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RESEARCH ARTICLE

Properties of Sustainable Concrete Consisting Crushed Eggshell Waste as Fine Aggregate Replacement

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ABSTRACT - The excessive extraction of sand from riverbeds has adverse effects on river ecosystems and aquatic life. Simultaneously, the disposal of eggshells from certain food manufacturing facilities into landfills contributes to pollution. Incorporating crushed eggshells as a partial replacement for sand in concrete can reduce the demand for natural sand, thus decreasing the need for sand mining from rivers. The present research investigates the effect of crushed eggshells as partial sand replacement on workability, compressive strength, and splitting tensile strength of concrete. Five different concrete mixtures were tested, with crushed eggshells replacing sand at percentages ranging from 0% to 20% by weight. All specimens underwent water curing and were subjected to three tests: slump, compressive strength, and splitting tensile strength. The incorporation of eggshells, finer than sand, reduced workability but showed acceptable strength up to a 10% replacement rate. In conclusion, using eggshells as a sand substitute in concrete production can contribute to a cleaner environment and support river ecosystem sustainability.

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1.0 INTRODUCTION

After water, concrete was the most commonly used substance on earth. The projected global population growth and urbanization trends in the coming decades indicate that the demand for cement and concrete will continue to rise [1]. It is one of the most employed materials owing to its strength, ease of being molded to the desired shape, incombustible, inexpensive, and readily available [2]. Concrete is widely employed in the construction industry [3, 4]. It is used in the construction of a variety of structures, including buildings, bridges, dams, and highways. This composite material is formed by combining cement, fine aggregate, coarse aggregate, and water, and it gradually solidifies over time [5, 6, 7]. The ease of acquiring raw materials, especially aggregates found in many parts of the world for concrete manufacturing and the steps of producing this material attract the builders. Good quality raw materials, particularly river sand, have been in high demand for sustainable infrastructural development [8] as this type of sand is the most convenient supply of fine aggregate available anywhere worldwide [9]. Nowadays, sand has been gradually decreasing due to sand mining activities in river areas that have been carried out globally [10, 11, 12]. This is because the need for raw materials for building construction is going to double by 2030 [13]. According to Garside, [14], in 2020, industrial aggregates globally produced 265 million tons compared to 2008, with an output of 118 million metric tons. Sand mining has resulted in environmental disparities and has been seen as an exaggerated resource [8]. River sand mining induces incision deformation of the riverbed by affecting not only the levee of the reach holding the pit but also the higher reaches of the pit in both vertical and horizontal directions and lowering the water table of the river [15, 16]. In addition, the sand mining activity also causes erosion of soil, harming local wildlife, destroying aquatic ecosystems, and tarnishing the beauty of the surroundings contributing to the tourism industry [17]. The construction sand and gravel industry remained vigilant in addressing various regulatory concerns, including those related to the environment, health, permitting, safety, and zoning [18]. Thus, researchers have been studying several new sustainable and environmentally friendly building materials in the last decades to replace natural ones [19]. Transforming discarded waste from industries would lessen waste disposal at dumpsite and support efforts towards cleaner surrounding.

The widely used eggs for various types of food preparation including biscuits, cakes and desserts in many parts of the world has led to generation of eggshell. About 8.58 million metric tons of eggshells were produced worldwide [20]. Eggshell is largely obtained from chick hatcheries, homes, industries, restaurants, and bakeries [21, 22]. This organic waste is disposed of in large quantities in Malaysia [8]. Environmental Protection Agency has described eggshell waste as the 15th major pollution challenge in the food industry [23]. When not properly dumped off in designated areas, it poses health threats due to fungal growth later on and attracts worms and mice [3, 23]. The smell of the eggshell when left in the garbage for a longer period is undesirable [24, 25] and creates discomfort to the community surrounding. Eggshells, being organic waste, are biodegradable and have a tendency to decompose when disposed of as waste. In composition, they primarily consist of calcium compounds, magnesium carbonate (lime), and protein [17, 26]. Approximately,

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exceeding 90% $CaCO_3$ form from eggshells, there are other micro components including boron, copper, iron, manganese, molybdenum, sulfur, magnesium, silicon, and zinc [27]. The continuous availability of eggshells in large amounts has inspired research on the utilization of this material in sustainable construction material development. Eggshell has been used as a mixing ingredient in the production of certain materials in civil engineering application [28]. Success in utilizing this material as partial sand replacement in concrete would have positive impacts on the environment. Thus, the present research investigates the effect of crushed eggshells as partial sand replacement on the workability, compressive strength and splitting tensile strength of concrete.

2.0 EXPERIMENTAL WORK

2.1 Materials

In this research, Ordinary Portland Cement (OPC) sourced from a single supplier was utilized. Fine aggregate was obtained from local river sand with a fineness modulus of 2.14. Coarse aggregate consisted of crushed granite. The mixing and curing of fresh concrete were carried out using tap water available in the laboratory. Eggshells were collected from bakeries, cleaned with water, and then air-dried for 10 hours under sunlight to remove moisture content. Subsequently, the dried eggshells were crushed using a crushing machine and passed through a 1.18 mm sieve size. The fineness modulus of the crushed eggshells was determined to be 1.80. Figure 1 illustrates the step-by-step process of preparing the eggshells for use in the research.

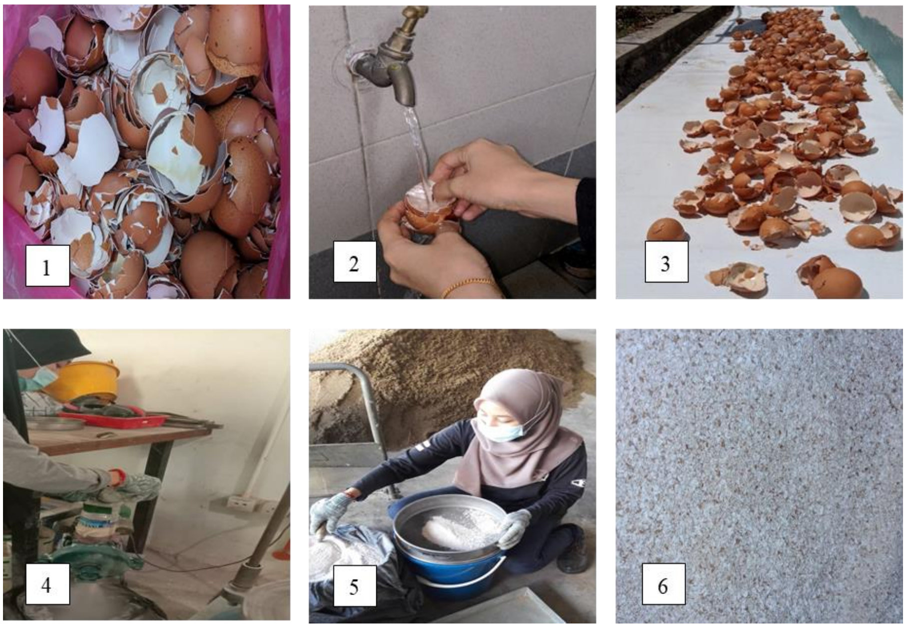

Figure 1. Eggshell powder preparation process

2.2 Specimen preparation and testing

Five different types of mixtures were employed in this experimental study. The control reference specimen consisted of concrete CES-0, which was created using 100% sand as fine aggregate. Whereas, other mixtures were formulated by incorporating crushed eggshells as a partial replacement for sand, specifically at proportions of 5%, 10%, 15%, and 20% of the total sand weight. The specific mix ratios utilized in this research can be found in Table 1. The concrete mixing process was carried out using a concrete mixer, the specimens were compacted using a vibrating table to eliminate any trapped air and achieve maximum compaction. Each layer underwent approximately 5 seconds of vibration. After 24 hours of casting, the samples were remolded and clearly labeled for easy identification. Subsequently, the specimens were subjected to water curing until the date of testing. Figure 2 visually depicts the sequence of steps involved in preparing these specimens.

In this experimental study, three types of tests were conducted. The first test was a slump test, which followed the BS EN 12350: Part 2 [29] standard. This test involved promptly assessing the consistency of the fresh concrete mixture. The concrete was placed in a mould in three equal layers, each compacted with 25 tamping rod strokes. After compacting the top layer, the surface was smoothed using a sawing and rolling motion with the compacting rod. The mould was then carefully lifted within 2 to 5 seconds, and the slump measurement was recorded as the difference between the mould's height and the highest point of the slumped test specimen. The second and third tests, compressive strength and splitting tensile strength, were conducted on hardened specimens at curing ages of 7 and 28 days. The compressive strength test involved cube shaped specimens with dimensions of 100 mm x 100 mm x 100 mm, following the procedure outlined in BS 1881: Part 116: 1983 [30]. Before testing, the specimen surfaces were meticulously cleaned to remove any residual moisture. The samples were then carefully positioned at the center of the lower platen, and a controlled loading rate, typically within the range of 1.0 MPa/s ($N/mm^2 \cdot s$), was consistently applied to ensure smooth and gradual loading without abrupt impacts during the testing. The splitting tensile strength tests were conducted on cylindrical specimens with dimensions of 100 mm in diameter and 200 mm in height, following BS 1881:117-83 [31] standards. Prior to testing, the specimens were removed from the water curing tank, and excess moisture was wiped off from their surfaces. Subsequently, the specimens were placed in the testing machine, ensuring central positioning. Throughout the loading process, care was taken to keep the upper platen parallel to the lower platen to maintain uniform and accurate testing conditions.

Table 1. Mix proportion for concrete mixes in kg/m^3

Mixes	Cement	Sand	Crushed Eggshell	Coarse Aggregate	Water
CES-0	460	900	-	1190	320
CES-5	460	850	40	1190	320
CES-10	460	810	90	1190	320
CES-15	460	760	130	1190	320
CES-20	460	720	180	1190	320

Figure 2. Specimens preparation process

3.0 RESULTS AND DISCUSSION

3.1 Workability

The findings presented in Figure 3 indicate that the inclusion of crushed eggshells as a partial replacement for sand in concrete has a noticeable impact on the workability of the fresh mixture. The slump value of the concrete decreases as the proportion of crushed eggshells incorporated into the mixture increases. The slump value of the mixes is in the range of 35 mm to 23 mm. Notably, the control concrete exhibits a highest slump value. Concrete containing 20% crushed eggshell displays the lowest slump value amongst all mixes. Figure 4 illustrates the variation in concrete slump due to inclusion of eggshell at different percentage. The use of crushed eggshell which is finer than sand increases the water requirement in the mix resulting in a stiffer mixture. Based on Hakeem et al., [32], the utilization of eggshells in the casting process results in the substantial absorption of water, which subsequently reduces the workability of the concrete. Thus, the integration of crushed eggshells in larger quantities results in a reduction in the mix workability. The effect of smaller size fine aggregate towards the formation of a stiffer mix has been reported by [33]. Past researchers Sulaiman et al. [34] and Kuo et al. [35] who integrated waste material having a smaller size than natural sand as partial fine aggregate also reported a similar trend of results.

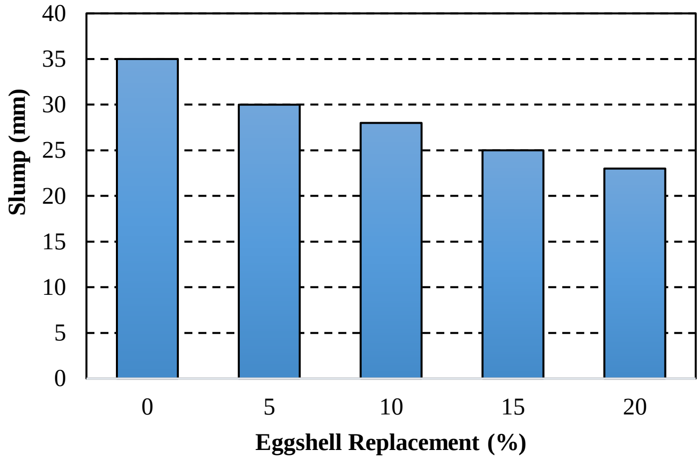

Figure 3. Workability test result

Figure 4. Slump variation

3.2 Compressive strength

Figure 5 illustrates the compressive strength of concrete in which crushed eggshells were utilized as a partial replacement for sand. The incorporation of crushed eggshells which physical properties is different from river sand influenced the compressive strength of concrete. The concrete mixture exhibit slight strength declination as larger content of crushed eggshell were integrated as partial fine aggregate replacement. Specifically, at the age 28-day, the compressive strength varied from 24.5 MPa for the control (0% eggshell replacement) to 18.4 MPa for specimens containing 20% crushed eggshells. Concrete with 0% crushed eggshell replacement exhibited the highest compressive strength of all samples. Using up to 10% crushed eggshells as a partial sand replacement produced concrete that met the targeted strength of 20 MPa. Concrete with 20% eggshell replacement recorded the lowest compressive strength. Excessive substitution of crushed eggshells needs to be avoided as it can lead to significant reduction in strength. Using a higher amount of eggshells results in a stiffer mixture with reduced workability, making it challenging to achieve homogeneous blend during mixing work. Additionally, the mixture becomes difficult to compact and contains more voids, leading to weaker hardened concrete. This observation aligns with the findings of other researchers, such as Panda et al. [37], who noted a similar trend of strength decline resulting from the inclusion of finer-sized material as a partial sand replacement in concrete.

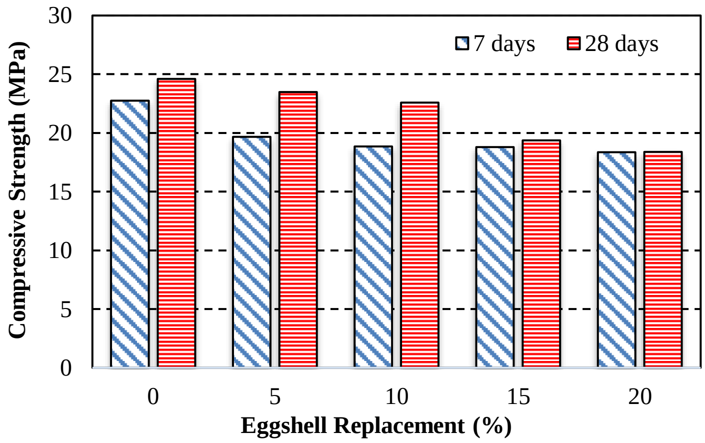

Figure 5. Compressive strength test result

3.3 Splitting tensile strength

Figure 6 depicts the results of splitting tensile strength in concrete specimens where crushed eggshells were employed as a partial replacement for sand. The data clearly demonstrates that a higher proportion of crushed eggshells tends to reduce the splitting tensile strength. After 7 days of curing, the strength for specimens with 0%, 5%, 10%, 15%, and 20% eggshell replacements are as follows: 2.19 MPa, 2.14 MPa, 2.08 MPa, 2.08 MPa, and 2.03 MPa, respectively. When the curing period extended to 28 days, the corresponding strengths are: 2.80 MPa, 2.54 MPa, 2.53 MPa, 2.46 MPa, and 2.37 MPa, respectively. In general, all specimens exhibit an increase in strength as the curing duration progresses. Akinwumi, and Gbadamosi [38] have mentioned that the curing process ensures consistent hydration of concrete, resulting in an ongoing increase in strength. Longer curing periods enable better hydration due to the continuous availability of moisture, leading to the production of a larger quantity of CSH gel. A higher presence of CSH gel contributes to a denser internal structure in the composite material, leading to increased concrete strength. The results also indicate that concrete with 0% eggshell replacement exhibits the highest tensile strength, while concrete with 20% eggshell replacement demonstrates the lowest tensile strength. This can be attributed to the smaller particle size of crushed eggshells, which is finer than river sand, resulting in increased surface area and enhanced water absorption, ultimately leading to reduced strength. Chen et al. [39] noted that highly water-absorbent materials can reduce the effective water-cement ratio in concrete, leading to decreased hardness, lower density, and increased structural defects. Shetty and Jain [40] have mentioned that aggregate properties, such as size, shape, surface roughness, and grading, can influence the strength of concrete. Figure 7 displays a similar trend in the results of compressive strength and splitting tensile strength.

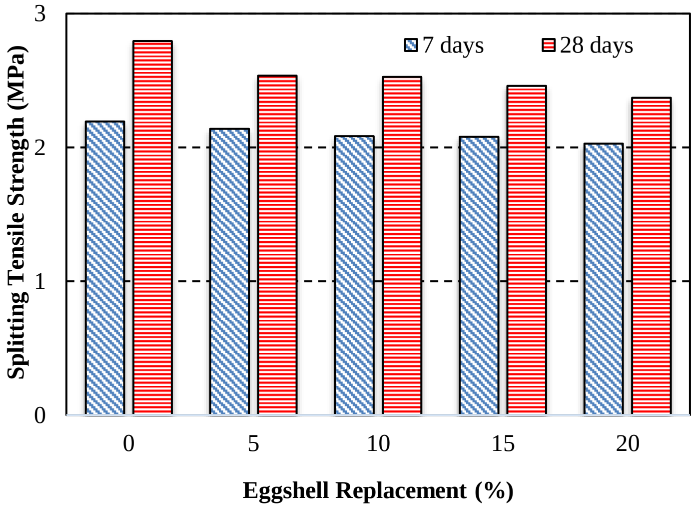

Figure 6. Splitting tensile strength test result

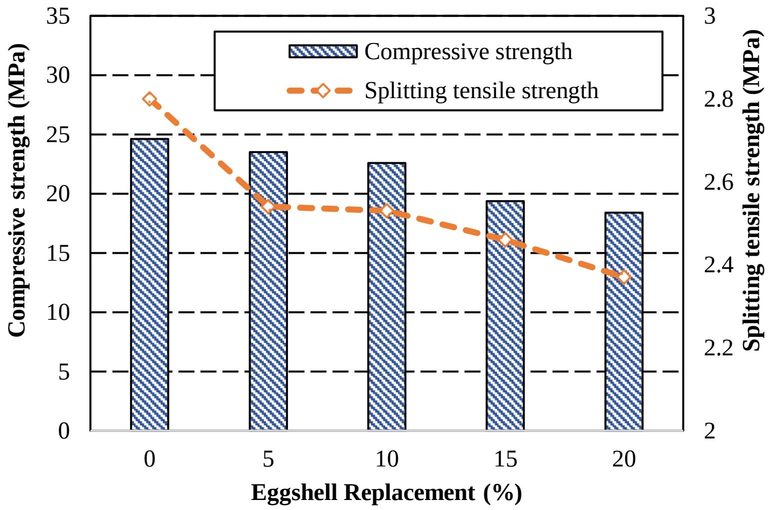

Figure 7. The correlation between the compressive strength and splitting tensile strength of concrete after 28 days

4.0 CONCLUSION

In summary, the inclusion of crushed eggshells as a partial replacement for sand has a noticeable impact on the workability, compressive strength, and splitting tensile strength of concrete. The substitution of up to 10% crushed eggshells as fine aggregates is effective in producing concrete with the desired strength. Incorporating eggshell waste as a replacement for fine aggregates in concrete production not only reduces the amount of eggshell waste disposed of but also contributes to environmental pollution reduction, leading to a cleaner and more sustainable living environment.

5.0 AUTHOR CONTRIBUTIONS

Khairunisa Muthusamy: Conceptualization, Methodology, Reviewing and Editing

Abidatul Munawwarah Kamaruzaman: Data curation, Writing- Original draft preparation

Hanis Nadiah Ruslan: Visualization and Editing

Mohammed A. Ismail: Reviewing and Editing

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7.0 DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included in the article.

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9.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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