Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: http://www.science-gate.com/IJAAS.html

Eggshell powder as partial cement replacement and its effect on the workability and compressive strength of concrete

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ARTICLE INFO

Article history:
Received 28 March 2019
Received in revised form
7 July 2019
Accepted 9 July 2019

Keywords:
Partial cement replacement
Supplementary cementitious materials
Eggshell powder
Natural resources depletion
Solid waste materials

ABSTRACT

Concrete is the most preferred building material in the world and its production has increased exponentially with the rapid construction of infrastructures. The generation of waste materials has also increased due to rapid urbanization. Eggshell is one such solid waste material which is being generated in huge quantity due to it being a cheap source of nutrition. Cement, the vital ingredient of concrete has been reported to contribute approximately 7% of total global Carbon Dioxide (CO_2) gas emissions. This experimental study was carried out to study the workability and compressive strength of M40 grade concrete incorporating Eggshell Powder (ESP) as supplementary cementitious material, to reduce the cement content in concrete. ESP was ground into two fineness (50 um and 100 um) and three different percentages (5%, 10% and 15% by weight of cement) of ESP was used to replace cement content. It was observed that partial cement replacement using ESP was successful in achieving higher strength compared to the control sample. It was determined that 10% ESP was optimum, where the highest compressive strength was achieved. Furthermore, the fineness of ESP also had an influence on the compressive strength, the ESP which passed 50 um resulted in better strength. The optimum ESP to be utilized was determined to be 10% in both fineness.

1. Introduction

Construction industry has played major in uplifting the socio-economic development of any country (Sohu et al., 2018), as such over the year's rapid urbanization has occurred throughout the world. Most of the concrete's infrastructures is constructed using concrete, which is the most preferred construction and building material in the construction industry (Lakhiar et al., 2018). The popularity of concrete has increased due to its availability, flexibility and durability (Memon et al., 2018), that is why concrete has been utilized in vast civil engineering applications ranging from the construction of foundations, retaining walls to bridges and dams (Sandhu et al., 2019).

Concrete is a man-made construction and building material which is comprised of binder (cement), aggregates (fine and coarse) and water. It has been estimated in a report that the concrete industry utilizes 1.5 billion, 20 billion and 0.8 billion tons of cement, aggregates and water respectively every year (Kubissa et al., 2015). Though cement plays a vital role in the manufacturing of concrete, it has risen environmental concerns. According to the report of Benhelal et al. (2013), the cement industry contributed to approximately 7% of the total global Carbon Dioxide (CO_2) gas emissions. Furthermore, production of one ton of cement emits approximately equal amount of CO_2. Another concern is the amount of raw materials required for production of cement. According to Naik and Moriconi (2005), to produce 1.6 billion tons of cement, 2.5 billion tons of raw natural resources such as limestone and clay are required. Each year, the demand for concrete is increasing and as such the production of cement is also on the rise. The non-stop production of cement is consuming natural resources at an alarming rate. Therefore, to reduce

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the dependency on cement as a binder in the manufacturing of concrete, researches have been done to find an alternative binder material which can substitute cement and reduce the natural resources depletion. The waste materials can be potential Supplementary cementitious materials (SCMs). Eggshell is one such waste material which could be used as partial cement replacement. Though full replacement of cement cannot be done at present, replacing 15% of cement worldwide can significantly reduce the CO_2 emissions up to 250 million tons (Naik and Moriconi, 2005).

Nowadays, the construction industry is trying to achieve sustainability, in which the development of current infrastructures satisfies the present requirements without limiting the possibilities of fulfilling the needs in the future (Kubissa et al., 2015). Reducing the utilization of natural resources and energy, decreasing of greenhouse gases emission has become a necessity as volume of cement and concrete production is projected to continuously increase over the years (Kubissa et al., 2015). The eggshell itself the hard shell is made of a material called a carbonate, which contains both carbon and oxygen atoms. One of the possible methods of reducing of environment effects is utilizing waste in other products where it is useful as in concrete manufacturing. Reusing waste is the method of processing the waste material for use in creating new product. Use of egg shell in concrete can be useful for environmental protection as well as economical construction. Egg shells are the total waste materials for the public but not for engineers. Therefore, this experimental research aims at studying the effect of different fineness of Eggshell Powder (ESP) on the workability and compressive strength of concrete.

2. Literature review

The rise of depletion of natural resources and the increasing emission of Carbon Dioxide (CO_2) gas, has forced the construction industry to seek innovative solutions to these problems and achieve sustainable construction by using eco-friendly concrete (Jhatial et al., 2018). Cement is a vital component in the manufacturing of concrete, as it acts as a binder, gluing together other components to produce a solid, strong and durable material. The demand of concrete has risen over the years, which subsequently increased the demand for cement. According to a report, the cement industry produces approximately 7% of the global CO_2 gas emissions (Benhelal et al., 2013) as well as consume natural resources such as clay, limestone etc. Researchers have over the years investigated cement's alternatives, in an attempt to reduce the cement content and in turn reduce the rising demand for cement for constructional purposes. Waste materials have the potential to be used as partial cement replacement, and an additional benefit of waste material utilization is the solid waste management. With the increase in urbanization, waste generation has increased exponentially, such has caused solid waste management problems.

Eggshell is one of the waste materials being generated in abundance across the world, especially in Pakistan where, poultry sector is one of the vibrant segments of livestock sector in Pakistan, as it is responsible for employment of over 1.5 million people (GOP, 2014). The poultry has contributed 1.4 percent in GDP during 2016-17 while its contribution in agriculture and livestock value added stood at 7.1 percent and 12.2 percent respectively. According to PPA (2019), Pakistan produces approximately 18 billion eggs annually. Eggshell amount to approximately 11% of the total weight of an average medium size chicken egg, which weighs 55 grams. The eggshells are generally thrown into garbage, which end up in landfills. Without going through proper treatment, this solid waste possess signficiant environmental pollution due to its availability and chemical composition (Raji and Samuel, 2015). The continious diposal of waste materials such as eggshells, increases the landfill numbers and cause serious environmental issue in all over the world.

To achieve sustainability in construction industry and at the same time reduce the waste materials that are being generated, researchers have tried to utilize waste materials as cement replacement. As such, previous research on eggshell's chemical composition has found that it contains almost similar amount of Calcium Oxide (CaO) as cement (Yerramala, 2014). CaO plays a significant role in cement, as precise amount is required to achieve strength. The high amount of CaO means that it can be potentially utilized as supplementary cementitious material (SCM).

Based upon past studies (Parthasarathi et al., 2017; Ujin et al., 2017; Ansari et al., 2016; Dhanalakshmi et al., 2015; Yerramala, 2014) it is evident that eggshells powder can be utilized as partial cement replacement, though it's still lacks study on the effect on higher grade concrete and different fineness of eggshell powder. Therefore, this study was conducted to study the effect of normal strength concrete of M40 grade when different dosages of eggshell powder is incorporated and at different fineness.

3. Research methodology

3.1. Materials

To achieve the objectives of this study, an M40 grade concrete was prepared using ordinary Portland cement (OPC), fine and coarse aggregates and water. Table 1 shows the properties of the aggregates used in this study.

Table 1: Properties of aggregates

Property	Fine Aggregates	Coarse Aggregates
Water Absorption	0.81 %	1.21 %
Specific Gravity	2.70	2.58

Apart from the constituent materials, ESP was also utilized in this experimental work as partial cement replacement material. Eggshells were collected from various bakeries and food stalls in the vicinity. The raw eggshells contained yellowish fluid which was washed using clean water. Once washed properly, the eggshells were oven dried for 24 hours at a temperature of 105 ± 5°C (Yu et al., 2017) to remove the moisture that may have been gained during the cleaning. Once the eggshells were oven-dried, the eggshells were grinded using a blender. The grinded eggshell was then sieved through 50 and 100 μm.

3.2. Experimental work

The concrete mixer mixed the dry raw materials uniformly for few minutes, after which the specified water was added. The mixer was left running for few more minutes. The workability of the concrete mix was determined using the slump test according to BS EN (2009a) to observe the effect of different percentage and fineness of ESP on the workability of concrete. Upon recording the slump values for each mix, the wet mix was then poured into cubic moulds of 150 x 150 x 150 mm and kept for 24 hours. Afterwards they were demoulded and kept for water curing for 3-, 7-, 14- and 28 days. Once the samples achieved specified curing, the cubic samples were tested in universal testing machine for compressive strength test according to the guidelines of BS EN (2009b).

4. Results and discussion

4.1. Workability

The workability was determined in accordance to BS standard, in order to observe the effect of eggshell powder on the flowability of concrete, it can be observed that the workability decreases with the increase in ESP content as shown in Fig. 1. This may be attributed to the high water absorption of ESP which consumes the water and restricts the flowability.

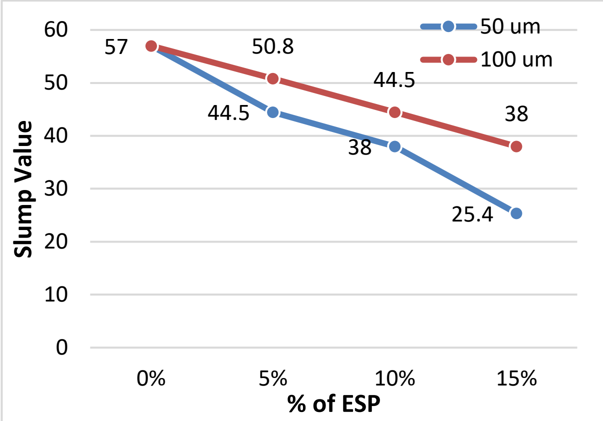

Fig. 1: Comparison of slump loss of concrete

4.2. Compressive strength

The average compressive strength testing was conducted in guidelines with BS EN (2009b) after the samples were cured for specified ages (3-, 7-, 14- and 28 days). Table 2 shows the results of average compressive strength of concrete incorporating 50 μm ESP while Table 3 shows the results of average compressive strength of concrete incorporating 100 μm ESP. Although previously ESP (Bandhavya et al., 2017; Ansari et al., 2016; Dhanalakshmi et al., 2015; Yerramala, 2014) has been utilized as partial cement replacement material in concrete of lower grades, yet the optimum range for replacement has been observed to range from 7.5 % to 15 %. The same trend was observed in this study on higher (M40) grade concrete, where the optimum dosage was observed to be 10% for both fineness.

Table 2: Average compressive strength of concrete incorporating 50 μm ESP

% of ESP	3 Days		7 Days		14 Days		28 Days	
	Compressive Strength (MPa)	Diff. w.r.t. control sample (%)	Compressive Strength (MPa)	Diff. w.r.t. control sample (%)	Compressive Strength (MPa)	Diff. w.r.t. control sample (%)	Compressive Strength (MPa)	Diff. w.r.t. control sample (%)
0% (control)	20.75	---	27.66	---	34.20	---	44.73	---
5%	21.85	+ 5.30 %	28.06	+ 1.45 %	35.73	+ 4.47 %	45.48	+ 1.68 %
10%	22.3	+ 7.47 %	30.57	+ 10.52 %	39.98	+ 16.90 %	47.35	+ 5.88 %
15%	20.36	- 1.88 %	26.73	- 3.62 %	29.89	- 12.60 %	41.37	- 7.51 %

Table 3: Average compressive strength of concrete incorporating 100 μm ESP

% of ESP	3 Days		7 Days		14 Days		28 Days	
	Compressive Strength (MPa)	Diff. w.r.t. control sample (%)	Compressive Strength (MPa)	Diff. w.r.t. control sample (%)	Compressive Strength (MPa)	Diff. w.r.t. control sample (%)	Compressive Strength (MPa)	Diff. w.r.t. control sample (%)
0% (control)	20.75	---	27.66	---	34.20	---	44.73	---
5%	20.93	+ 0.87 %	27.31	- 1.27 %	32.69	- 4.42 %	45.07	+ 0.76 %
10%	21.46	+ 3.42 %	28.36	+ 2.53 %	35.73	+ 4.47 %	45.88	+ 2.57 %
15%	19.14	- 7.76 %	26.13	- 5.53 %	31.60	- 7.60 %	38.94	- 12.94 %

Furthermore, previous studies (Lawrence et al., 2005; Day and Shi, 1994) on the fineness of mineral admixtures and supplementary cementitious materials (SCMs) when utilized to replace cement in concrete confirms that the strength of concrete increases with the increase in fineness. The findings of this study relate to previous studies on fineness, as 50 µm ESP achieved slightly higher compressive strength as compared to 100 µm ESP when utilized as partial cement replacement.

5. Conclusion

Based upon the experimental work conducted on the utilization of eggshell powder as partial cement replacement, the following conclusions are drawn:

1. Eggshells, once grinded properly into powder form, can be utilized as supplementary cementitious material, which can reduce the dependency of cement in for production of concrete as well as reducing the disposal of eggshells in open air landfills, which causes significant health issues to the residents living around the landfill areas.
2. The fineness of supplementary cementitious materials greatly influences the properties of concrete. To achieve finer material, extensive grinding is required which in turn increases the specific surface area of the material, this surface area is main factor due to which the finer materials achieve higher water absorption.
3. The workability is directly affected by the higher water absorption of eggshell powder. Fine materials absorb significant amount of water during mixing, which reduces the workability of the mix, while coarser materials do not absorb that much amount of water which may have significant reduction in workability.
4. The fineness of eggshell powder also had significant influence on the compressive strength of concrete. The 50-micron eggshell powder performed better in compressive strength development over the curing period.
5. It was found that the optimum cement replacement irrespective of fineness of eggshell powder was 10%, which achieved the maximum compressive strength. Further increase in cement replacement resulted in decrease in compressive strength.

Acknowledgment

The authors would like to acknowledge and appreciate the support received from the staff of Department of Civil Engineering, Mehran University of Engineering and Technology, Shaheed Zulfiqar Ali Bhutto Campus, Khairpur Mir's, Sindh, Pakistan during this experimental work.

Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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