E3S Web of Conferences **427**, 02014 (2023) https://doi.org/10.1051/e3sconf/202342702014
ICGEE 2023

Predicting Optimum Content of Eggshell Ash for Best Mechanical and Structural Properties of Concrete

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Abstract. Through an optimization procedure using Minitab software, the optimum waste eggshells-ash powder (WESP) content is used in reinforced concrete. The following percentages of WESP, 0%, 2.5%, 5%, 7.5%, 10%, 12.5%, and 15%, have partially replaced natural fine aggregate. With increasing WWESP, it was discovered that compressive strength, elastic modulus, impact-resisting, and bonding strength between steel bar and concrete increased for WWESP% up to 7.5%. The optimal WESP content was optimized using the Minitab software to be 3.64%.

Keywords: Bond strength; eggshell ash; impact resistance; optimization.

1. INTRODUCTION

Utilizing waste eggshell ash powder rather than natural lime as a partial substitute for cement has advantages such as reducing cement usage and utilizing the waste product. Waste eggshell ash powder's (WESP) effect on setting time was researched by Mtallib and Rabiu and Mansoor et al. They concluded that WWESP is an accelerator based on the study's findings[1,2]. Gowsika et al. used waste eggshells from industrial sources as a powder to partially replace cement. In the scenario of 5% ESP with a 20% micro silica replacement ratio, they discovered no loss in either compressive or flexural strengths [3]. Hama et al. [4] looked into how waste eggshell powder (WESP) affected the micro-structure of normal-weight concrete. WESP of more than 5% resulted in a dense internal structure compared to the one for reference structure without WESP. Using WESP in place of cement increased the strength of a one-way slab for ≤ 8% WESP [4].

While adding WESP to lightweight aggregate concrete caused the strength to drop by 5% WESP[5]. A different investigation discovered that utilizing WESP enhanced strength, with the maximum value being attained at 10% WESP. They also discovered that a w/b (water/binder) of 0.4 gave a moderate slump value. Adding WESP to concrete has decreased water penetration and absorption [6]. According to Yerramala, 10% WESP in place of cement produced results for split strength and sorptivity values similar to control concrete [7]. The workability, density, and compressive strength of concrete were all increased by adding fly ash to the recommended amounts of WESP. According to another study, mortars with WESP had little radioactive permeability [8]. Dhanalakshmi et al. investigated how several qualities, such as workability, density, and compressive strength, were affected when FA (fly ash) and WESP were used to partially replace cement. They discovered that WESP decreased concrete's workability, density, and compressive strength [9]. Concrete and steel reinforcing rebar had stronger bonds when 2.5% WESP was used instead of cement, whereas 7.5% WESP had the opposite effect [10]. This work aims to use waste eggshells by adding them to concrete in the form of eggshell ash as a partial substitute for cement.

2. EXPERIMENTAL PROGRAM

2.1 Materials and Proportions for Mixing

The typical Cem1 was used, and the XRF results are stated in Table 1, and it complies with Iraqi standard (IQS.) No. 5/2019 [11]. Eggshell waste is a byproduct of the food industry, such as from restaurants or the poultry farming sector of agriculture. Chicken eggshells are the primary waste source utilized in this experiment; WES were collected from restaurants in Ramadi, Iraq. The waste eggshells were dried and then burned to 500°C, and the resulting material was sieved using a sieve no. 100 (75 μm) to remove larger ash particles. The fully sieved eggshell ash is depicted in Figure 1. Table 1 displays the eggshell ash's chemical characteristics. Sand, which has a specific gravity of 2.62, was used as a natural fine aggregate. Crushed stone with a specific gravity of 2.76 was used as a natural coarse aggregate. The results of a sieve test on each of the aggregates used in this work are displayed in Figure 2, and all of them passed the IQS, limits No. 45/1984 [12]. Table 2 shows the mix proportions in detail.

Table 1: XRF results for cement and WESAP.

Oxides	Cement	Limits of IQS	WESAP	Oxides	Cement	Limits of IQS	WESAP
CaO	62.0	-	55.00	SO_3	1.48	-	0.034
SiO_2	24.2	-	0.078	Fe_2O_3	5.14	-	0.018
MgO	**2.2**	**5% (Max.)**	0.014	Al_2O_3	5.8	≤ 3.5	0.058

Figure 1: Steps of preparing eggshell ash.

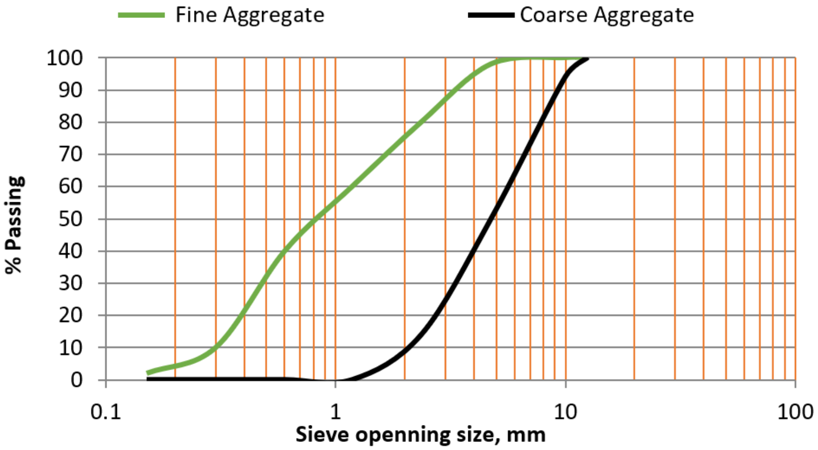

Figure 2: Aggregate sieve analysis.

Table 2: Proportions for mixes (kg/m^3).

Cement	Gravel	Sand	WESAP%	WESAP	Water
350.00	1140.0	750.0	0%	0.00	150.0
341.25	1140.0	750.0	2.5%	8.75	150.0
332.50	1140.0	750.0	5%	17.50	150.0
323.75	1140.0	750.0	7.5%	26.25	150.0
315.00	1140.0	750.0	10%	35.00	150.0
306.25	1140.0	750.0	12.5%	43.75	150.0
297.50	1140.0	750.0	15%	52.50	150.0

2.2 Tests

The list of tests in this work includes workability, compressive strength, modulus of rupture, modulus of elasticity from stress-strain relation, and bond strength, which were made following ASTMC143[13], ASTMC39/C39M [14], ASTMC469[15], and RILEM-CEB-FIP-RC6[16], respectively. The blows' number that caused the specimens' failure was investigated. The details for the bond test are illustrated in Figure 3. Figure 4 illustrates the details of steel-reinforced two-way slabs.

Figure 3: Tests that have been made in this work.

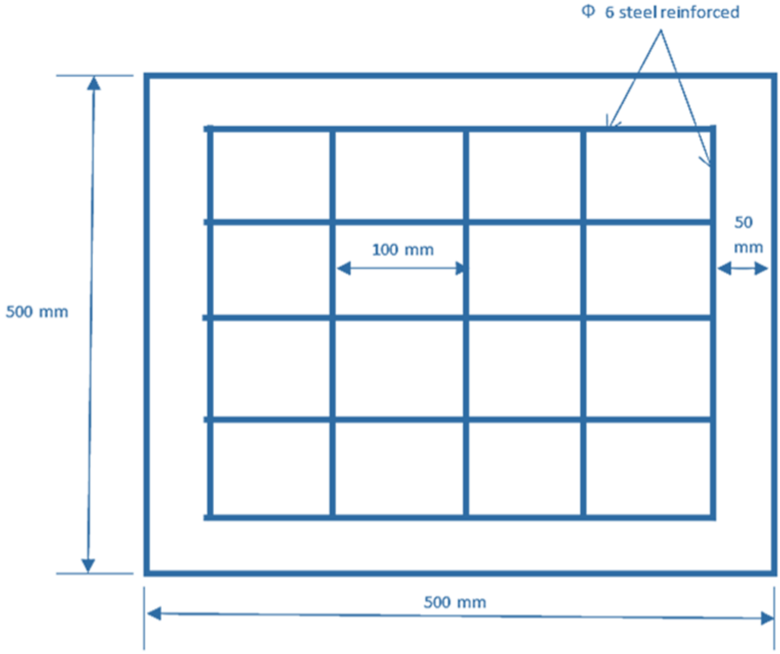

Figure 4: Details of two-way slabs used in the impact test.

3. RESULTS AND DISCUSSION

3.1. Slump

The workability of mixes has been evaluated through a slump test. From Figure 5, one can see that the slump of mix reduced with higher content of WESAP increased. The decrease in the slump of mix with increasing WESAP% is the ability of the adding powder to absorb more water. A linear relation was noticed between WESAP % and the slump and can be formulated by the following equation:

$$\text{Slump} = -181.43\ \text{WESAP}\ \% + 94.75 \qquad R^2 = 0.9684 \qquad (1)$$

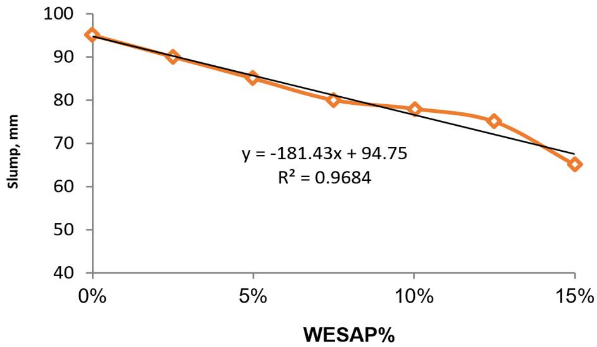

Figure 5: Slump versus WESAP%.

3.2. Mechanical Properties

Figures 6 to 8 illustrate the results of the compression strength (f_c), modulus of rupture (f_r), and modulus of elasticity (E_c) tests. Adding WESAP improved these properties for percentages up to 5%. For WESAP content ≥ 10%, the mechanical strat is to be decreased. Similar conclusions were found by other researchers [17-20]. From experimental results, the following empirical equations have been suggested, as follows:

$$f'c = -1790.5 \text{ ESA\% } 2 + 171.43 \text{ WESAP \% } + 32.548 \qquad R^2 = 0.8641 \qquad (2)$$

$$fr = -134.67 \text{ ESA\%2 } + 12.7 \text{ WESAP \% } + 3.146 \qquad R^2 = 0.8353 \qquad (3)$$

$$Ec = -685.71 \text{ ESA\%2 } + 37.143 \text{ WESAP \% } + 26.786 \qquad R^2 = 0.8585 \qquad (4)$$

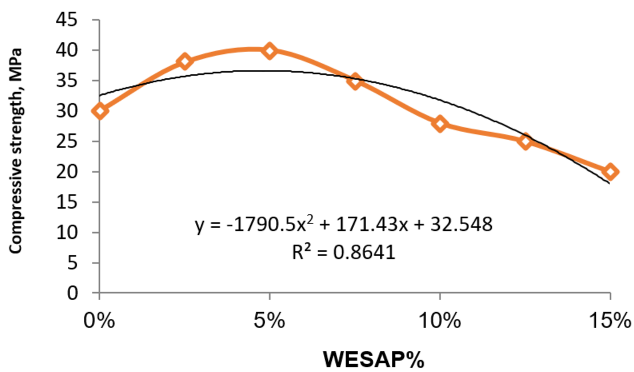

Figure 6: Compressive strength versus WESAP %.

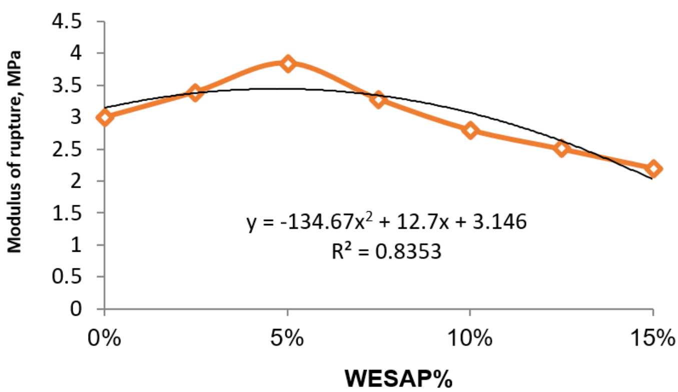

Figure 7: Modulus of rupture versus WESAP %.

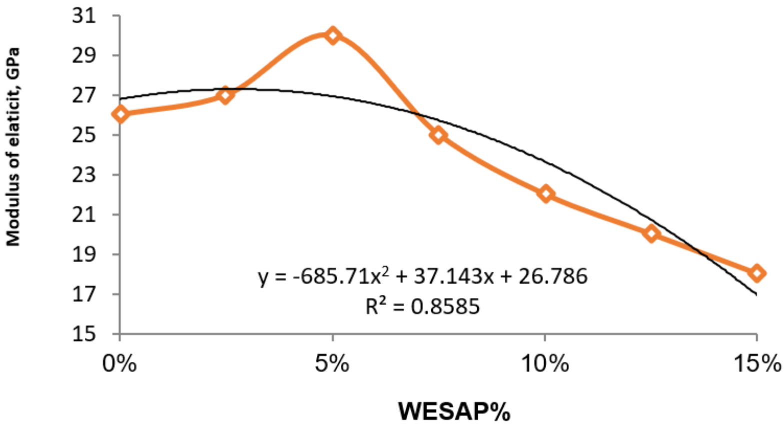

Figure 8: Modulus of elasticity versus WESAP %.

3.3. Bond Resistance

Figure 9 illustrates bond strength variation with WESAP%. Bond strength has been found by utilizing the following equation:

$$\text{Bond strength} = \text{load}/(\pi \times \text{ diameter of the steel bar } \times \text{ diameter of the steel bar}) \quad (5)$$

The bond between concrete and steel reinforcing improved by percentages up to 10%. For WESAP content ≥ 10%, the mechanical properties are to be decreased. An empirical equation has been proposed to represent the relation between bond strength and ESA% as follows:

$$\tau = -62.571 \text{ WESAP } \% + 23.464 \qquad R^2 = 0.6627 \quad (6)$$

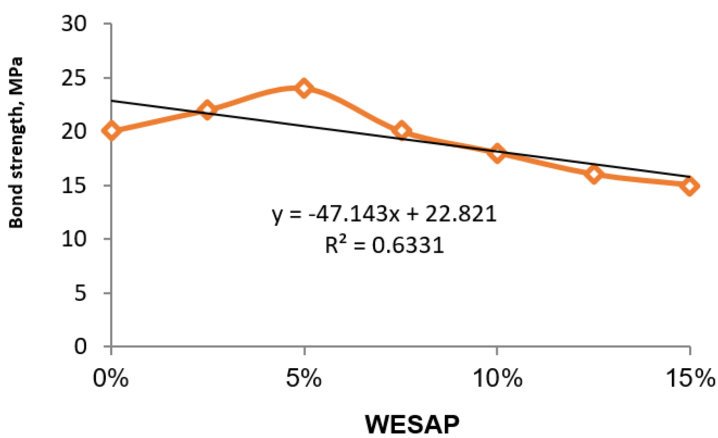

Figure 9: Bond strength with WESAP %.

3.4. Impact test results

To investigate the influence of WESAP% on the impact resistance for two-way square reinforced slabs, the blows until the specimen's failure were recorded; the results are shown in Figure 10. The impact resistance improved for percentages up to 10%. For WESAP content ≥ 10%, the ability to absorb more energy decreased. An empirical equation was proposed between blows at failure (N) and WESAP content as follows:

$$\text{N} = -533.33\text{ESA}\%2 + 57.143 \text{ WESAP } \% + 15.19 \quad (7)$$

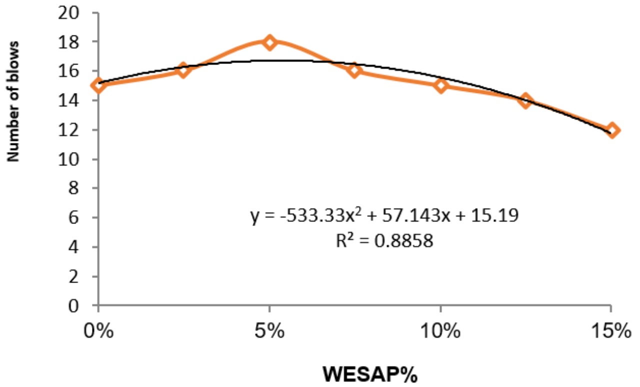

Figure 10: No. of blows versus WESAP %.

3.5. Optimization

An analysis was made using Minitab software to find the optimum content from WESP to be used in concrete. All properties above have been considered in the analysis process, which are considered independent parameters, while the WESP% has been considered as dependent parameters. Utilizing the fit regression model in analysis, the optimum content of WESAP was found to be 3.64%, as shown in Figure 11.

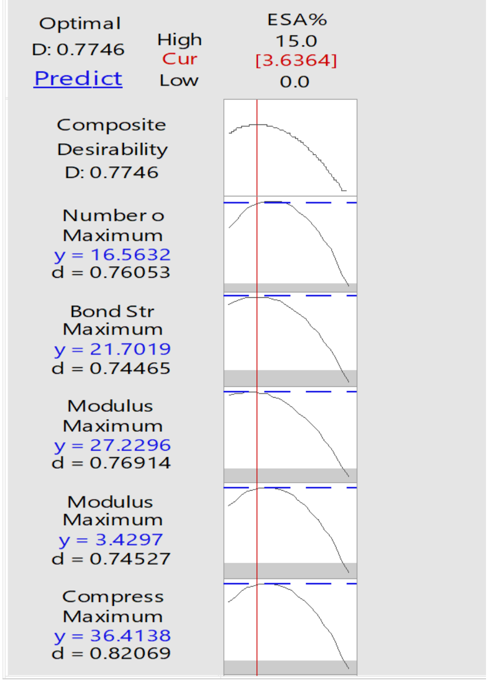

Figure 11: Optimization analysis.

4. CONCLUSIONS

- After being burned and grounded to powder, waste eggshells have been reused to produce concrete with good properties, as illustrated by experimental work.
- The slump reduced with increased WESAP% content, as shown in the slump test.
- Mechanical properties improved for percentages up to 10%. For WESAP% content ≥ 10%, a decrease in the recorded value of these properties was found.
- Also, bond and impact resistance improved for percentages up to 10%. For WESP% content ≥ 10%, a decrease in the recorded value of these properties was found.
- Based on optimization analysis, it was found that the optimum WESAP % content is 3.64%.

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