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Properties of Mortar Using Oyster Shell as Partial Fine Aggregate Replacement

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Abstract. The awareness about the massive extraction of river sand increases because it intensifies the destruction of river. At the same time, the oyster shell waste disposal from fisheries industry is rising and pollutes the environment. Therefore, the present research explores the effect of using crushed oyster shell as a partial fine aggregate on the flowability, compressive strength, and water absorption of mortar. Four mortar mixtures were made by replacing 0%, 10%, 20%, and 30% of the sand with crushed oyster shells. The mixtures were then tested on their flowability, strength, and water absorption. The findings show that at 28 days, all mixes reached the targeted strength, with values varying from 22.87 MPa to 35.20 MPa. Generally, using cockle shell as fine aggregate replacement would decrease the demand of natural river sand for the construction industry and the pollution caused from oyster shell waste dumping.

INTRODUCTION

River sand is commonly used in the mix as fine aggregate [1], accounting for 70 - 90% of the entire cement-sand mix by weight [2]. Then, more than 70% of the mortar's volume was made up of sand [3]. Increasing demand for fine aggregates has led to rising sand mining activities. In 2021, natural sand exports from all countries reached USD 1.71 billion [4]. Global sand and gravel extraction is expected to reach 82 billion metric tons by 2060 [5]. The rising demand for this non-renewable resource that can easily be harvested from the river, resulted in uncontrolled and illegal sand mining. This situation poses undesirable impact on the river and the aquatic life. Excessive extraction of sand depletes river sand and ruins the current river environment, resulting in an unbalanced ecology [6] and causing deterioration of the river bed [7]. The contour of the riverbed is directly influenced by indiscriminate river sand mining [8]. The changes of river environment also contribute towards the extinction of certain aquatic animal that may cause ecological imbalance. Due to these environmental concerns, the government has placed different limits on river sand extraction, resulting in price increases [9]. As a result, many researchers have examined the efficacy of refuse as a replacement for natural fine aggregate. The goal of using refuse as natural river sand is to reduce environmental problems.

Recent innovations in the aquaculture sector, has increased the output of oysters dramatically, particularly rising fivefold since 1990 [10]. Since oyster shells waste materials can persist for a considerable amount of time without breaking down, it can lead to an accumulation of this waste at dumping sites as well as pollution of soil and water [11]. Currently, some oyster shells are recycled for seedlings and nourishment, but the majority are not [12]. Waste oyster shells are progressively posing a severe environmental problem, especially in light of the fact that solid waste management is one of the major barriers to the creation of a sustainable earth [13]. The degradation of residual meat that is still adhered to oyster shells has the potential to produce foul-smelling smells. Due to the environmental issues created by oyster shell waste, few researchers Yang, Yi, & Leem, [14]; Yang, Kim, Park, & Yi, [15]; Wang, Kuo, Lin, & Po-yo, [16] have explored the performance of oyster shell as fine aggregate in construction material.

Yang, Yi, & Leem, [14] discovered that as the substitution rate of oyster shell as a fine aggregate replacement increased, the workability of concrete decreased, while the compressive strength increased. Oyster shell concrete demonstrated a significant increase in strength during the early stages, but as the ages increased, it approached the strength of normal concrete. Yang, Kim, Park, & Yi, [15] reported comparable results, stating that the use of oyster

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shells as a fine aggregate replacement had a negligible impact on concrete's compressive strength up to 28 days. Wang, Kuo, Lin, & Po-yo, [16] investigated the effect of fly ash on oyster shell cement mortar and found that oyster shell sand had only a minor impact on compressive strength. However, the present study on using oyster shell as a fine aggregate replacement in mortar is limited. The purpose of this research is to ascertain how oyster shell replacement affects mortar's flowability, compressive strength, and water absorption.

METHOD

Materials Used

Oyster shell mortar is produced using four primary materials, namely cement, fine aggregate, oyster shell, and water. Ordinary Portland Cement (OPC) complying to BS EN 197-1 [17] is used as binder. Fine aggregate was sourced from river sand. Crushed oyster shell was used as a partial replacement of fine aggregate. Figure 1 illustrate the raw oyster shell and the finely crushed shell. Both river sand and oyster shell employed in this research study passed through sieve 1.18 mm. Table 1 presents the physical characteristics of both sand and oyster shell, including their fineness modulus, specific gravity, and water absorption. The findings revealed that oyster shell has a greater water absorption (22.5%), lower fineness modulus (18.92%) and specific gravity (4.78%) than river sand. In this study, tap water was used.


(a)


(b)

FIGURE 1. Raw oyster shell (a), and fine crushed oyster shell (b).

TABLE 1. Physical properties**.**

Properties	River sand	Oyster shell
Fineness modulus	3.70	3.00
Specific gravity (kg/m^3)	2.72	2.59
Water absorption (%)	8.00	9.78

Mix Proportion and Specimen Preparation

In order to achieve the targeted compressive strength of 20 MPa, the trial mix method was employed to produce the mortar mixture. Four types of mixes were used in this experimental study, as presented in Table 2. The control specimen consists of plain mortar made entirely of sand as the fine aggregate. The remaining mixes were formulated by introducing crushed oyster shell (COS) as a partial replacement of sand by weight of fine aggregate, with replacement percentages of 10%, 20%, and 30%. The specimens were created by weighing all the materials and mixing them in a mixer. The mixture was then poured into a cube mold measuring 50 x 50 x 50 (mm^3) in three layers whereby each layer being compacted using a vibrator table. It was then being moulded, the specimens were left overnight and then removed from the mould the next day. It was subsequently submerged in water for curing until the day of testing.

TABLE 2. Mix Proportion (kg/m^3).

Percentage (%)	Cement	Water	Sand	COS
0	300	200	600	0
10	300	200	540	60
20	300	200	480	120
30	300	200	420	180

Experimental Method

In this study, the performance of mortar was assessed in terms of flowability, compressive strength, and water absorption. In order to determine the flowability of mortar, the flow table test was conducted following the procedure outlined in ASTM C1437 [18]. Firstly, the flow table was cleaned, and the mold was placed at the center. The mold was then filled with three levels of the mixture and tamped 20 times each. After taking the mold from the mixture, the table was dropped 25 times, and four readings were taken and calculated using the standard's formula. The compressive strength test was conducted according to ASTM C109, [19]. The testing was conducted at 7 and 28 days after water curing. Prior to testing, the machine's surface was cleaned to ensure the accuracy of the results. The cube was placed in the center of the compression machine to ensure an even distribution of load on the specimens. Water absorption test were conducted in accordance with ASTM C642 [20].

RESULTS AND DISCUSSION

Flowability

Figure 2 displays the flowability of mortar mixes. As the percentage of crushed oyster shell used as a partial replacement for fine aggregate increases, the flow of mortar decreases. The control specimen exhibits the highest flowability value at 150%, while the mortar with 30% COS as a fine aggregate replacement shows the lowest flowability value at 136%. The decrease in flow value is due to the lower fineness modulus of the COS (3.00) as compared to sand (3.70). The use of finer sized COS results in a larger surface area and increased water demand that forms stickier mixture. According to Mo et al., [21], seashell waste can reduce the workability of mortar/concrete due to the increased surface area and water demand. Additionally, Wang et al., [15] discovered that the flowability of mortar decreases because of unevenly flat particles, low filling water content between the particles, and increased mixture friction. Similar findings have been reported by Yang et al., [13] and Liao et al., [22] regarding the decreased workability of concrete and mortar mixtures as the substitution rate of oyster shell increases.

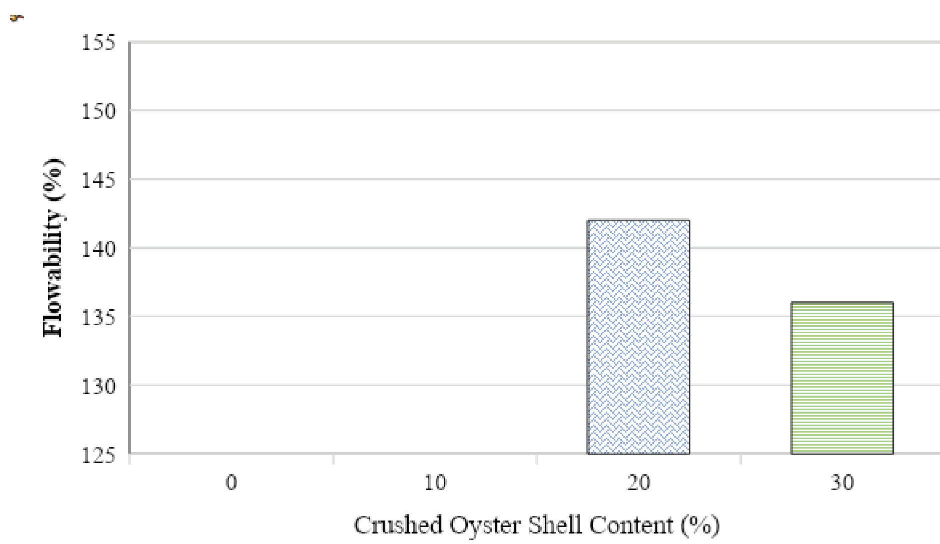

FIGURE 2. Flowability of COS mortar.

Compressive Strength

Figure 3 demonstrates the effect of COS as a fine aggregate on compressive strength properties. All mixes demonstrate increment rise in strength as curing duration become longer resulting from the undisturbed hydration process. It is due to the constant production of calcium silicate hydrate (CSH) gel product [23]. The approach of blending COS as partial fine aggregate replacement influences the compressive strength of mortar. The trend shows that mortar experience slight strength declination as larger percentage of COS is integrated into the mix. Control specimens exhibit the highest strength value at 7 and 28 days, with value 26.39 MPa and 35.20 MPa, respectively. Mortar consisting 10% COS achieved the targeted compressive strength. While, 30% specimens exhibit the lowest strength at both curing age. The use of COS with the porous structure and greater absorption rate than sand affects the compressive strength of concrete. Similar trend of result has been reported by previous researcher Kuo et al., [24] and Panda et al., [25].

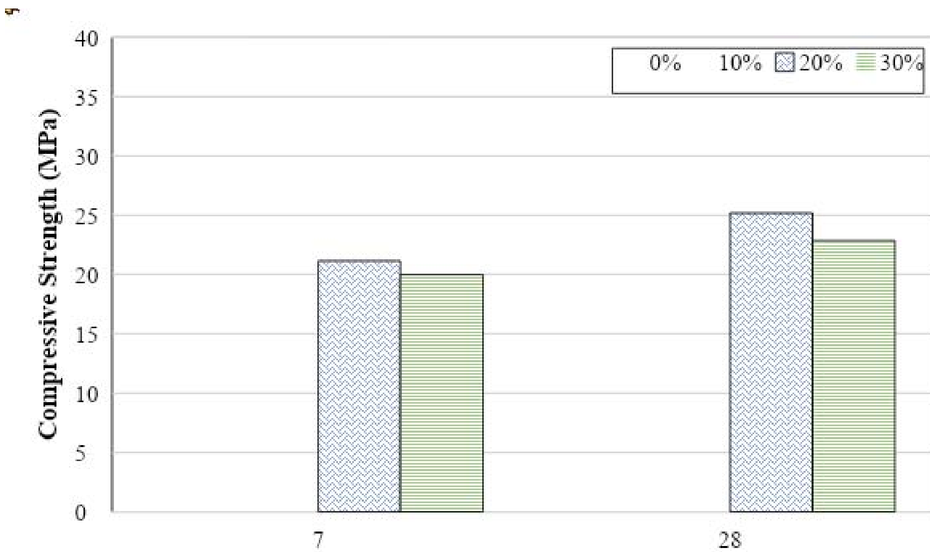

FIGURE 3. Compressive strength results.

Water Absorption

The content of COS in mortar has influenced the water absorption value as illustrated in Fig. 4. The water absorption increases when the crushed oyster shell content increase. Control specimen exhibit the lowest water absorption and specimen produced using 30% of COS present the highest water absorption with value 4.31% and 5.51%, respectively. Borhan & Mohamed, [26] stated that the greater the water absorption, the less durable the mortar. Martínez-García et al [27], observed that the water absorption of mortar containing seashell is increased due to the flaky shape of the shells and their low bond with the cement paste, resulting in the formation of larger pores and higher water absorption. Additionally, the increase in water absorption value as the proportion of replacement rises can be attributed to the higher water absorption capacity of COS in comparison to river sand.

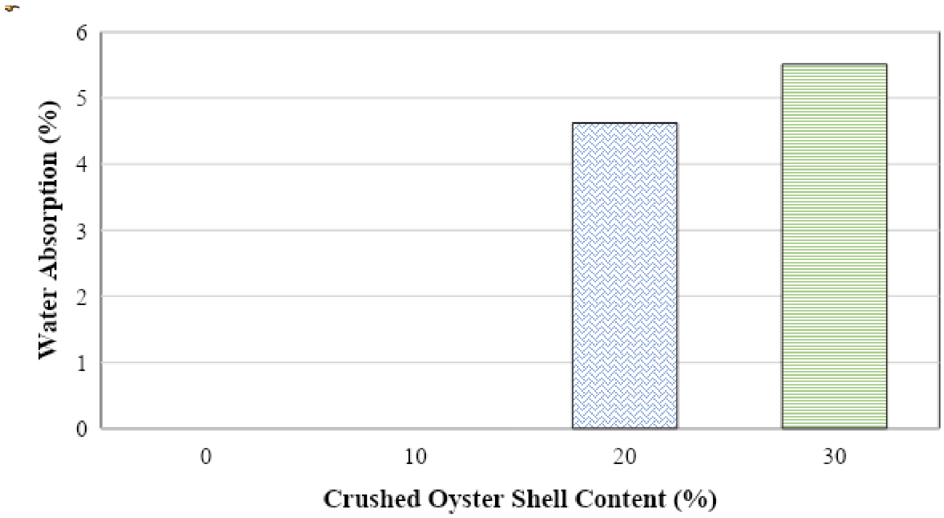

FIGURE 4. Water absorption of mortar with diverse content of COS.

Sustainable Mortar Mixture

Table 3 shows that mortar with 10% COS as fine aggregate replacement exhibit the highest flowability, compressive strength and lowest water absorption compared to mixture with COS (20% & 30%). The use of COS as a substitute for fine aggregate has the potential to foster a more sustainable building industry and decrease reliance on the river sand supply.

TABLE 3. The study's findings can be summarized as follows.

Percentage of replacement (%)	Flowability (%)	Compressive strength at 28 days (MPa)	Water absorption (%)
0	150	35.20	4.31
10	145	31.06	4.45
20	142	25.19	4.62
30	136	22.87	5.51

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CONCLUSION

Incorporating COS as a partial fine aggregate replacement has a notable effect on the flowability, compressive strength, and water absorption of mortar. It was observed that mixing 10% COS is sufficient to produce mortar with the desired strength. Further research is proposed to examine the durability performance and fire resistance of the mixture blended with COS. The continuously produced COS from aquaculture trade should be channeled for suitable construction material production to alleviate these wastes from being stockpiled at dumpsite.

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