Experimental Study on Compressive Strength of Concrete by Partial Replacement of Cement with Eggshell Powder

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Abstract-In this research work, influence of eggshell powder (ESP) as partial replacement of cement in concrete was investigated. Cement was replaced by ESP by an amount of 5, 10, 15 and 20% by weight; all other parameters of mixture were kept constant. Workability of fresh concrete and compressive strength of hardened concrete were evaluated and compared with conventional concrete. Compressive strength of all types of mixture was investigated after 7, 14, 28 and 63 days of standard moist curing. Workability was decreased with the increase in amount of ESP; whereas delay in strength gain was observed with the increasing amount of ESP. Compressive strength of specimens with ESP is comparable with conventional concrete after 63 days of age. However, a huge difference was observed between compressive strengths to age of 28 days. It concluded that ESP has the potential to be used as partial replacement of cement and can also be used as retarder in concrete production.

Keywords-Eggshell Powder, Cement Replacement, Workability, Compressive Strength.

I. Introduction

Concrete is considered as the back bone of construction industry and has major role for the development of infrastructure. Currently, developing countries are taking major steps for the development of infrastructure and for fulfilling this aim, huge amount of concrete is required. Portland cement is one of the major ingredients of concrete and is generally very expensive. It is also a big source of environmental pollution as 1kg of cement production emits about 0.8 to 0.9kg of carbon di-oxide (CO_2)[i]. Large amount of cement is manufactured in Asia. Previous studies showed that out of total production of cement in the world 60% cement is produced in Asia and annually almost 900 million metric tons of cement is produced. Out of which only 18 million tons are produced in Pakistan [ii].

Efforts are made by different researchers for sustainable development of construction industry and solving the problem of waste management, simultaneously, by replacing cement by various waste materials [iii-xiii]. Physical and chemical composition of a non-treatedavian eggshell waste specimens were analyzed and examined its usage in wall tile paste. Different tests were performed to analyze the chemical composition of specimen and it was concluded that eggshells are rich in $CaCO_3$ and has the potential to be used as an alternative raw material in the production of wall tile materials [iii]. Cree and Rutter worked on eggshell powder and tries to industrialize the application of eggshell powder. The eggshell membrane was heated and grinded to form $CaCO_3$. Pure calcite was produced by heating at 300 °C for 2 hours [iv]. Kumar et al. studied experimental study on partial replacement of cement with eggshell powder (ESP) and investigated the effect on strength of the concrete [v].Vinothan et al. also replaced cement successfully with ESP by 5, 10 and 15%. Increase in mechanical properties (compression, tensile and flexural strengths) were observed with the increase in the amount of ESP [vi]. Gowiska et al. had increased the amount of ESP upto 25% by an interval of 20% and 5% replacement of cement with ESP showed the best results in term of mechanical strength as compared to other specimens [vii]. Eggshells can also be used as a shielding against radiations. Concrete with eggshells was prepared and check their performance against the radioactivity and recommended to use such concrete walls which resist the radioactive areas [viii]. ESP was also used to produce light weight concrete by using Porcelanite as aggregate and contribution of 5% ESP had minor effect on the mechanical properties of such concrete and increase in the amount of ESP may improve the mechanical strength and durability of light weight concrete [ix].

Silica fume was also added to enhance the strength of concrete and its addition was 5, 10 and 15%, whereas ESP addition as partial replacement of cement was10, 20 and 30%by weight. Improvement in compressive strength was observed with the addition of ESP and was further improved with silica fume addition. The flexural strength of the concrete having ESP also increases with the addition of ESP [iv]. Pliya & Cree worked on the performance of white and brown chicken eggshell waste powders as potential replacements of conventional quarried limestone in Portland cement mortars [x]. Compression and flexural strength tests were carried out on mortar specimens with partial replacement of Portland cement by limestone and it was found that eggshells derived limestone powder have inferior properties even with 5% replacement as compared to natural conventional limestone [v].

Instead of cement replacement, ESP was also used as partial replacement of sand and 20% replacement of fine aggregate was observed in one research work [xi-xii]. The compressive strength, split tensile strength and flexural strength were carried out. The strength properties obtained were compared with the conventional concrete after the curing period of 7, 14 and 28 days. It was observed that the waste of ESP used in the concrete was comparatively low in cost when compared with normal concrete and the concrete with the addition of different percentages of polypropylene fiber by weight of concrete with 20% constant replacement of fine aggregate by ESP had given the better result when compared with the conventional concrete. The weight of concrete was also reduced by using ESP due to lighter unit weight of ESP [ix].

Based on these findings it is investigated that ESP has the ability to be used as partial replacement agent of cement powder in concrete. On the other hand disposal of eggshell is a major concern and using large amount of land to fill with it. Consequently by using the ESP as cement replacing material not only play important role in reducing the cost of construction but also put major step for solving the problem of environmental pollution that the whole world is facing now a days. With these objectives, tests were performed in different stages as per normal test processes. In first stage, physical properties of materials, chemical compositions, and categorization of ESP and cement were accomplished. Second stage comprised of casting of concrete by incorporating ESP by different amounts and investigating fresh properties of concrete. The third phase included evaluation of compressive strength test on concrete specimens at different ages, and comparison was made with the conventional concrete.

II. EXPERIMENTAL PROGRAM

To investigate the behavior of concrete with ESP, experimental plan was established to evaluate the properties of constitutive materials of concrete, fresh and hardened properties of concrete were evaluated. Details of material and tests performed on those materials are explained in following sub-sections.

TABLE I
PHYSICAL PROPERTIES OF CEMENT AND EGGSHELL POWDER

Physical Properties	Cement	Eggshell powder
Particle size	8% retained on sieve # 200	11% retained on sieve # 200
Colour	Grey	White
Type	ASTM Type1	-----
Specific gravity	3.15	2.27
Standard consistency (%)	31	-------
Initial setting time (Minutes)	95	-------
Final setting time (Minutes)	165	-------
Fineness	3656 cm^2/g	2157.25 cm^2/g

A. *Materials*

Regionally accessible materials were used for concrete casting. Ordinary Portland cement of ASTM Type-I in compliance with ASTM C150 [xiv] was employed. The physical properties of cement are given in Table I. Locally available river sand passing through 4.75 mm was used as fine aggregate. The coarse aggregate was regionally available compacted Margala crush, passing through 12.5 mm sieve and retained on 4.75 mm sieve compliant to ASTM C-136 [xv]. Physical properties of both aggregates are presented in Table II. Eggshells were procured from local market of Faisalabad city of Pakistan. Eggshells were cleaned completely to remove dust and organic properties. These shells were dried in sun light for 5 to 7 days followed by grinding and sieving to a very fine powder before used Table I.

TABLE II
PHYSICAL PROPERTIES OF CONVENTIONAL AGGREGATES

Physical Properties	Coarse aggregate	Fine aggregate
Source	Margala	Lawrence pur
Particle size	½ inch down	Fine
Water absorption test (%)	0.93	0.3
Loose bulk density kg/m^3	1358.31	1579.5
Compacted bulk density kg/m^3	1555.24	1757.08
Impact value (%)	16.23	Not found
Specific gravity	2.85	2.74

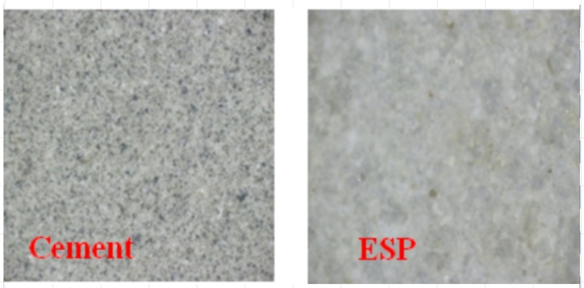
B. *Comparative analysis of properties of ESP and Cement*

Before using ESP as cement replacement agent several comparative tests were performed. The morphology and texture of the ESP particles and cement particles were examined by field emission scanning electron microscopy (FESEM). Images of respective materials were captured at magnification of 50-X to 200-X, as shown in Fig. 1. Results were also verified by fineness test as presented in Table I.

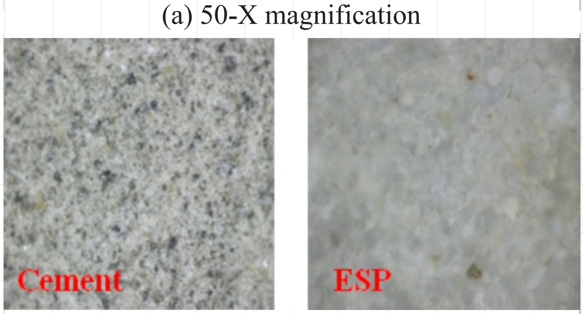
TABLE III
AMOUNT OF OXIDES IN CEMENT AND ESP

Oxides	Chemical Name	Cement	Eggshell powder
CaO	Calcium oxide	62.18	50.7
SiO_2	Silicon dioxide	20.65	0.09
Al_2O_3	Aluminum oxide	5.12	0.03
MgO	Magnesium oxide	2.05	0.01
Fe_2O_3	Iron oxide	3.19	0.02
Na_2O	Disodium monoxide	0.32	0.19
So_3	sulfur trioxide	1.93	0.57
P_2O_5	Phosphorus pentoxide	—	0.24
SrO	Strontium oxide	—	0.13
So_3	Sulfur trioxide	0.45	0.57
Cl	Chloride ion	0.15	0.219

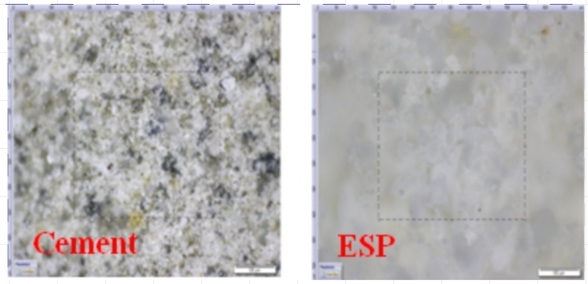
Chemical examination for oxides composition of cement and ESP were determined by X-ray diffraction test followed by ASTM C 1365 [xvi]. Table III illustrates the chemical composition of ESP and ordinary Portland cement, which shows that calcium oxide (CaO) contributes about 51% in ESP which seems quite comparable with cement. ESP specimen also contained small amounts of aluminum oxide (Al_2O_3), silicon dioxide (SiO_2), iron oxide (Fe_2O_3) and sulphar trioxide (SO_3) reporting only 1.5% of total composition. These oxides are present in high quantities in cement which are conscientious for early age strength.



(a) 50-X magnification



(b) 100-X magnification



(c) 200-X magnification

Fig. 1. FESEM images of cement and ESP at different magnifications.

Fig. 2. Dry mixing of Eggshell powder

C. Mix design and casting of concrete

Ordinary Portland cement of ASTM type-I was partially replaced with ESP by an amount of 5, 10, 15 and 20% by weight. The volumetric ratio of cement: sand: aggregate used was 1:2:4. ESP was mixed in cement and sand in dry condition for 3 to 5 minutes Fig. 2. After the addition of aggregate water was added and mixed for 5 to 10 minutes. Each substitution along with the control mix were prepared with a water to binder (water/(cement + ESP)) ratio of 0.6. Five batches of concrete cubes were fabricated and were referred as: the control mixture without ESP were presented as ES-00 and ES-05, ES-10, ES-15 and ES-20 containing 5, 10, 15 and 20% of ESP, respectively. The mix proportions for each batch for one cubic meter are presented in Table IV. Twelve cubes of size 100 mm were casted for each mix design to find out compressive strength at 7, 14, 28 and 63 days. After 24 hours of casting each cube was demoulded and cured at room temperature in wet condition.

Workability of fresh concrete was measured by slump test and compacting factor test according to guidelines [xvii-xviii]. All cubes of concrete specimens were cured for 7, 14, 28 and 63 days at room temperature. The specimens were taken for testing under compression test by following ASTM C-39 [xix]. Summary of the test performed along with number of specimens used are given in Table V. All specimens were tested under uniaxial compression at different days. Influence of curing age and influence of replacement of cement are investigated in detail and explained in following sections.

TABLE IV
MIXING PROPORTIONS FOR ALL TYPES OF CONCRETE

Materials	Specimen identification				
	ES-00	ES-05	ES-10	ES-15	ES-20
Cement (kg/m^3)	529	503	476	450	423
Aggregate (kg/m^3)	2116	2116	2116	2116	2116
Sand (kg/m^3)	1055	1055	1055	1055	1055
Water (litter)	317	317	317	317	317
ESP (kg/m^3)	0	26.5	53	79	106
Cement (kg/m^3)	529	503	476	450	423

TABLE V
SUMMARY OF CONDUCTED TEST AND NUMBER OF SPECIMENS

Specimen	S.V[a]	C.F[b]	Compressive strength(days)			
			7	14	28	63
ES-00	2	1	3	3	3	3
ES-05	2	1	3	3	3	3
ES-10	2	1	3	3	3	3
ES-15	2	1	3	3	3	3
ES-20	2	1	3	3	3	3

S.V[a]= slump value; C.F[b]= compacting factor

III. RESULTS AND DISCUSSION

Test performed on fresh and hardened properties of concrete with ESP were investigated and detail discussions are given in following sub-sections.

A. Workability of concrete

Workability of all types of concrete was measured by slump test and compacting factor test. It was observed that inclusion of ESP as partial replacement of cement reduces the workability of concrete. Reduction in workability was observed with 5% ESP substitution and further decreases by increasing the amount of ESP. The specimen ES-20 confirms minimum workability among all mixtures and there was almost 100% reduction in workability as compared to standard mixture. However all mixtures countered very well to mechanical vibration and could be placed and compacted easily with fewer efforts. Comparison was made between workability and replacement amount of cement with ESP and presented in Fig. 3.

ESP particles are coarser than cement particles so by increasing the amount of ESP, the fineness of mixture decreases which reflect great impact on workability of concrete. As the fineness of concrete mix decreases workability also decreases and there occurs a gradual fall in workability of concrete with increasing amount of ESP.

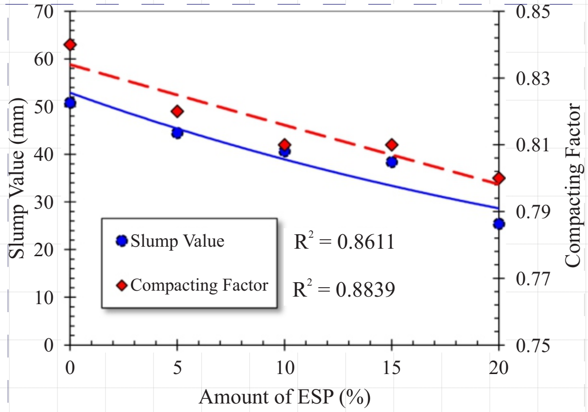


Fig. 3. Amount of ESP (%) versus workability.

B. Compressive strength of concrete

1) With Respect to Curing Age

Evaluation of the data for compressive strength at 7, 14, 28 and 63 days of curing age disclose the fact that the compressive strength of control mixture continue to increase with age. Tri-calcium silicate ($3CaSiO_2(C_3S)$) and tri-calcium aluminate($3CaOAl_2O_3$ (C_3A)) are formed after the reaction of aluminum (Al) and $SiO_2$with CaO, which are the primary motive of early age strength [xx].The behavior of ESP concrete was quite different from the control specimen. The 7 days compressive strength of all specimens containing ESP are lesser then that of the normal concrete and this strength further decreases at the age of 14 days. However, improvement was recorded after 28 days by ES-15 as the compressive strength attains the roughly identical strength as that of control specimen and at the age of 63 days the mix depicted perfection in compressive strength results. The compressive strength boosted when 15% cement was replaced with ESP and proves superior comparative strength to control mixture. But in case of ES-20the strength again declined as compared to control mixture.

It is crystal clear that early age compressive strength of all specimens containing ESP is less as measure up to normal concrete. For instance, adding 5%, 10% and 15%of ESP decreased the compressive strength by 33%, 32%, and 37% at 7 days from that of concrete without ESP. Consequently, mixtures ES-10 and ES-15 shows 4% and 18% enhancement in compressive strength at an age of 63 days as depicted in Fig.4.Fine cement filler particles are responsible to accelerate the hydration of concrete and subsequently increase the early strength. Cement powder had smaller particles than the eggshell powder and therefore results in high quality fineness and more surface area was available to react with water. So the coarser particle size of ESP adversely affects the early age compressive strengths of concrete, moreover Si and Al particles are present in very small quantities in ESP as compared to cement powder, generally responsible for the formation of C_3S and C_3A.The observable fact can be verified from another study [xxi]. Thus reduction in strength at 7 days could be explained by this phenomenon.

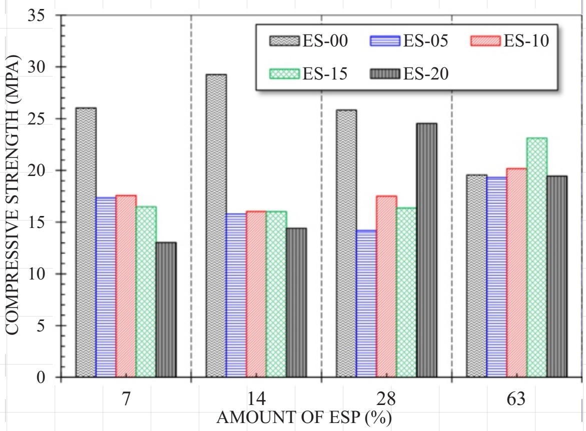


Fig. 4. Comparison of compressive strength at various ages of all mixtures.

2) With Respect to Amount of ESP

To find out the optimum percentage of ESP as cement replacement agent, comparison was made between amount of ESP (x-axis) and compressive strength (y–axis) Fig. 5 and analysis were made.

Replacing the cement powder with ESP affected the compressive strength of all mixtures. It is observed from the Fig. 5 that the mixes of all proportions containing ESP show poor results of compressive strength at the age of 7 and 14 days when compared to control specimen and this reduction become more pronounced as the percentage increases. Decrease in early age compressive strength may be due to the lower amount of cementing properties of the eggshell powder and increased quantity in non-cementing materials. The reason lies in reduction of strength was explained in a recent research [xxii]. It was found that limestone cement mortar was not completely hydrated even after 28 days of curing age [xxii]. Beyond 28 days of age, it was noticed that compressive strengths of ESP incorporated mixtures are higher than that of control mixtures. The mix ES-15 confirms almost identical strength when compared to control concrete at the age of 28 days. And at 63 days the value boosted up and proves 14% increment to control mix. In case of mix ES-20 the 28 and 63 days strengths were slightly reduced as compared to control mixture. Conversely the strength was satisfactory to meet the requirements of ASTMC-39 [xix]. It is also concluded that the ratio 5and 10%of ESP showed lower compressive strength results values than control mixture and these values are not sufficient to meet the compressive strength requirement of ASTM standards of concrete. On the other hand the results are in agreement with another research which showed that up to at an age of 28 days compressive strengths of limestone–silica fume mortars were lower than that of controlled mixture. However, at later ages; 90 and 180 days, limestone-silica fume mortars showed similar compressive strength values compared to control mortar. It is believed that opposite results were recorded due to the pozzolanic effect of silica fume [xxiii].Silica fume is a highly pozzolanic material which forms additional calcium silicate hydrate by reaction with calcium hydroxide formed upon cement hydration. This results in increase in the strength of the blended cement. Since at early ages of hydration of cement sufficient amount of calcium hydroxide is not available, the early strength of blended cements is lower than that of ordinary cements. But at higher age sufficient amount of calcium hydroxide was available, which was the main reason of opposite results obtained at this age as compared to early age.

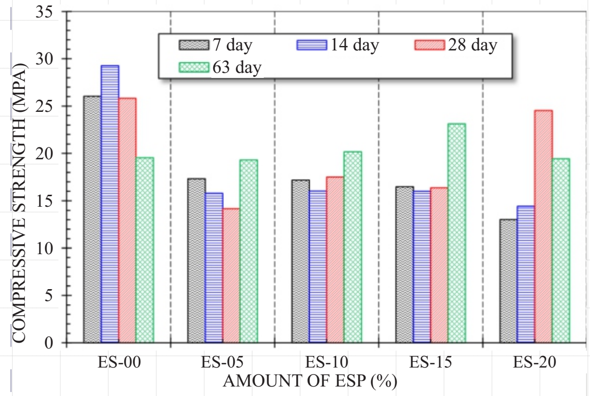


Fig. 5. Comparison of compressive strength at various amount of ESP.

3) With Respect to Normal Concrete

To make the results more clear it was necessary to compare the strength of all specimens containing ESP to the conventional concrete specimens. For this reason comparison was made between the compressive strength of percentage replacements of cement with ESP and normalized compressive strength. The comparative behavior of all mixtures with control mixture is shown in Fig. 6.

From Fig. 6, it is clear that compared to control mixture, compressive strength of concrete containing different content of eggshell powder reduced at early ages and these reductions continues with increasing ESP content. At 7 days of age the strength ratio of ES-05 was 0.69.For the same curing time, as amount of ESP were increased to 10%, the reduction was more pronounced with the strength ratio value of 0.65 and the value kept on decreasing with increasing ESP content. Similar trends were obtained for strength ratio at 14 days of curing age. As it is noticed that strength ratio through ES-05 to ES-20 concrete specimens constantly reduces with enhancement in ESP substitution content and the maximum recorded value of normalized compressive strength was 0.539 by mixture ES-05.The results recorded at 28 days of curing age were quite different from results obtained at 7 and 14 days. The maximum value evidenced by specimen ES-20 was

0.95 which demonstrates the strength of specimen at that age was almost equal to normal concrete. Beyond 28 days the results were more favorable for ESP concrete. It can be concluded that the addition of ESP improves the compressive at the age of 63 days. Strength ratio was 0.98 in case of ES-05 and superior results were observed for ES-10 and ES-15 with the recorded value of 1.03 and 1.18 respectively. The value again decreases to 0.98 in case of ES-20. It can be derived from the results that difference between compressive strength values of control mortar and ESP incorporated mixtures were generally higher at early ages compared to those at later ages. Considering the compressive strength values of concrete, the optimum percentage of eggshell powder as partial replacement of cement in concrete is 10 and 15%.

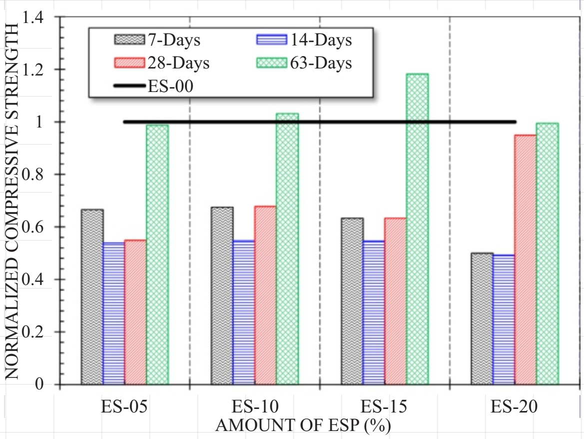


Fig. 6. Comparison of normalized compressive strength with various amount of ESP.

IV. CONCLUSIONS

Experimental investigations were conducted to determine the characteristics of normal strength concrete with 5, 10, 15 and 20% replacement of cement by eggshell powder (ESP) by weight of the cement. Workability and compressive strength were evaluated and following conclusions were extracted from entire work.

1. The workability of concrete having eggshell powder was less than conventional concrete and further reduced by increasing in the amount of ESP.
2. Particle size, quality and amount of eggshell as cement powder replacement are the major parameters affecting on the strength of concrete.
3. It was observed that gain in strength of concrete with ESP was delayed as compared to conventional concrete because ordinary Portland cement concrete had better accelerated hydration at 7 days as shown by the early strength gain as compared to ESP concrete.
4. The negative effect of eggshell powder on compressive strength of concrete was compensated up to some extent at later ages. Because beyond the age of 28 days the compressive strength observed by mix ES-15 was higher than that of control mixture (0% eggshell concrete).
5. Concrete replacing 10% and 15% of cement with ESP has the potential to be used as retarder in areas where temperature is low and early hardening of concrete causes problem.

Although eggshell based concrete (as partial replacement of cement) led to inferior compressive strength properties at early ages. Addition of eggshell powder to cement could lower the amount of cement content in concrete which reduces the CO_2 and energy consumption both related to cement production. Concrete made with ESP addition is also relatively less expensive than normal concrete. So it is recommended that projects where strength may not be the primary requirement could potentially be used provided further testing is conducted on their plastic and durability properties.

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REFERENCES

[i] M. Glavind, "Sustainability of construction materials", Danish Technological Institute, Denmark, (2009) 120-147.

[ii] S. F. A. Rafeeqi, "Pakistan –Concrete Construction Industry – Cement Based Materials and Civil Infrastructure." CBM-CI International Workshop, Karachi, Pakistan, 91-102.

[iii] M. N. Freire, S. J. G. Sousa and J. N. F. Holanda., "Using eggshell waste in red wall tiles", Waste Resource Management, Vol. 161 (2008) 23–27.

[iv] D. Cree and A. Rutter, "Sustainable Bio-Inspired Limestone Eggshell Powder for Potential Industrialized Applications", ACS Sustainable Chemistry & Engineering, Vol. 3(5) (2015) 941–949.

[v] P. R. Kumar, R. S. Vijaya and R. B. Jose, "Experimental Study on Partial Replacement of Cement with Eggshell Powder", International Journal of Innovation in Engineering and Technology, Vol. 4, (2015) 334-341.

[vi] K.G.Vinothan,T. Janani, R. Revathi, R. Bhuvaneshwari, S. Santhiya and K. S. H. Naveen, "Study and experimental investigation of partial replacement of Eggshell powder as cement in concrete", SSRG International Journal of Civil Engineering, Vol. 4(3) (2017) 76-80.

[vii] D. Gowsika, S. Sarankokila and K. Sargunan, "Experimental Investigation of Egg Shell Powder as Partial Replacement with Cement in Concrete", International Journal of Engineering Trends and Technology, Vol. 14(2) (2014) 65-68.

[viii] B. Hanifi, A.Orhan, H.S. Ahmet and C.Erdi, "Mechanical and radioactivity shielding performances of mortars made with cement, sand and egg shells", Construction and Building Materials, Vol. 93 (2015) 1145-1150.

[ix] M. Hsheelan, "Improving mechanical properties of lightweight Porcelanite aggregate concrete using different waste material", International Journal of Sustainable Built Environment, Vol. 6 (2017) 81–90.

[x] P. Pliya and D. Cree, "Limestone derived eggshell powder as a replacement in Portland cement mortar",Construction and Building Materials, Vol. 95 (2015) 1–9.

[xi] R. Siddique, "Waste Materials and By-Products in Concrete", Springer Science & Business Media, 2007.

[xii] R. Jayasankar, N. Mahindran and R. Ilangovan, "Studies on Concrete using Fly Ash, Rice Husk Ash and Eggshell Powder", International Journal of Civil and Structural Engineering, Vol. 1, (2010) 362-372.

[xiii] M. Dhanalakshmi, N. J. Sowmya, and A. Chandrashekar, "A Comparative Study on Eggshell Concrete with Partial Replacement of Cement by Fly Ash", International Journal of Engineering Research & Technology, Vol. 4(5), (2015) 1532-1538.

[xiv] ASTM C-150: "Standard Specification for Portland Cement" American Society for Testing and Materials, Washington, D. C, 2007.

[xv] ASTM C136-01, "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates", American Society for Testing and Materials, Washington, D.C, 2001.

[xvi] P. Stutzman, "Development of An ASTM Standard Test Method On X-Ray Powder Diffraction Analysis Of Hydraulic Cements", International Centre for Diffraction Data 2004, Advances in X-ray Analysis, (2004), Volume 47. pp 206-211.

[xvii] ASTM C-143 "Standard Test Method for Slump of Hydraulic-Cement Concrete", American Society for Testing and Materials, Washington, D. C, 2015.

[xviii] BS. 1881-103:1983, "Testing concrete. Method for determination of compacting factor", 1993.

[xix] ASTM C 39/C 39M "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" American Society for Testing and Materials, Washington, D., 1997.

[xx] M. O. A. Mtallib and A.Rabiu, "Effects of Eggshells Ash on the Setting Time of Cement", Nigerian Journal of Technology, University of Nigeria Nsukka, ISSN 1115-8443, Vol. 28 (2) (2009) 29-38.

[xxi] I. Soroka and N.Stern, "The effect of fillers on strength of cement mortars", Cement and Concrete Research, Vol. 7 (4) (1977) 449–456.

[xxii] P. Yan, "Effect of limestone powder on microstructure of concrete", Journal of Wuhan University. Tech. Material Sciences, Vol. 25(2) (2010) 328–331.

[xxiii] G. İ. Sezer, "Compressive strength and sulfate resistance of limestone and/or silica fume mortars",Construction and Building Materials, Vol. 26 (2012) 613–618.