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Assessment of Strength of Concrete containing ESP and IESP as Partial Cement Replacement

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ABSTRACT

In the present era of technically feasible and environmentally compatible low-cost material substitution with the basic ingredients of conventional concrete mix, the infusion of eggshell powder in its raw as well as incinerated forms was tried with the cement mantle. Experimentations carried out to endorse the compressive strength, split tensile strength, flexural strength, workability and durability aspects revealed that it had the edge over the properties standardized for the conventional concrete mix at a specific mix strength of 20 MPa. The experimental results for variations in the treatments of eggshell powder and incinerated eggshell powder corresponding to the responses on the evaluation parameters were compared with the conventional concrete mix by means of regression analysis and modelling. The regression model at more than 95% correlation level of the experimental data fortified the relative supremacy of eggshell powder and incinerated eggshell powder-infused concrete mixes over the conventional concrete mix in terms of workability, strength, and durability. Based on the statistical regression point of inflexion and the point of tolerance, it was clearly established that 20% optimal proportional addition of eggshell powder or 30% addition of incinerated eggshell powder could result in a superlative performance compared to the conventional concrete mix. This final outcome of the optimal combinations of eggshell powder and incinerated eggshell powder incorporated concrete (EPIC) was also test verified by SEM and EDAX analyses.

Keywords: Eggshell powder; Incinerated eggshell powder-infused concrete mixes.

1. INTRODUCTION

In the modern era of blooming urbanization coupled with booming industrialization, simmered by lateral state-of-the-art technological developments, the need for designing chartered infrastructure is consistently increasing. Exponentially increasing population growth also adds to the demographic pressure, requiring safer and more convenient housing projects. This implies that multi-dimensional civil engineering construction activities are expected to take wings in diversified directions such as residential buildings, institutional buildings, commercial complexes, highways, etc.

However, to maintain a sustainable supply of basic building materials as to the demands, it becomes imperative to get ourselves caught in a quandary of unscrupulous quarrying and mining activities. This precarious situation results in the over-exploitation of our non-renewable building material resources, thereby widening the demand-supply gap for the availability of ingredients and compounds of core building materials in the near future.

For decades, concrete has been ruling the roost as the impeccable building material compound that inevitably requires a sustainable supply of its indispensable essential ingredients *viz.*, cement, sand, aggregates, and water. To balance the availability of concrete, the current focus is on exploring possible and promising alternate and equivalent materials that can either be partially substituted with or may totally replace the different ingredient mantles of a concrete matrix. For instance, contemporary researchers contemplate on the replacement of the cement mantle with optimal combinational proportioning of alternate materials such as fly ash, GGBS, etc. By the same token, the Research and Development activities are bound to focus on the usage of industrial byproduct wastage such as steel slag to replace the coarse aggregate mantle. Even the river sand as the fine aggregate in vogue can also be replaced by M-sand or other equivalent artificial sand materials. The mushroom growth of various kinds of processing industries also produces wastewater effluents that are simply disposed into the natural streams or water bodies. The simple dumping of such wasted materials may ultimately cause ecological imbalance and environmental degradation by way of pollution and contamination. Instead, if these wasted materials can be envisaged to undergo some treatment transformations to get eventually hidden into the building structures as part of the concrete matrix, an economically viable and eco-friendly ambience can be established (the Null Hypothesis for this study) towards the perspective sustenance of construction activities.

2. RESEARCH SIGNIFICANCE: SCOPE AND PERSPECTIVES

The possibility of cost reduction by way of partial material substitution in comparison with conventional concrete ingredients assumes paramount importance. Functionally a concrete mix comprises a cementitious component that binds other ingredients (mostly Portland cement or any other specific-purpose cements), a filler material to reduce the porosity (fine aggregates mostly by means of river sand), a strength-stabilizing cover material (coarse aggregate) and a liquid medium that creates a stabilized bonding between the sand material upon setting over a nominal curing period (mostly portable quality of water).

These conventional concrete ingredients are likely to face a critical situation of scarcity or total unavailability, on account of unscrupulous mining and over-exploitation.

2.1 LITERATURE SURVEY

The silica fume was substituted by incremental additions from 5 to 25% in steps of 5% for a water-binder ratio range of 0.26 to 0.42 at a curing spell of 28 days. The results endorsed that the tensile strength, compressive strength, and flexure strengths increased with silica fume incorporation proportionately, but the optimum replacement percentage depended on the water-cement material ratio. Based on the regression analyses, mathematical relationships between split tensile, compressive and flexure strengths with respect to percentage silica fume additions and concrete were established for interpolation and extrapolation predictions. The optimum silica fume substitution percentages with reference to the nominal 28-day curing spell ranged from 15% to 25% depending on the w/c ratio of the mix. The optimal proportion percentage of silica fume against cement increased with the increase in water-cement ratio from 0.28 to 0.35 (Katkhuda *et al.* 2009).

The effects of silica fume on the strength criteria for high-strength (50 to 70MPa) concrete mixes keeping different water-cement ratios and incremental % additions of silica fume. The results endorsed that the optimum replacement of cement by partial substitution with silica fume with a w/c ratio of 0.28 in a high-strength concrete at a nominal curing spell 28 days is 15 percent (Yogendran *et al.* 1987).

The utilization of alternate and equivalent cementing materials like the calcinated clay material called the Metakaolin increases the overall performance of the concrete, with considerable savings in procuring cement. Experimentation ended up with the conclusion that adding 10 to 15% metakaolin could increase the strengths considerably. However, on the negative side, metakaolin was found to increase shrinkage and heat evolved during hydration (Farhan *et al.* 2017).

Silica-fume (very fine particle size; contains silica content more than 90%), is one of the largely substituted pozzolanic materials (particle packing or micro-filling) and tests verified its high cementing efficacy on account of significantly higher silica content. The hydration process could result in the formation of Calcium Silicate Hydrate (CSH) gel for cementation bonding that in turn improves the strength and microstructure distribution of concrete filling in the spaces between cement grains. The results revealed that higher compressive strength of concrete could be obtained by partial substitution of 8% of silica-fume and the maximum strength attained was 55.83 MPa at the end of the nominal curing spell of 28 days. The investigation leads to the conclusion that concrete mixes containing silica fume can be partially substituted in the cement mantle of a concrete matrix up to 8% to produce high-strength concrete with optimal workability (Sounthararajan *et al.* 2013).

The hydration heat of mortars or concretes could be brought down through pozzolanic material additions replacing a portion of cement within the concrete matrix. This investigation had thrown light on the impact of pozzolanic activity associated with the metakaolin (MK) on the hydration heat suppression, compared with other pozzolanic materials such as fly ash and silica fume (Frias *et al.* 2000).

Blending of cementitious pozzolanic materials such as fly ash, silica fume, metakaolin and blast furnace slag with ordinary Portland cement can improve the cementing properties and strength criteria (Pawar *et al.* 2017). The partial substitution of cement with metakaolin improved the strengths of the cement mortars and concrete on account of identical mineral morphology serving as a better binding material equivalent. The authors recommended using 10 to 15% metakaolin with an optimal combination of fiber content in the range of 1 to 3% by weight of cement to increase the compressive strength, flexure strength, split strength, and tensile strength. They also observed that this proportion of substitution could reduce efflorescence associated with calcium transportation by water to the surface. Resistance to chemical attack and alkalinity could also be brought down due to the silica reactivity thereby enhancing the workability of the concrete mix and surface finishing. A reduction in shrinkage on account of particle packing was found.

Brooks *et al.* (2000) investigated the effects of incorporating silica fume (SF), metakaolin (MK), fly ash (FA) and ground granulated blast-furnace slag (GGBS) on the properties of the finished concrete mixes. Following ASTM C: 403, Penetration Resistance Method (PRM) was followed. They also studied the effect of a

Shrinkage-Reducing Admixture (SRA) on the setting times of concrete. The infusion of GGBS at replacement proportions of 40% and more resulted in significant reductions in setting times. They suggested that addition of these substitute materials shall not exceed 10% by weight of cement to be replaced with, from a safety point of view.

Fig. 1: Raw eggshell powder

Fig. 2: Incinerated eggshell powder

The possible combinations of a local natural pozzolan alongside silica fume (at 15% of the weight of cement) to generate relatively high workability and high strength in mortars and concretes with a design mix compressive strength stipulated from 69 MPa - 110 MPa for multiple purposes (Shannag, 2000).

In accordance with the chemical and phase composition of mineral admixtures on pozzolanic activity, thermal treatments were also performed for activating the minerals (Shwarzman *et al.* 2001).

The prospects of Metakaolin as a replacement material with 10 to 30% of cement to ascertain the compressive strength associated with flexural and split tensile strengths alongside the workability and durability of an M70 grade concrete design mix. They also prescribed the optimal proportional combination of metakaolin not to exceed 15% replacing cement by weight (Viswanadha Varma *et al.* 2014).

Roy *et al.* 2001 experimented upon the effects of aggressive chemical environments (sulfuric acid, hydrochloric acid, nitric acid, acetic acid, phosphoric acid, and a mixture of sodium and magnesium sulfates) on the mortars prepared with Ordinary Portland Cement (OPC) and Silica Fume (SF)/Metakaolin (MK)/Low-calcium fly ash at varying proportions of replacement levels.

The effects of the usage of metakaolin replacing part cement on the engineering properties of mortars were studied. The study incorporated 5, 10, 15 and 20% cement replacement by metakaolin (by weight) to develop five kinds of mortar. The resistance of mortars comprising metakaolin to sulfate and the alkali-silica reaction was determined under ASTM C: 1012 and ASTM C: 1260 standards, respectively (Semsi Yazıcı *et al.* 2014).

Table 1: Physical properties of cement

S. No.	Physical properties	Test values	Permissible values as per IS:4031-1988
1.	Fineness modulus	3.2%	≤ 10%
2.	Standard consistency	33%	26-34%
3.	Initial setting time	29 min	Min. 30 min
4.	Final setting time	550 min	Max. 600 min
5.	Specific gravity	3.12	3.1 – 3.15
6.	Compressive strength after 28 days	54 MPa	53 MPa

3. MATERIALS

3.1 CEMENT

Ordinary Portland Cement 53 Grade with a specific gravity of 3.12 and density of 1440 kg/m^3 conforming to IS:12269:2013 was used in making concrete mixes. The chemical and physical properties of cement furnished below in Tables 1 and 2 are determined with reference to IS: 12269-2013 and IS: 4031-1988.

3.2 FINE AGGREGATE

In line with cement, fine aggregates are also vital ingredients in cement concrete due to commendable properties of shrinkage reduction and economy. Locally available aggregate retained on 150 µ-size sieve and with fractions passing on 4.75 mm was used with reference to IS: 2386 -1963. The arrived parameters of physical properties are listed in Table 3.

Table 2: Chemical composition of Cement

S. No.	Chemical composition	Test values	Permissible values as per IS: 12269:2013
1.	Calcium Oxide (CaO)	64.1%	-
2.	Silicon dioxide (SiO_2)	22.5%	-
3.	Alumina (Al_2O_3)	5.7%	-
4.	Iron oxide (Fe_2O_3)	3.1%	-
5.	Magnesia (MgO)	0.5%	Max. 6%
6.	Sulphuric anhydride (SO_3)	4.11%	Max. 3.5%
7.	Ratio of percentage of lime to percentages of silica, alumina and iron oxide	0.9	0.80-1.02
8.	Chloride content	0.007%	Max. 0.1%
9.	Ratio of percentage of alumina to that of Iron oxide	0.92	Min. 0.66
10.	Loss on ignition	2.52	Max. 4%
11.	Insoluble Residue	0.6%	Max. 4%

Table 3: Physical properties of Fine Aggregate

S. No.	Physical properties	Test values
1.	Specific gravity	2.63
2.	Water absorption	0.51%
3.	Fineness modulus	3.64 %
4.	Bulk density (loose)	1495 kg/m^3
5.	Bulk density (compacted)	1600 m^3

3.3 COARSE AGGREGATE

The prevailing coarse aggregates with distinct sorts such as hard, strong, dense, durable and free from loamy admixtures were used for the work. These coarse aggregates are crushed stones with angularity and smooth non-powdery surfaces that are screened and washed meticulously before their usage. The physical properties of coarse aggregates were assessed in reference to IS:2386 -1963 and were presented in Table 4.

Table 4: Physical properties of Coarse Aggregate

S. No.	Physical properties	Test values
1.	Specific gravity	2.68
2.	Water absorption	0.3%
3.	Bulk density (loose)	1525 kg/m^3
4.	Bulk density (compacted)	1592 kg/m^3
5.	Fineness modulus	6.0
6.	Impact value	13.93%
7.	Crushing value	18.6%

Fig. 3: Furnace for incineration

Fig. 4: Sample before incineration in furnace

3.4 WATER

Locally available potable tap water with a pH value of 7.0 ± 1 and conforming to IS: 456-2000, was used for mixing concrete and curing the specimens at room temperature.

3.5 EGGSHELL POWDER

The chemical composition of raw eggshells was found to be 94% calcium carbonate, 1% magnesium carbonate, 1% calcium phosphate and 4% organic matter. The incinerated eggshell has 52.3% CaO and other parameters are in traces. Primarily, it was collected in eggshell mash form from an egg products industry - SKM Egg Products, Erode, Tamil Nadu, India. Sun-dried dirt-free eggshell mash was ground to a very fine powder using the eggshell grinder; then the powder was made to pass through a 90-micron sieve.

Fig. 5: Sample after incineration in the furnace

4. MIX PROPORTION OF CONCRETE INGREDIENTS

Based on the nominal workability criteria concrete mixes with 0.50 w-c ratio was used. The details of mix ratios for 1m^3 of concrete are furnished in Table 5. For technical reference, blends were designated with mix ID; T(0)/C represents conventional/control mix, T20 represents cement replaced with 20% eggshell powder and TI30 represents cement replaced with 30% incinerated eggshell powder.

5. PROPERTIES OF FRESH CONCRETE

Slump cone test is done as per IS: 1199-1959 to assess the workability of fresh concrete using a hollow fixture of 200 mm base diameter and 100 mm top diameter over a height of 300 mm. The blows at the rate of 25 per phase were imparted in four consecutive concrete fills. Then the top layer was flush-leveled at the rim, and the cone fixture was lifted to allow the free suppression of concrete mix. Out of 300 mm cone height, the relative depression was noted for a slump value in the range 50 to 80 mm (Table 6) that was well within the code specifications. This implies that the fresh concrete mix is applicable for columns, retaining walls, beams, slabs and decks of bridges.

Table 5: Mix Proportions of concrete

S. No.	Mix id	Cement (kg/m^3)	Raw eggshell powder (kg/m^3)	Incinerated eggshell powder (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
1.	T(0)/C	383	0	0	656	1229	191.5
2.	T(10)	344.7	38.3	0	656	1229	191.5
3.	T(20)	306.4	76.6	0	656	1229	191.5
4.	T(30)	268.1	114.9	0	656	1229	191.5
5.	T(40)	229.8	153.2	0	656	1229	191.5
6.	T(50)	191.5	191.5	0	656	1229	191.5
7.	TI(10)	344.7	0	38.3	656	1229	191.5
8.	TI(20)	306.4	0	76.6	656	1229	191.5
9.	TI(30)	268.1	0	114.9	656	1229	191.5
10.	TI(40)	229.8	0	153.2	656	1229	191.5
11.	TI(50)	191.5	0	191.5	656	1229	191.5

Fig. 6: Slump test on fresh concrete

Table 6: Workability properties of fresh eggshell powder infused mixes with the slump test

S. No.	Treatment	Slump of ESP specimens (mm)	Slump of IESP specimens (mm)
1.	T(0)/C	70	70
2.	T(10)	73	76
3.	T(20)	78	80
4.	T(30)	76	79
5.	T(40)	75	78
6.	T(50)	72	76

6. STRENGTH CHARACTERISTICS OF HARDENED EGG SHELL POWDER CONCRETE

The present investigation has been restrained only to the usage of eggshell powder as a partial replacement with cement at an optimal proportional combination in conventional cement concrete. Hence for a comparative analysis with the conventional control concrete mix, mechanical properties such as compressive strength test, split tensile strength test, modulus of rupture test, pull out test and flexural behavior of RC beam of eggcretes (eggshell cement concrete) are investigated with specimens confirming to the proportions arrived.

6.1 COMPRESSIVE STRENGTH TEST

In this investigation standard concrete cubes of size 150 mm × 150 mm × 150 mm, prepared as the test specimens, were subjected to the temporal variations in the strength pertaining to different curing spells covering up the pre-nominal (7 days and 14 days), nominal (28 days) and post-nominal cases (56 days). The test formalities for curing spells *vs.* compressive strength for the conventional concrete mix and 10-50% eggshell powder and incinerated eggshell powder-incorporated concrete, involved casting of 132 cube specimens for endorsement purposes. The test was carried out as per IS: 516-1959.

6.2 SPLIT TENSILE STRENGTH TEST

It is customary that alongside the compressive strength test, the split-tensile strength test and flexural strength test are carried out for assessing the overall strength criteria for any improvisation attempted on the conventional concrete mix. In the present investigation, the split-tensile strengths attained were evaluated at the end of pronominal curing spells of 7 days and 14 days, nominal curing spell of 28 days and post-nominal spell at the end of 56 days. For this purpose, standard concrete cylinder specimens of 150 mm diameter and 300 mm height were subjected to 3000 kN compression on the conventional testing machine as per IS: 5816-1970. The results are shown in Table 9 and Table 10.

Fig. 7: Split tensile strength test

Table 7: Compressive strength of ESP concrete

S. No.	Treatment	Load{P}, kN /Curing spell {days}/Compressive strength (N/mm^2)							
		P	7	P	14	P	28	P	56
1.	T(0)/C	389.3	17.3	486.2	21.61	592.9	26.35	622.1	27.65
2.	T(10)	409.5	18.2	509.2	22.63	625.7	27.8	657.0	29.20
3.	T(20)	429.8	19.1	535.5	23.8	657.0	29.2	690.8	30.7
4.	T(30)	423.0	18.8	532.1	23.65	643.5	28.6	663.8	29.5
5.	T(40)	402.3	17.88	507.2	22.54	621.0	27.6	630.0	28
6.	T(50)	383.2	17.03	483.8	21.5	589.5	26.2	602.6	26.78

Table 8: Compressive strength of IESP concrete

S. No.	Treatment	Load{P}, kN/Curing spell {days}/Compressive strength (N/mm^2)							
		P	7	P	14	P	28	P	56
1.	T(0)/C	389.3	17.3	486.2	21.61	592.9	26.35	622.1	27.65
2.	TI(10)	414.0	18.4	519.8	23.1	639.0	28.4	664.2	29.52
3.	TI(20)	433.8	19.28	551.3	24.5	671.0	29.82	702.0	31.2
4.	TI(30)	440.1	19.56	559.1	24.85	680.6	30.25	708.3	31.48
5.	TI(40)	421.0	18.71	531.0	23.6	648.0	28.8	670.5	29.8
6.	TI(50)	400.5	17.8	490.5	21.8	614.3	27.3	634.5	28.2

Table 9: Split tensile strength of ESP concrete

S. No.	Mix Proportion in %	Curing spell {days}/Split tensile strength (N/mm^2)			
		7	14	28	56
1.	T(0)/C	1.09	1.87	2.91	3.68
2.	T(10)	1.16	1.95	2.95	3.77
3.	T(20)	1.2	2.02	3	3.82
4.	T(30)	1.19	1.99	2.94	3.78
5.	T(40)	1.15	1.86	2.87	3.61
6.	T(50)	1.12	1.77	2.79	3.4

Table 10: Split tensile strength of IESP concrete

S. No.	Mix Proportion in %	Curing spell {days}/Split tensile strength N/mm^2			
		7	14	28	56
1.	T(0)/C	1.09	1.87	2.91	3.68
2.	TI(10)	1.16	2.04	2.99	3.8
3.	TI(20)	1.22	2.15	3.07	3.86
4.	TI(30)	1.28	2.26	3.13	3.88
5.	TI(40)	1.26	2.15	3	3.64
6.	TI(50)	1.18	1.98	2.8	3.4

Table 11: Modulus of rupture of ESP concrete

S. No.	Mix Proportion in %	Curing spell {days}/ Modulus of rupture (N/mm^2)			
		7	14	28	56
1.	T(0)/C	3.81	4.92	5.87	7.24
2.	T(10)	3.88	4.97	5.92	7.38
3.	T(20)	3.95	4.99	5.98	7.49
4.	T(30)	3.93	4.96	5.82	7.47
5.	T(40)	3.88	4.92	5.77	7.42
6.	T(50)	3.73	4.85	5.69	7.37

Table 12: Modulus of Rupture of IESP concrete

S. No.	Mix Proportion in %	Curing spell {days}/ Modulus of rupture (N/mm²)			
		7	14	28	56
1.	T(0)/C	3.81	4.92	5.86	7.24
2.	TI(10)	3.87	4.98	5.96	7.42
3.	TI(20)	3.97	5.02	6.03	7.56
4.	TI(30)	4	5.06	6.09	7.62
5.	TI(40)	3.98	5.01	5.88	7.54
6.	TI(50)	3.87	4.95	5.74	7.38

6.3 Modulus of Rupture or Flexural Strength Test

For the same curing spells for compression and tensile strengths, the modulus of rupture was also examined simultaneously using prism specimens of size 100 mm x 100 m x 500 mm on a 600 kN capacity Universal testing machine as per IS: 516-1959. The results are presented in Table 11 and Table 12.

Fig. 8: Modulus of Rupture test

7. SUMMARY AND CONCLUSION

- As regards the workability of the fresh concrete, 30% incinerated eggshell powder concrete mix and 20% eggshell powder concrete mix are acceptable on par with the conventional concrete mix in as much as the slump values were obtained in the code range of 50 mm to 80 mm.

- A family of curves for compressive strength in MPa vs. curing spells in days was prepared. Irrespective of the curing spells, the improvised concrete mix with 30% incinerated eggshell powder infusion showed higher values of compressive strengths followed by 20% eggshell powder concrete mix, compared to the conventional concrete mix.

- In the case of incinerated eggshell powder substituted concrete, the regression model suggested a point of inflection of about 30 MPa against 30% replacement of cement with incinerated eggshell powder and point of tolerance of 50% incinerated eggshell powder corresponding to the economically viable 26.35 MPa for conventional concrete mix. Again, from the point of view of safety against foreign matter addition within concrete, the percentage addition of incinerated eggshell powder was limited to 30% only to replace cement at the levels of technical feasibility without detrimental to the strength criteria.

- Interactive comparison between compressive strength, modulus of rupture and split-tensile strength were also arrived at. The linear regression equations obtained at more than 90% correlation levels clearly indicated the choice of eggshell powder to be limited to 20% and incinerated eggshell powder to 30% only for partially replacing the cement mantle of a concrete matrix.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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