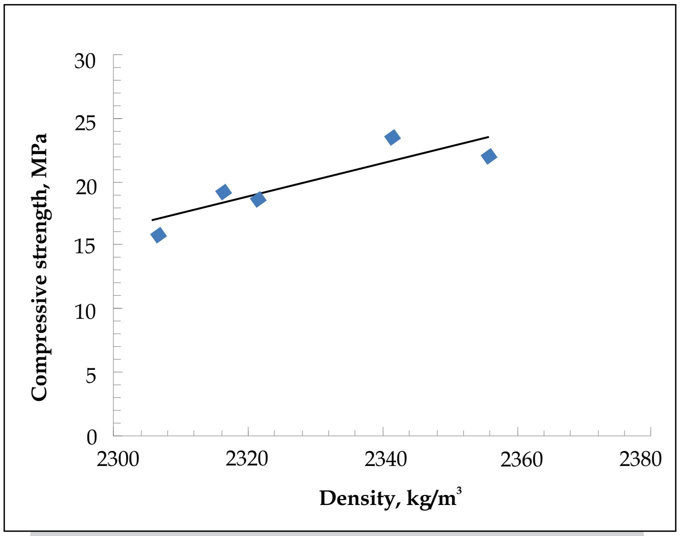

Figure 4. Relationship between compressive strength and density

Figure 2 it can be observed that the strength increased with the curing age for all the concretes. Control concrete gained 31 % at one day and 50 % after 7 days of curing over its 28 days compressive strength. The ESP concretes gained 20-43 % at one day and 56-61 % after 7 days of curing than their corresponding 28 days strengths. M5 mix which contained both ESP and fly ash attained 23 % and 57 % strengths over 28 day strength at one and 7 days respectively. This observation suggests that the strength enhancement of ESP concretes is lower than control concrete between 7 and 28 days.

Figure 3 depicts change in compressive strength with different ESP replacements. At one day curing, the compressive strength of M2 concrete was lower than M1 concrete. However, the compressive strength increased to 30 % and 7 % at 7 and 28 days of curing over control concrete (M1). The strength increase of M2 concrete was higher between one and 7 days over control concrete. One day strength of M3 and M4 was nearly same as that of control concrete (M1). However, the compressive strengths of these concretes were lower than control concrete at 7 and 28 days of curing. The strengths were 4 % and 12 % lower at 7 days for M3 and M4, whereas, the strengths were 15 % and 28 % lower than control concrete at 28 days of curing. M5 concrete had 35 %, 1 % and 13 % lower strengths than control concrete for 1, 7 and 28 days of curing. This observation suggests that ESP replacement of 5 % can give higher strength than control concrete. However, further increase of ESP will decrease compressive strength at all curing ages. Furthermore, addition of fly ash increases compressive strength over its corresponding ESP replaced concrete.

Relationship between 28 day compressive strength and density of the concretes is shown in Figure 4. There is good linear relationship between the parameters with $R^2 = 0.91$, the strength increased with the density.

4.3 Split tensile strength

Split tensile strength of all the concretes is shown in Table 3. All the concretes failed to show enough resistance against split tensile strength at one day. However, the split tensile strengths of the concretes were between 0.8 - 1.4 MPa for 7 days of curing. The control concrete (M1) attained 32 % of its 28 day strength. The ESP concretes had higher strength enhancement than control concrete at 7 days of curing. Maximum strength gain was for M4 concrete with 88 % over its 28 days split tensile strength. Strength gain for M5 also had higher strength gain at 7 days of curing than control concrete. This observation suggests that similar to compressive strength, addition of ESP, especially above 10% will retard strength gain between 7 and 28 days. Split tensile strength of the concretes at 28 days of curing was between 1.6-2.4 MPa. The lowest strength was for M4. Although there was good strength enhancement between one and seven days of curing, this mix failed to maintain same enhancement between 7 and 28 days of curing. The remaining concretes did not show any major difference in split tensile strengths with control concrete after 28 days of curing.

It appears there is a good relationship between compressive strength and split tensile strength. The regression analysis between the variables is shown in Figure 5. From the figure it can be seen that the compressive and the split tensile strengths are directly related. Split tensile strength increased with compressive strength. The figure also includes equation suggested by Raphael, 1984 [13] for normal concrete, it appears the equation well predicts the present data.

4.4 Water absorption and permeable voids

Variation of the water absorption with time for the concretes is shown in Figure 6. It shows that the water absorption of all the concretes is maximum for first 3 hours and it becomes nearly constant with time. From the figure it can also be observed that the water absorption for M2 and M3 is lower than control concrete, whereas, M4 show nearly same absorption as that of control concrete. M5 concrete show higher water absorption than control concrete.

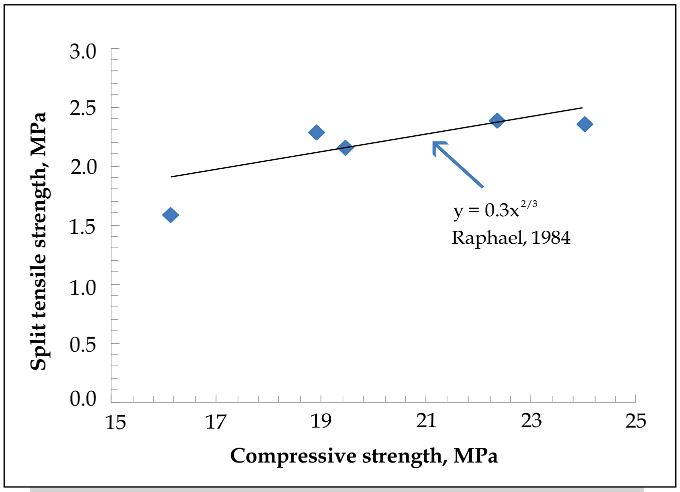

Figure 5. Relationship between compressive strength and split tensile strength

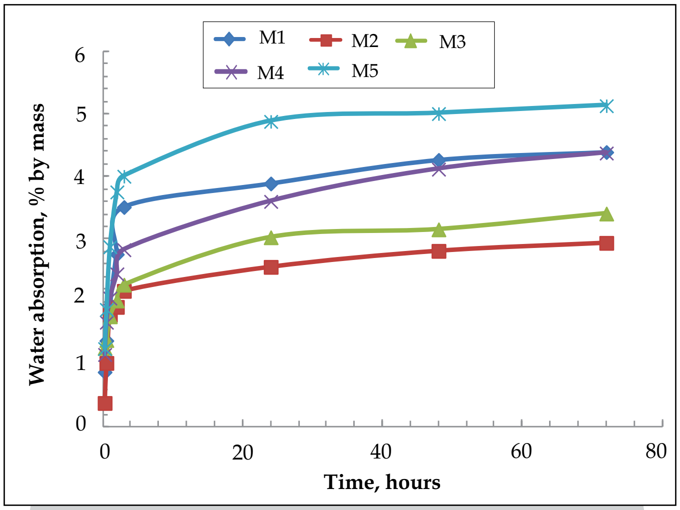

Figure 6. Variation of water absorption with time

The absorption in 30 min (initial surface absorption) and the absorption after 72 h (final absorption) for the concretes are presented in Figure 7. It can be seen that the initial surface absorption of all the concretes is lower than 3%, the limit specified for ''good'' concrete by CEB [17]. The final absorption at the end of 72 h for these concretes also followed a similar trend. The figure also includes relationship between compressive strength and initial and

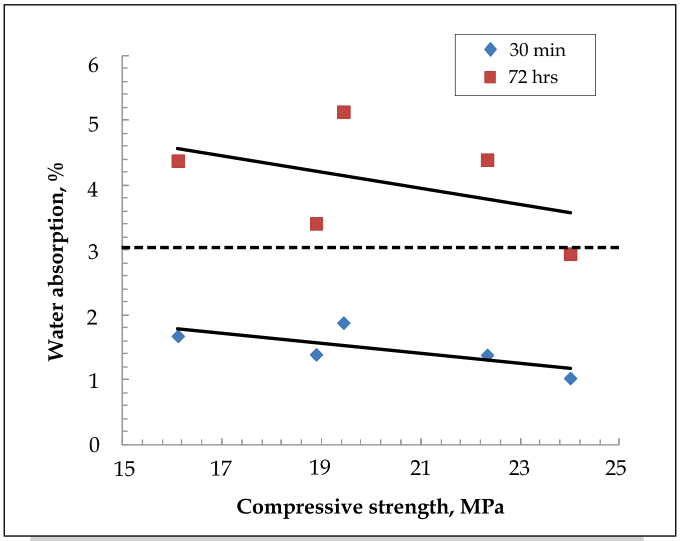

Figure 7. Relationship between water absorption and compressive strength

final water absorption. As compressive strength increased both initial and final water absorptions decreased.

Relationship between ESP replacement and permeable voids is shown in Figure 8. The permeable voids increased with increase in ESP replacement. A relationship between percentage of permeable voids and final water absorption is depicted in Figure 9. Although scatter between the data points is observed, overall, the water absorption increased with increase in permeable voids.

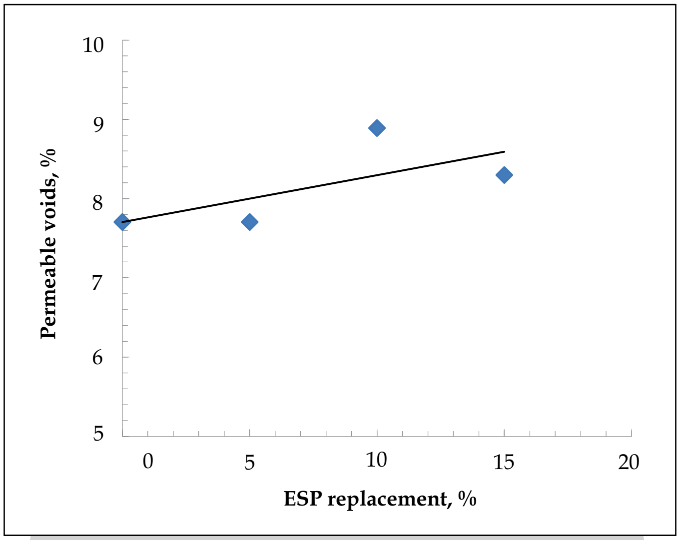

Figure 8. Relationship between permeable voids and ESP replacement

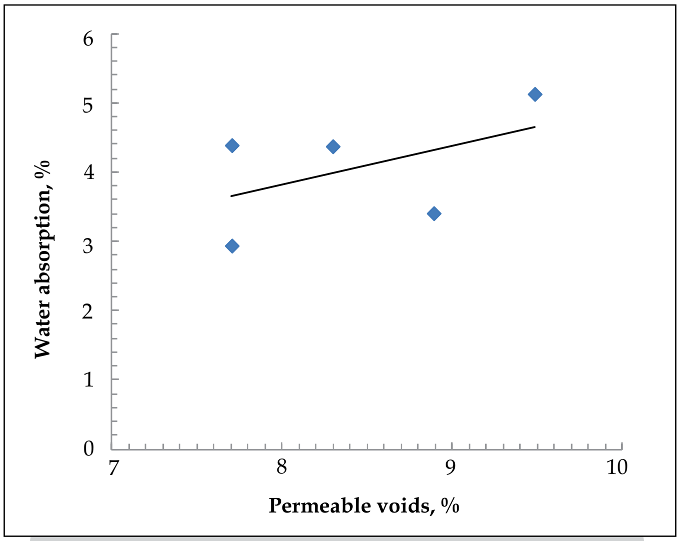

Figure 9. Variation of final absorption with permeable voids

4.5 Sorptivity – capillary water absorption

Sorptivity of the concretes is shown in Table 3. Sorptivity of the concretes is between 0.106-0.17 mm/s$^{0.5}$. The lowest sorptivity is for M2 concrete and the highest sorptivity is for M5 concrete. Similar to water absorption, sorptivity also decreased with increase in compressive strength (Figure 10). Figure 11 shows relationship between water absorption and sorption. As water absorption increased sorption also increased. As in water absorption,

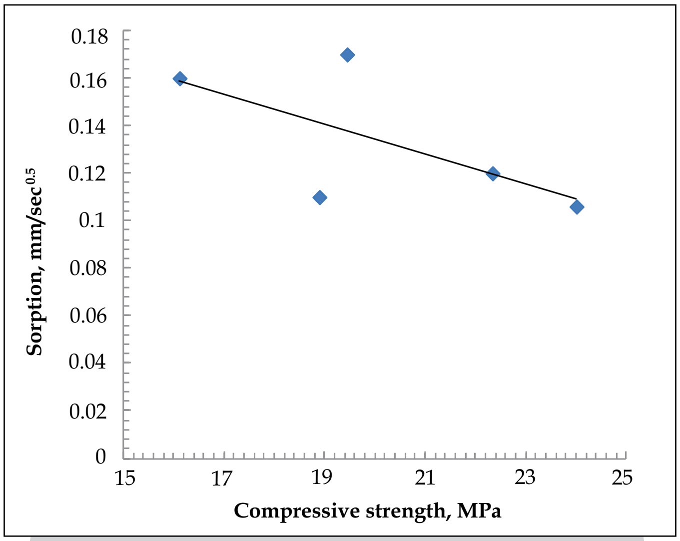

Figure 10. Relationship between sorption and compressive strength

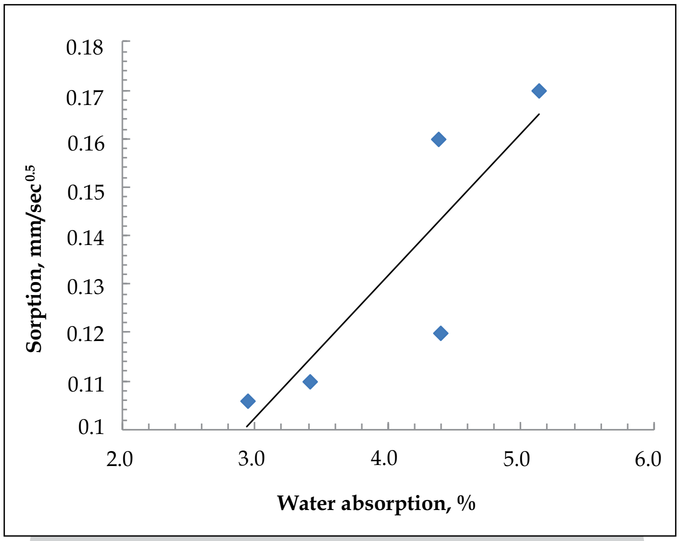

Figure 11. Relationship between sorption and final water absorption

sorption also increased with increase in permeable voids (Figure 12). Although the expected trends are observed, the scatter between the data points is high.

4.6 further discussion

As stated earlier since the chemical composition of the egg shell powder is very close to lime stone composition (Table 1), the behaviour of ESP concretes of this study can be compared with lime stone replaced concretes. Limestone reacts with the alumina pastes of cement to form a calcium mono-carboaluminate hydrate phase and contributes to strength change [14]. Slightly higher strength at 5% replacement of ESP could be due to chemical reaction between ESP and cement paste as in lime stone concrete. At higher lime stone replacement the pore size increases and consequently the strength decreases [9]. Evidently, in this investigation the strength of the concretes decreased at higher ESP percentages. Furthermore, in literature it was reported that for the strength range between 25-30 MPa replacement of 10 % lime stone reduced 15 % of 28 day strength when compared to control concrete [15]. Similar observations are made in this investigation. With 10 % ESP replacement the 28 day strength decreased around 14 % when compared to the control concrete. From this discussion it can be concluded that the ESP behaviour is nearly same as that of lime stone filler in strength property. Improved strength due to fly ash addition along with ESP in M5 when compared to corresponding ESP replaced concrete (M4) may be due to improved particle packing along with pozzolanic activity [16]. Evidently, density of M5 is higher than M4 (Table 3). Contribution of fly ash to the strength is time dependent phenomenon, further increase in strength could be expected in M5 at later age. The tests could not be extended in the present study to later ages due to time constrain.

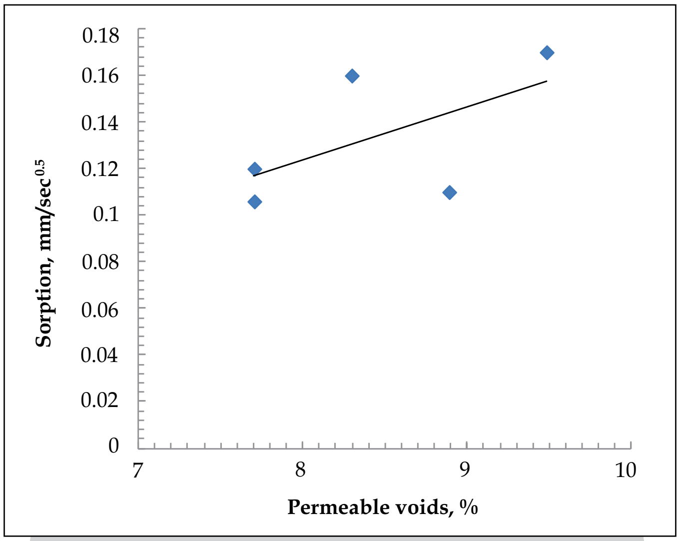

Figure 12. Relationship between sorption and permeable voids

Overall, the main factors that control transport properties of concrete materials are relative volume of paste matrix, the pore structure of the bulk matrix and the interfacial zone around the aggregate particles. As explained earlier, it is thought that the ESP with calcium could have reacted with cement and have aided for good compacted structure thus resulted in comparable performance as that of control concrete in terms of transport properties. However, at higher replacements transport properties of ESP concretes were relatively higher than control and 5% ESP replaced concretes. This may be due to heterogeneous structure. No studies are available on microstructure of concrete with ESP. Clearly further research is needed to understand microstructure of ESP replaced concrete. Furthermore, in this investigation, the ESP was sieved through 90µm sieve. There may be improved performance of concrete if particle size is reduced. Therefore, study on influence of ESP particle size on concrete may also be a useful contribution. As LOI of ESP is high, effect of LOI need to be investigated on durability properties of ESP concretes.

5. CONCLUSIONS

The data show the ESP can be replaced in place of cement. However, percentage ESP replacement has influence on concrete properties. The main points of this study are outlined below.

1. 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. Addition of fly ash improved compressive strength of ESP concrete.

2. Split tensile strengths of ESP concretes were comparable with control concrete up to 10 %

ESP replacement. However, concrete with 15 % ESP had lower split tensile strength than control concrete. As in compressive strength, addition of fly ash improved split tensile strength of 15 % ESP concrete. ESP performance was nearly same as that of lime stone filler in concrete.

3. The results demonstrated that, irrespective of ESP percentage replacement there was good relationship between compressive strength and split tensile strength. The trend was predicting the equation proposed by Raphael, 1984 [13].

4. Absorption characteristics show that the initial 30 min absorption values for all the concretes were lower than limits commonly associated with good quality concrete [17]. The maximum absorption observed was 1.87 % for 15 % ESP and 15 % fly ash concrete. The absorption decreased with decrease in permeable voids.

5. Sorptivity of the concretes was comparable with control concrete up to 10 % ESP replacement. However, sorptivity of 15 % ESP concrete and 15 % ESP and 15 % fly ash concrete was higher than control concrete. The maximum sorptivity was for ESP and fly ash replaced concrete with 0.17 mm/s$^{0.5}$. Sorptivity decreased with strength and increased with water absorption.

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