The behavior of eco-friendly self – compacting concrete partially utilized ultra-fine eggshell powder waste

Ayad S Aadi 1, Nadhim Hamah Sor 2,3,* and Ahmed Ali Mohammed 4

1 Dams and Water Resources Eng. Dep., College of Engineering, University Of Anbar, Iraq
2 Civil Engineering Department, University of Garmian, Kalar, Kurdistan Region, Iraq
3 Department of Civil Engineering, Harran University, Sanliurfa, Turkey
4 University of Fallujah, Fallujah, Iraq

* Corresponding author: nadhim.abdulwahid@garmian.edu.krd
nadhim.hamahsor@gmail.com

Abstract. From food wastes, there are many materials that can be used as building materials like eggshells. This paper examined the effect of ultra-fine eggshell powder (UFESP) as a partial cement replacement by (0-25% with 5% increments) in weight on fresh and compressive strength of sustainable Self-Compacting Concrete (SCC) with a constant water to binder ratio and binder content of 0.38 and 450 kg/m³, respectively. All mixes were tested for fresh properties of slump flow diameter and time, V-funnel time, L-box height ratio, dry density and compressive strength. The results of fresh properties for all mixtures satisfied the requirements recommended by EFNARC for SCC. However, the compressive strength of SCC mixes increased by the addition of UFESP up to 15% compared to the control mixture, then decreased and recorded 42 MPa for the mix containing 25% of UFESP. Meanwhile, the dry density decreased as UFESP utilization increased in the mixtures.

Keyword: Self-compacting concrete, UFESP, fresh properties, dry density, compressive strength.

1. Introduction

Self-compacting concrete (SCC) considered one of the special concrete that flows and compacts under its own weight without bleeding and segregation, suitable for congested steel bars and narrow sections. However, the production of SCC mixtures need a high amount of binders (Bauchkar and Chore, 2014). Therefore, the researchers used many kinds of waste materials as binder with cement for SCC mixture production. There were several investigations utilised pozzolanic and waste powder materials as binder for cement replacement such as fly ash (Öz et al, 2017) and ceramic powder (Hilal et al, 2021). Actually, Egg is one of the major breakfast meals around the world. High consumption of eggs has generated a large amount of eggshell to be disposed and affect the environment negatively because of it’s a bio-waste material and causing environmental pollution as well as health hazards (Hamada et al, 2020).

On the other hand, Hilal et al, (2021) studied the effect of eggshell powder (ESP) with/without plastic fiber on fresh and hardened properties of SCC. The experimental results explained that
mechanical and workability increased from 10% to 30% substitution of cement with ESP, but the highest strengths were recorded at 10% ESP with 1% plastic fiber. Meanwhile, Arif et al. (2021) reported that the workability of concrete decreased as ESP increased but the compressive strength increased up to 10% incorporation. Oofuyatan et al. (2020) reported that fresh properties of SCC were reduced as ESP increased and hardened strengths developed up to 20% replacement with cement in weight.

Furthermore, Yerramala (2014) investigated the effect of using eggshell powder (ESP) as a replacement for cement in the production of normal concrete and concluded that the splitting tensile strength and sorptivity recorded the optimum value at 10% ESP replacement and 5% for compressive strength at different ages when compared to the control mix. Dhanalakshmi et al. (2015) studied the mechanical properties of conventional concrete incorporating fly ash (FA) and ESP as a substitution of cement. The percentage of ESP varied up to 12.5% then FA was used with the best ESP content. According to the investigation results, the use of ESP only had a negative effect on the workability, density and compressive strength of concrete but enhanced these properties when FA was used with the best ESP content. However, Afolayan et al. (2017) studied on the outcome of partial replacement of cement with ESP from 0% to 40% by weight in steps of 5% for production of sandcrete block. The results explained that the optimum replacement level was 30%.

On the other hand, Yu et al. (2017) studied on the effect of different curing conditions for the concrete containing ESP in term of compressive strength after the experimental work found water curing was more suitable than open air curing. Tan et al (2018) discovered that substituting ESP for cement up to 15% resulted in the development of compressive strength but had a negative effect on the workability of concrete as ESP incorporation increased.

From the literature, most researchers focused on utilization of ESP in conventional concrete and there were a few experimental papers studied on the use of ESP in SCCs. However, in this study, ultra-fine eggshell powder (UFESP) was used as a cement replacement at various ratios in the production of SCCs to examine the fresh properties of slump flow time and diameter, V-funnel time, and L-box height ratio with dry density and compressive strength.

2. Materials and Experimental Program

2.1 Materials

In this experimental investigation, ordinary Portland cement CEM I 42.5R was used with a specific gravity of 3.15 and its chemical compositions are shown in Table 1. The production of eggshell powder (ESP) was carried out by collecting broken eggshells from restaurants. The shells were washed by tap water then dried by using an oven at 110±5° C for 24 h. Then, the shells have been crushed and grinded to a powder. The specific gravity of UFESP is 2.77 and its chemical composition is presented in Table 1.

| Chemical compound | Cement | UFESP |
|-------------------|--------|-------|
| CaO               | 64.02  | 95.00 |
| SiO₂              | 22.15  | 2.703 |
| Al₂O₃             | 5.40   | 0.04  |
| Fe₂O₃             | 4.08   | 0.425 |
| MgO               | 2.80   | 0.95  |
| SO₃               | 2.48   | 0.123 |
| K₂O               | 0.95   | 0.425 |
| Na₂O              | 0.20   | 0.20  |
The river gravel was utilized as coarse aggregate with a maximum size and specific gravity of 12.5 mm and 2.7, respectively. However, normal river sand was used as fine aggregates with a maximum size and specific gravity of 4 mm and 2.67, respectively.

A dose of superplasticizer must be used to make self-compacting concrete more workable with a low range of water content. For this experimental work, the Sika ViscoCrete - 5930 with a density of 1.08 kg/lit was utilized as a high range water reducer and satisfied the requirements of ASTM C494 Type F (ASTM C494 / C494, 2019). However, several trials have been carried out in order to obtain the best superplasticizer dosage for the mixes, which effects on the workability and hardened characteristics of SCC mixtures (Sor, 2018).

2.2. Mixture Design:
In this study, self-compacting concrete (SCC) mixes were planned with a fixed water/binder (w/b) ratio of 0.38 and a total binder content of 450 kg/m³. In all mixes, the volume of total aggregates was divided equally between fine and coarse aggregates. Moreover, all the mixes were the same except that the cement substitute with ultrafine eggshell powder (UFESP) at various quantities to examine the influence of UFESP amounts on slump flow time and diameter, V shape, L-box height ratio, dry density and compressive strengths. A total of six various SCCs were designed in this investigation; the cement was replaced with UFESP at the quantities of 0, 5, 10, 15, 20 and 25% in weight. The mixtures proportions are explained in Table 2. In the mix ID, ESP is the abbreviation of the mix containing ESP by weight.

Table 2. Mixture proportions (kg/m³)

| MID | (w/c) | Cement | UFESP | water | Superplasticizer | Coarse aggregate | Fine aggregate |
|-----|-------|--------|-------|-------|----------------|-----------------|----------------|
| ESP0| 0.38  | 450    | 0     | 171   | 9              | 912.5           | 907.3          |
| ESP5| 0.38  | 405    | 22    | 171   | 9              | 912.5           | 907.3          |
| ESP10| 0.38 | 370    | 40    | 171   | 9              | 912.5           | 907.3          |
| ESP15| 0.38 | 340    | 55    | 171   | 9              | 912.5           | 907.3          |
| ESP20| 0.38 | 327    | 67    | 171   | 9              | 912.5           | 907.3          |
| ESP25| 0.38 | 314    | 79    | 171   | 9              | 912.5           | 907.3          |

2.3 Concrete mixing
Because the mixing period and sequences affect SCC production, all SCC mixtures were mixed using a revolving mixer and the recommended procedures by (Khayat et al, 2000) for batching and mixing the mixtures to satisfy a homogeneous and uniform concrete in all SCCs. The coarse and fine aggregates were added to the mixer and mixed homogeneously for 30 seconds, according to these procedures. Then, one-third of the mixing water was added to the mixer, and it was allowed to mix for another 60 seconds before being left for another minute. As a result, the powder materials (cement and ultra-fine eggshell powder) were added to the wetted aggregates-containing mixture and mixed for an additional 1 minute. The remaining water was mixed with the superplasticizer and poured into the mixer; the mixture was mixed for 3 minutes and the rest for 2 minutes. Finally, the mixture was mixed for about 2 minutes to complete the production. However, the workability of SCC was indicated by using slump flow diameter and V funnel flow and slump flow time. Actually, these fresh tests were done according to the European standards EFNARC (EFNARC, 2005) of SCC. Fresh concrete is poured into molds and kept in the laboratory room for one day to determine the hardened
properties tests of SCCs, then demolded and placed in water for curing until the testing date. The dry density and compressive strength were calculated on the average of three samples of 15 cm cubes.

2.4 Testing procedures
In this experimental study, the fresh properties of SCC mixtures performed according to EFNARC (EFNARC, 2005) recommendations. The rheological properties examined the slump flow diameter, V-funnel flow time and slump flow time ($T_{500}$). However, the mixture uniformity and segregation resistance were visually observed from conducting the slump flow test. Moreover, the viscosity was obtained in terms of the flow time from slump and V-funnel. On the other hand, the dry density and compressive strength test was examined as a hardened properties test, which used three samples for each test at 28 days curing age. Furthermore, the compression test was carried out on 150 mm cubic according to BS EN 12390-3 (2019) and the dry density test was carried out according to ASTM C138 / C138M - 17a (2017).

3. Experimental Results and Discussion
3.1 Fresh Properties of SCC
The results of fresh properties of SCC mixtures were compared to EFNARC’s (EFNARC, 2005) standard recommendations. The incorporation percentages of UFESP significantly affected the workability of SCC mixtures. As illustrated in Fig. 1, the slump flow diameter increased as UFESP utilization increased up to 15% and then decreased. However, the reason for increasing the diameter of flow then decreased and the increasing of flow time with increasing UFESP content in SCC mixtures were related to finer and higher surface area of UFESP particles which led to the speed of the hydration process. However, the same results were achieved by (Ofuyatan et al, 2020; Arif et al, 2021; Hilal et al, 2021). Usually, the slump flow diameter is categorized into three classes according to the respective standard. The first class (SF1) ranged 550 – 650 mm, the second class (SF2) ranged 650 – 750 mm and the third class (SF3) ranged 750 – 850 mm. In this study, the results are within classes of SF2 and SF3, which class SF3 is more workable and suitable for narrow sections. On the other hand, the slump flow time ($T_{500}$) increased with increasing UFESP incorporation in SCC mixtures as shown in Fig. 2, which is related to the presence of finer ESP in the mixes. Moreover, other researchers have reported similar effects of EPS on slump flow time. (Ofuyatan et al, 2020; Hilal et al, 2021).

![Figure 1. Slump flow diameter vs. UFESP ratio](image-url)
Figure 2. Variation of $T_{500}$ of SCCs with UFESP replacement level (%).

The results of V-funnel flow time of SCC mixtures increased with increasing UFESP percentages in the mix, as shown graphically in Fig. 3, which is related to the presence of finer ESP in the mixes and made the hydration process faster, making the concrete more viscose. The V-funnel time ranges between 7 – 11 seconds. For the control mixture, the V-funnel flow time was 7 seconds in comparison to 11 seconds for the 25% UFESP mixture. The same outcome achieved previously by many researchers (Ofuyatan et al, 2020; Hilal et al, 2021). Moreover, all the results are within the ranges specified by the respective standards.

Figure 3. V-funnel time with UFESA Ratio

3.2 Hardened properties

As indicated in Fig. 4, increasing the amount of UFESP in SCC blends had a substantial impact on dry density. However, depending on the UFESP content, which has a low density compared to cement, the
results ranged from 2275 to 2425 kg/m\(^3\) after 28 days. Meanwhile, as the UFESP ratio in SCC combinations increased, the dry density decreased. However, this fact was reported by many researchers in the literature that using lower density of one or more concrete ingredients led to a decrease in dry density (Mermerdaş et al, 2020, Hilal et al, 2021).

![Graph showing variation of dry density of SCCs with UFESP replacement level](image_url)

**Figure 4.** Variation of dry density of SCCs with UFESP replacement level (%).

The fluctuation of the compressive strength of SCC with the different percentages of UFESP at 28 days was explained in Fig.5. The compressive strength results increased as the replacement level of UFESP content increased up to 15 percent, then decreased sharply. However, according to ACI 318, all mixes meet the minimum value required for structural purposes (ACI 318, 2019). There were many researchers reported the same effect of ESP on compressive strength (Ofuyatan et al, 2020; Arif et al, 2021; Hilal et al, 2021).

![Graph showing variation of compressive strength of SCCs with UFESP replacement level](image_url)

**Figure 5.** Variation of compressive strength of SCCs with UFESP replacement level (%).
4. Conclusions

Depending on the results of this study, it was concluded that the use of ultra-fine eggshell powder in SCC mixture as cement replacement had an effect on their fresh and hardened properties and the following conclusions are made:

- The fresh properties of all SCC mixtures met the EFNARC requirements for SCC.
- The slump flow diameter increased as the UFESP level increased, reaching a maximum of 780 mm for the mix containing 15% UFESP. Furthermore, the mixes contained 0, 20, and 25% of UFESP classed as SF2 classes, with the remaining mixes classed as SF3.
- V-Funnel flow time and T500 increased as UFESP utilization increased.
- The compressive strength developed with increasing UFESP content in SCC mixture up to 15% then reduced.
- The minimum value of compressive strength was 42 MPa for the mix contained 25% of UFESP and this value is greater than the minimum value required for structural purposes.
- The dry density of the mixes decreased as the amount of UFESP incorporation in the mixtures increased.

[1] References

[2] Afolayan, J. O., F. O. P. Oriola, G. Moses, and J. E. Sani. "Investigating the effect of eggshell ash on the properties of sandcrete block." International Journal of Civil Engineering, Construction and Estate Management 5, no. 3 (2017): 43-54.
[3] Arif, S. Mohd, O. Rokiah, M. Khairunisa, B. W. Chong, Y. C. Chek, D. Youventhanar, P. J. Ramadhsanyah, and S. I. Doh. "Compressive Strength of Concrete containing Eggshell Powder as Partial Cement Replacement." In IOP Conference Series: Earth and Environmental Science, vol. 682, no. 1, p. 012031. IOP Publishing, 2021.
[4] ASTM C138 / C138M - 17a, Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete. West Conshohocken, ASTM, 2017.
[5] ASTM C494 / C494M – 19, Standard Specification for Chemical Admixtures for Concrete. West Conshohocken, ASTM, 2019.
[6] Bauchkar, Sunil D., and H. S. Chore. "Rheological properties of self consolidating concrete with various mineral admixtures." Structural engineering and mechanics: An international journal 51, no. 1 (2014): 1-13.
[7] BS EN 12390-3:2019 Testing hardened concrete. Compressive strength of test specimens.
[8] Dewald, Ulrich, and Matthias Achtenbosch. "Why more sustainable cements failed so far? Disruptive innovations and their barriers in a basic industry," Environmental Innovation and Societal Transitions 19 (2016): 15-30.
[9] Dhanalakshmi, M., N. J. Sowmya, and A. Chandrashekar. "A comparative study on egg shell concrete with partial replacement of cement by fly ash." International Journal for Research in Applied Science and Engineering Technology 3, no. Special Issue II (2015): 12-20.
[10] EFNARC (European Federation of Specialist Construction Chemicals and Concrete Systems): The European guidelines for self-compacting concrete: Specification, production and use. http://www.efnarc.org/pdf/SCCGuidelinesMay2005.pdf (2005).
[11] Hamada, Hussein M., Bassam A. Tayeh, Alyaa Al-Attar, Fadzil M. Yahaya, Khairunisa Muthusamy, and Ali M. Humada. "The present state of the use of eggshell powder in concrete: A review." Journal of Building Engineering (2020): 101583.
[12] Hamdullah, Dhifaf Natiq, Sheelan Mahmoud Hama, and Mohammed Maher Yaseen. "Effect of Eggshell Waste Powder on Impact Resistance and Bond Charcteristics of Reinforced Concrete." In Key Engineering Materials, vol. 870, pp. 21-28. Trans Tech Publications Ltd, 2020.
[13] Hilal, Nahla, Doha M. Al Saffar, and Taghreed Khaleefa Mohammed Ali. "Effect of egg shell ash and strap plastic waste on properties of high strength sustainable self-compacting concrete." Arabian Journal of Geosciences 14, no. 4 (2021): 1-11.
[14] Hilal, Nahla, Nadhim Hamah Sor, and Rabar H. Faraj. "Development of eco-efficient lightweight self-compacting concrete with high volume of recycled EPS waste materials." *Environmental Science and Pollution Research* (2021): 1-24. https://doi.org/10.1007/s11356-021-14213-w

[15] Khayat, Kamal H., John Bickley, and Michel Lessard. "Performance of self-consolidating concrete for casting basement and foundation walls." *Materials Journal* 97, no. 3 (2000): 374-380.

[16] Mermerdaş K, Süleyman İPEK, Sor NH, Mulapeer ES, Ekmen Ş (2020) The impact of artificial lightweight aggregate on the engineering features of geopolymer mortar. Türk Doğa ve Fen Dergisi 9(1): 79–90. https://doi.org/10.46810/tdfd.718895

[17] Ofuyatan, Olatokunbo M., Adewale George Adeniyi, David Ijie, Joshua O. Ighalo, and John Oluwafemi. "Development of high-performance self compacting concrete using eggshell powder and blast furnace slag as partial cement replacement." *Construction and Building Materials* 256 (2020): 119403.

[18] Öz, Hatice Öznur, Mehmet Gesoglu, Erhan Güneyisi, and Nadhim Hamah Sor. "Self-Consolidating Concretes Made with Cold-Bonded Fly Ash Lightweight Aggregates." *ACI Materials Journal* 114, no. 3 (2017). https://doi.org/10.14359/51689606

[19] Sor, Nadhim Abdulwahid Hamah. "The effect of superplasticizer dosage on fresh properties of self-compacting lightweight concrete produced with coarse pumice aggregate." *J. Garmian Univ* 5, no. 2 (2018): 190-209.

[20] Tan, Yeong Yu, Shu Ing Doh, and Siew Choo Chin. "Eggshell as a partial cement replacement in concrete development." *Magazine of Concrete Research* 70, no. 13 (2018): 662-670.

[21] Yerramala, Amarnath. "Properties of concrete with eggshell powder as cement replacement." *The Indian concrete journal* 88, no. 10 (2014): 94-105.

[22] Yu, Tan Yeong, Doh Shu Ing, and Chin Siew Choo. "The effect of different curing methods on the compressive strength of eggshell concrete." *Indian Journal of Science and Technology* 10, no. 6 (2017): 1-4.