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Properties of Sustainable Concrete Containing Different Percentages and Particles of Oil Palm Ash as Partial Sand Replacement

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ABSTRACT

Oil palm shell (OPS) in concrete is well studied as an alternative material of fine aggregate in concrete, as a way to use agricultural waste, and helps to contribute to environmental sustainability and economical construction cost. However, OPS addition will lead to lower properties of the concrete, and much research focuses on treating the OPS to overcome it. Many previous works focused on replacement without examining the effect of different particle sizes of OPS. Hence, this study focuses on the performance of concrete with different particle sizes of OPS as sand replacers in concrete at 25% and 50%. The physical and permeability properties of concrete prepared with OPS particle sizes in the ranges between 600µm to 4.75mm (L), 300µm to 1.18mm (M), and of less than 600µm (S) and two different percentages of 25% and 50% by weight as sand replacement are examined. More than 200 cubes, cylinders, and prisms were tested to determine their physical, mechanical, and permeability properties. The workability was measured by the slump height, the mechanical properties by the compressive strength test, flexural strength test, splitting tensile test, ultrasonic pulse velocity (UPV) test, and rebound hammer test. While the permeability properties by the water penetration test, sorptivity test, and rapid chloride permeability test. The findings showed that increasing the particle sizes of OPS would reduce concrete's physical and

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permeability properties. The optimum OPS particle size for structural concrete grade 30 is less than 600µm. With OPS particles of 600um, green concrete using OPS can be made for medium to low-strength applications in the construction industry.

Keywords: Different sieve size, oil palm shell (OPS), permeability properties, physical properties, sand replacement, sustainability

INTRODUCTION

Malaysia is the second-largest oil palm producer in the world, producing more than 52% of the world's total palm oil (Tripathi et al., 2015). Malaysia's oil palm tree land area has grown from 54,000 hectares in 1960 to 5.90 million in 2019 (Ting et al., 2020). At the same time, this industry generates an increasing number of by-products that are disposed of as waste. OPS is a by-product of palm oil mills produced after the fruit's oil is extracted. Using this substance as one of the mixing ingredients in concrete would increase the waste's functionality, reducing the quantity of OPS, which would otherwise end up in landfills. The open burning of OPS to eliminate solid waste also contributed to environmental pollution. The construction industry, on the other hand, is developing at a fast pace, and the demand for concrete for construction has greatly increased (Qasem et al., 2021). The high demand for concrete in construction leads to natural resource depletion, particularly sand. The sand formation takes thousands of years of erosion and rock breaking down, but it is used relatively quickly. In 2012, the yearly aggregate usage was predicted to be between 25 and 29 billion tonnes, with demands expected to reach 50 billion in 2019 (UNEP, 2019). The extensive usage of natural sand has negatively impacted the environment and ecosystem, threatening species (Sutherland et al., 2017). Numerous studies have been carried out on recycled materials for replacing aggregates in concrete to overcome these issues.

Substitution of aggregates with agricultural waste is an environmental-friendly option as agricultural waste is a type of sustainable material. Since OPS is cheap and easily available in Malaysia, it can replace the aggregate (Rahman et al., 2020). Huda et al. (2016) stated that the utilization of OPS as a replacement for the aggregates in concrete could solve the issue of natural aggregate depletion and air pollution resulting from the aggregate production process. Moreover, according to Olanipekun et al. (2006), the substitution of the aggregate with OPS has the potential to reduce the cost by 42%. The cost of concrete production is a crucial component in construction as it influences the construction cost of a project. In the last decade, extensive work has been conducted on using OPS as a replacement for the coarse aggregate in the production of concrete (Mo et al., 2017; Mannan & Ganapathy, 2002; Mannan & Ganapathy, 2004).

Maghfouri et al. (2018) reported on the performance of concrete containing different percentages of OPS to replace the coarse aggregates with percentages from zero to 100% with an interval of 20%. The authors reported that the percentage of OPS should not exceed 60% of the total volume of coarse aggregate. At the same time, Mo et al. (2015) studied the performance of concrete mixes containing the OPS as coarse aggregate lightweight concrete with different percentages of ground granulated blast slag (GGBS) on the mechanical and bond properties of OPS concrete (OPSC). The findings demonstrate that although a higher GGBS percentage reduced strength, the OPSC with GGBS as a 60% cement replacement material had compressive and splitting tensile strengths of 25 and 2.3 MPa, respectively, which were higher than the minimum stated strength required for lightweight structural concrete.

Mannan et al. (2006) investigated several pre-treatment techniques for increasing the quality of OPS aggregates to achieve higher OPSC strength. Their techniques were comparable to how wood is treated with preservatives. The authors achieved OPS concrete with compressive strength of 33 MPa, around 39% greater than the control concrete (with untreated OPS aggregate). However, no specific grading of OPS is recorded. Similarly, Nadh et al. (2021) also found that OPSC prepared with treated OPS exhibited higher strength than concrete with untreated OPS. Besides, the SEM images showed fewer gaps between the treated OPS and the cement matrix, which refer to better bonding between the constituents of the concrete.

The literature shows that several investigations on OPSC have been conducted, particularly for lightweight structures. However, there was insufficient information about the effect of grading the OPS particles on the mechanical characteristics, permeability, unit weight, and other attributes of the OPSC when utilized as a partial replacement for the fine aggregates. Studies mainly focused on the impacts of OPS content, the pre-treatment methods, curing conditions, and adding supplementary cementitious materials like the GGBS and fly ash.

The grading of the particles is one of the most important factors in evaluating the sand's quality. It directly impacts workability and paste requirements and may have an economic impact. Guan et al. (2020) reported that the size of sand particles significantly affects the strength and permeability of concrete.

The novelty of this work is to study the effect of OPS percentage and grading on the engineering properties of the concrete using this by-product as a partial replacement for the sand. Hence, the impact of OPS percentage and grading on various properties of OPSC was examined and compared with the control mix prepared with normal sand. The proportions of OPS with sizes ranging between 600μm to 4.75mm (L), 300μm to 1.18mm (M), and of less than 600μm (S) were used to form three categories of gradings.

MATERIALS AND METHOD

Materials

Cement, OPS, water, and aggregates produce concrete. All materials are carefully selected in accordance with the rules of practice that apply to all materials. Ordinary Portland Cement (OPC) is used to produce the samples, which are widely available locally. The coarse aggregates used in this research were with a maximum size of 10mm and a specific gravity of 2.7, while the specific gravity of the fine aggregates was 2.58. For this research, the OPS is sieved using a shaker machine according to their respective ranges of sizes of 600µm to 4.75mm, 300µm to 1.18mm, and less than 600µm forming three categories of gradings. The water absorption and the specific gravity of OPS were 25.31% and 1.14, respectively.

Mix Proportions and Preparation of Concrete

Seven batches of concrete mixtures were prepared. Variables in each mix are the percentage of OPS replacement, which are 25% and 50%, and the particle size of the OPS, between 600µm to 4.75mm, 300µm to 1.18mm, and of less than 600µm. The description of each batch of concrete is tabulated in Table 1.

The proportion of the coarse aggregates, fine aggregate, cement, and water is determined using British Mix Design Method (DOE Method) with a design concrete characteristic strength at 28 days is 30 N/mm^2, while the target slump height is in the range of 30mm to 60mm. Table 1 displays the mixed proportions of concrete materials with various ratios of sand replacement in OPS concrete. The 0% replacement is the control sample.

In the mixing process, the aggregates and the OPS were dry mixed for 4 minutes, and then the OPC was added and mixed for another 3 minutes. After that, the required water was added and mixed for 6 min before being poured into oiled moulds and vibrating. In total, more than 200 cubes, cylinders, and prisms were made using different batches of

Table 1
Mix Proportions in kg/m^3

Mix ID	OPS percentage %	Range of OPS particle size	Cement	Water	Coarse aggregate	Sand	OPS
OPSC 0	0	-	390	230	1130	660	0
OPSC L25	25	600µm to 4.75mm	390	230	1130	495	165
OPSC M25	25	300µm to 1.18mm	390	230	1130	495	165
OPSC S25	25	less than 600µm	390	230	1130	495	165
OPSC L50	50	600µm to 4.75mm	390	230	1130	330	330
OPSC M50	50	300µm to 1.18mm	390	230	1130	330	330
OPSC S50	50	less than 600µm	390	230	1130	330	330

concrete. Three repetitive samples were prepared for each test, and average testing results were calculated.

Sample Preparations

A total of 63 concrete cubes with dimensions of 100 mm were prepared to determine the compressive strength at 7, 28, and 56 days. For the tensile strength, sorptivity, and chloride tests, 84 concrete cylinders with dimensions of 100 mm × 200 mm were prepared. Furthermore, 21 concrete prism beams of 100 mm × 100 mm × 500 mm dimensions were cast for flexural strength test at 28 days. In order to determine the water penetration depth under pressure at 28 and 56 days, 56 big cubes of 150mm dimensions were also prepared.

Test Method

The workability of the fresh concrete was performed using the slump test according to ASTM C1437, as displayed in Figure 1(a). The compressive, flexural, and tensile strength tests were conducted following BS EN 12390-3 (2009), BS EN 12390-5 (2009) BS EN 12390-6 (2009), respectively, as shown in Figures 1(b), 1(c) and 1(d). For the Non-Destructive Tests (NDT), the UPV and the rebound hammer tests were performed according to ASTM C597-09 (2010) and ASTM C 805-02 (2002) guidelines, respectively, as presented in Figures 1(e) and 1(f). For the durability properties, BS EN 12390-8 (2009), ASTM C1585-13 (2013), and ASTM C1202 (2012) were followed to conduct the water penetration, sorptivity, and rapid chloride permeability test (RCPT) tests, respectively, as shown in Figures 1(g) and 1(h).

RESULTS AND DISCUSSION

Slump

The slump test is used to examine the fresh concrete's consistency and workability. The slump is set to fall from 30mm to 60mm. The slump height of various mixtures is presented in Figure 2. The inclusion of OPS in the mixtures decreased the workability by 34%. The slump height of the mixes containing OPS decreased gradually with increasing OPS percentage; however, including finer particles of OPS increased the slump.

The percentage of sand replacement in concrete with OPS influences the slump height. The highest slump of OPS concrete is 55 mm for the mixtures prepared with 25% OPS, while the lowest was obtained when the percentage of OPS increased to 50%. This trend might be associated with OPS's increased water absorption capacity when a higher amount is included in the mixtures. The decreasing slump height of OPS concrete with the increment in the OPS percentage is in line with Khan et al. (2016), who observed a decline of 44% in slump height of concrete with OPS when the percentage increased from 10% to 40%.

Figure 1. Test setup of (a) slump, (b) compressive strength, (c) flexural strength, (d) splitting tensile strength, (e) UPV, (f) rebound hammer, (g) water penetration, and (h) RCPT

The results also show that increasing the particle size of the OPS decreased the workability of the concrete mixtures. OPSC with smaller particle sizes (OPSC S25, OPSC, and S50) achieved a higher slump than OPSC with a larger particle size (OPSC L25 and OPSC L50) of all percentages. It could be justified by the fact that decreasing the OPS particles increased the packing of concrete and decreased the amount of entrapped air.

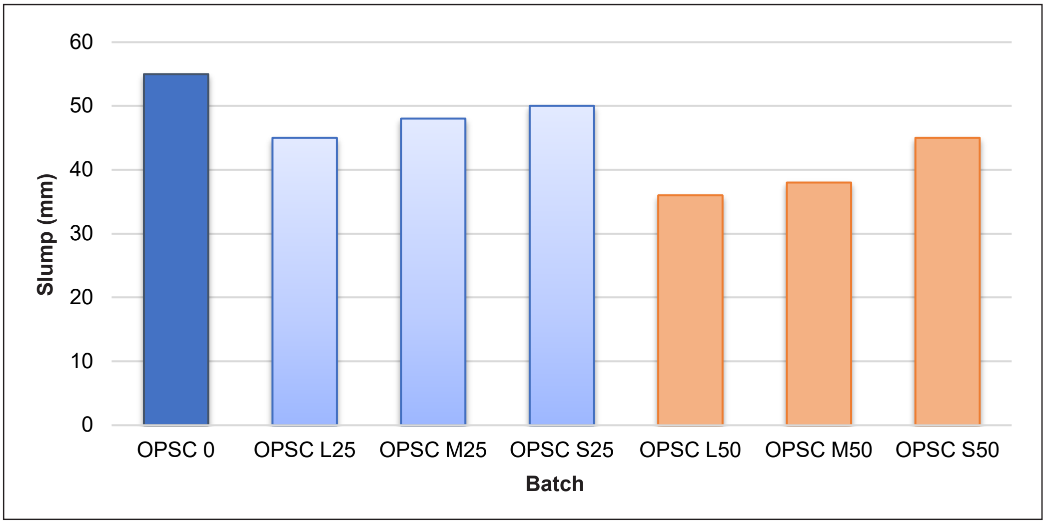

Figure 2. Slump height of concrete mixtures

Density

The density was measured by the dried density method. Concrete density is the ratio of weight to its unit volume. Concrete with a density of lower than 2000kg/m^3 is lightweight concrete (LWC), while concrete with a density of 2400 kg/m^3 is normal-weight concrete (NWC) (Teo et al., 2006). Figure 3 shows the average density of all concrete mixes at 28 days. The density of concrete decreased with the inclusion of OPS. Besides, increasing the percentage of OPS from 25% to 50% resulted in a higher reduction because the specific gravity of OPS is half of the sand, which is 1.14 and 2.58, respectively. Replacing the sand with OPS in concrete increased the void content of the mixture. Similar findings of density reduction were achieved by Babafemi & Olusola (2012), who reported that densities of concrete samples with 100% sand and 25% palm shell ranged between 2000 and 2400 kg/m^3, respectively classifying them as NWC. However, at 50%, 75%, and 100% palm shell replacement levels, the density values were between 1340 and 1900 kg/m^3, classifying them as LWC.

Figure 3 shows that the concrete changed from NWC for 25% OPS concrete to LWC for 50% OPS concrete due to the higher percentage of OPS with low specific gravity and higher porosities.

In terms of the grading effect, the findings show that increasing the particle size of the OPS decreased the density of the OPSC mixtures. OPSC with smaller particle sizes, OPSC M25, and OPSC S25 are considered NWC, while the other mixes are categorized as LWC. The lower density of OPSC with larger particles could be attributed to the air-entrapping impact, causing the formation of tiny air bubbles in the concrete structure (Abbas et al., 2022).

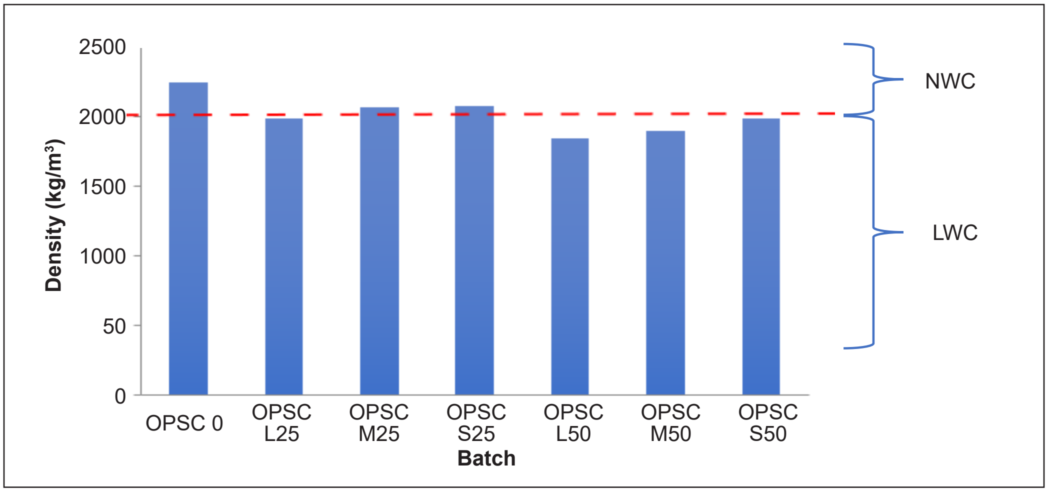

Figure 3. Average concrete density at 28 days

Compressive Strength

The average compressive strength of mixes is presented in Figure 4. The control specimen (OPSC 0) achieved the design concrete compressive strength of 30 MPa. The strength of concrete increases as the days of curing increase, except two mixtures exhibited a decrease in strength at 56 days compared to their values in 28 days, which are OPSC M50 and OPSC S50 mixes. The dimensional instability due to the high water absorption capacity of the OPS particles during curing contributes to this strength loss. It is evidenced by the high water absorption of OPS found in this study, which was 25.31%. As a result, the bond strength between OPS and the surrounding concrete matrix is weakened (Momoh & Osofero, 2019).

The compressive strength of OPSC is lower than the control sample at all testing ages. Also, an increasing percentage of OPS as a sand replacement caused a higher reduction in strength. A similar trend has been reported by other researchers (Muthusamy et al., 2013), confirming the best performance of concrete with 25% OPS. Mannan & Ganapathy (2002) also reported that the compressive strength development in concrete mixtures prepared with OPS was almost 49%–55% lower than in the reference sample. The compressive strength is affected by porosity. The OPS concrete showed a lower density (Figure 3), indicating a larger porosity than the control concrete, thus, lower compressive strength.

Figure 4 also shows that increasing the OPS particle size at both replacement percentages decreased the OPS compressive strength of the OPSC. The OPSC with finer particle size achieved higher compressive strength at all ages (OPSC S25 and OPSC S50). It could be attributed to finer particles' better filling and packing features (Lim et al., 2013). For OPSC with 25% of sand replacement, the compressive strength of OPSC S25 is the highest, while the compressive strength of OPSC L25 is the lowest. A similar trend for OPSC with 50% sand replacement can be observed.

In this research, all batches of OPSC with 25% sand replacement achieved the minimum structural concrete compressive strength of 17 MPa. While for OPS concrete with 50% sand replacement, the compressive strength of OPSC M50 and OPSC S50 is higher than 17 MPa. Only OPSC L50 does not achieve the minimum structural concrete compressive strength.

Thus, these findings indicate that the value of the compressive strength of OPSC highly depends on the percentage of the OPS in the mixtures in addition to the OPS particle size. The maximum amount of sand replacement in OPS concrete while achieving the structural concrete compressive strength is 50%, provided that small OPS particle sizes are used.

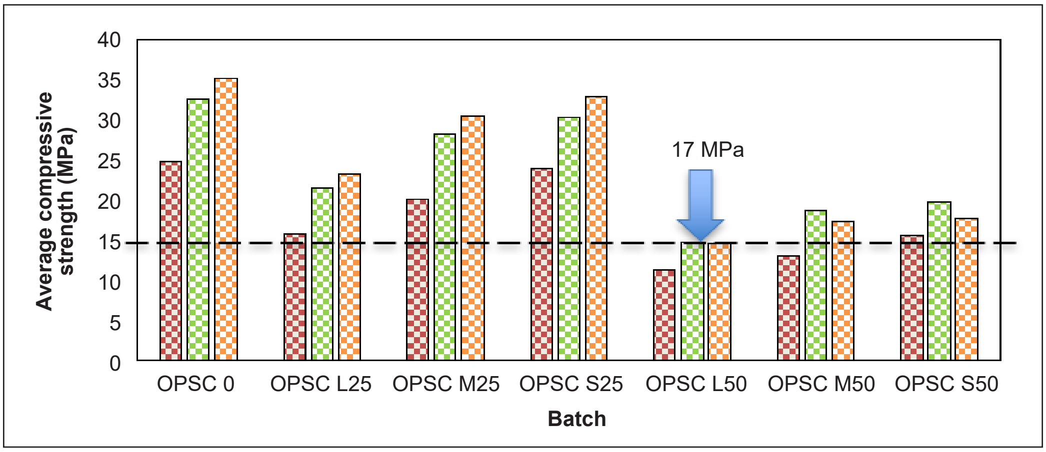

Figure 4: Average concrete compressive strength

The results are also analyzed by a two-way Analysis of Variance (ANOVA). The analysis used the composite strength as the dependent variable during the OPS and time as the explanatory variable. This statistical technique examined the effect of OPS and time and their interaction on the composite strength. An interaction effect happens when one explanatory variable's effect relies on another's level. Additionally, a post hoc Tukey test was utilized to detect significant differences between the levels of explanatory variables. The analysis results are in Table 2, indicating significant main effects of both the OPS and time on the composite strength at the significance level of 0.05. Also, a significant interaction effect was found between the OPS and time, suggesting that the differences in the effect of OPS depend on time (Figure 5).

Table 2
The effects of OPS and time on the composite strength

Source	Sum of Squares	Degree of Freedom	Mean Square	F-value	Level of Significance
OPS	2406.77	6	401.13	199.53	P < 0.01
TIME	548.75	2	274.38	136.48	P < 0.01
OPS*TIME	104.01	12	8.67	4.31	P < 0.01

The boxplot in Figure 6 shows no significant difference between OPSC0 and OPSCS25, as well as between OPSCM50 and OPSCS50. The boxplot indicates 28 days has no significant difference compared to 56 days (Figure 7). The post hoc Tukey test also supports these results. It means replacing 25% of 600µm fine particles of sand with OPS and 50% of less than 600µm to 1.18mm sand particles with OPS gives no significant differences in strength. It also proves that replacing 25% of sand with small particles of OPS will give similar strength. While at 50% replacement, small and medium particles of OPS give the same reduction effect to the strength.

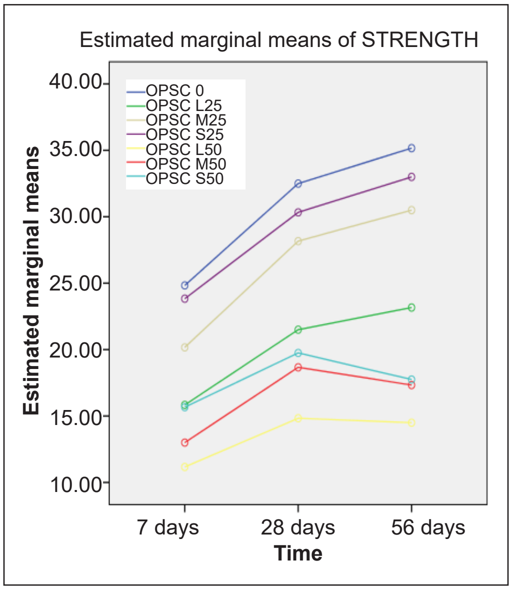

Figure 5. Interaction effect between OPS and time

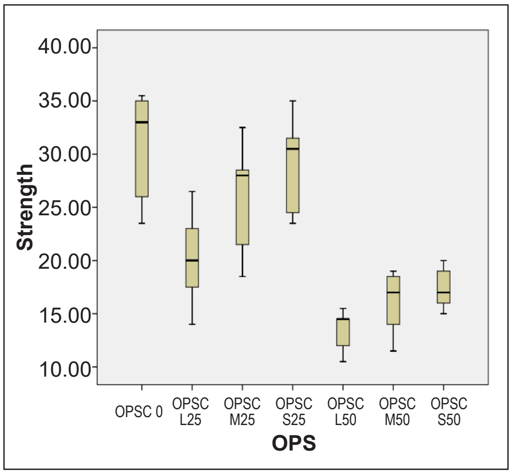

Figure 6. Boxplot of composite strength against OPS

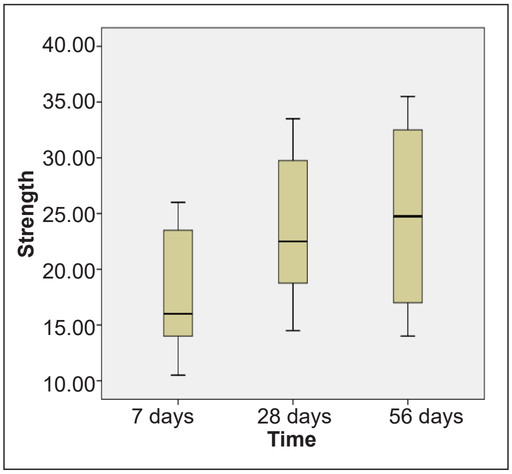

Figure 7. Boxplot of composite strength against time

Splitting Tensile Strength

The average splitting tensile strength is shown in Figure 8, and the relative changes in the strength of other concrete mixes than the control mixture are presented in Table 3. The results show that the tensile strength values range from 1.50–2.75 MPa. Besides, the samples containing OPS exhibited a loss in tensile strength ranging from 12% to 45% than that of the control sample (Table 3).

Similar to compressive strength results, including the OPS in the concrete mixtures decreased the tensile strength of the concrete. The tensile strength of OPSC S25 was close to that of the control specimen, which was 2.42 MPa. At the same time, the concrete samples containing 50% OPS recorded the lowest splitting tensile strength of 1.50 MPa. The reduction in strength is due to the porous nature of OPS that allows micro-cracks to spread during testing; hence lower strength is recorded (Karakoç et al., 2016). Alengaram et al. (2010) also reported that the concrete samples prepared with OPS achieved 30% lower tensile strength than that prepared with normal aggregates. The authors attributed the strength reduction to the weaker bond between the OPS particles and the concrete matrix.

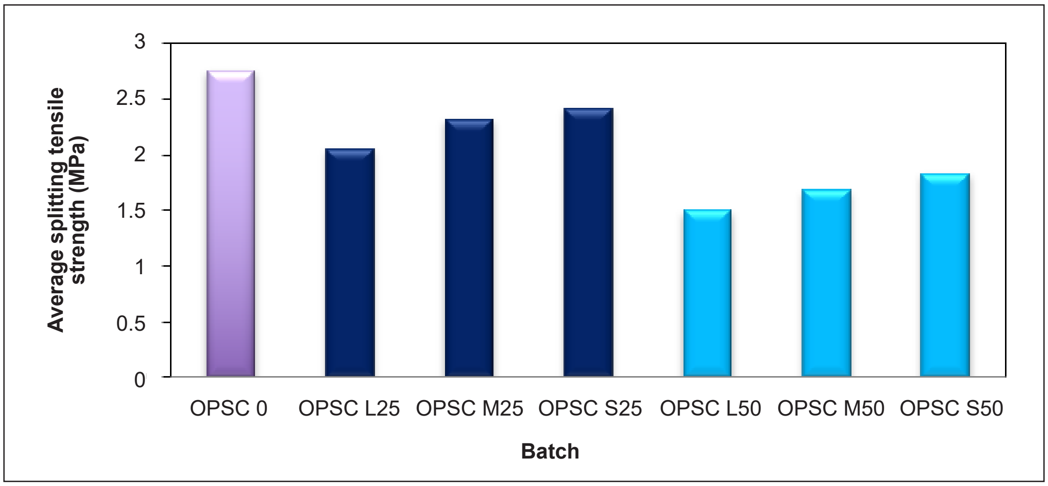

Figure 8. Average splitting tensile strength at 28 days

Table 3
Relative change in compressive, splitting tensile and flexural strength of concrete mixes

Batch	Compressive strength (MPa)	Splitting Tensile Strength (MPa)	Flexural Strength (MPa)
OPSC 0	32.5 (-)	2.75 (-)	4.6 (-)
OPSC L25	21.5 (-33.8%)	2.05 (-25%)	3.47 (-24.5%)
OPSC M25	28.17 (-13.3%)	2.32 (-15.6)	3.8 (-17%)
OPSC S25	30.33 (-6.6%)	2.42 (-12%)	4.2 (8.6)
OPSC L50	14.67 (-54.8%)	1.5 (-45%)	2.57 (-44%)
OPSC M50	18.67 (-42.5%)	1.68 (-38%)	2.8 (-39%)
OPSC S50	19.83 (-38.9)	1.83 (-33.4)	3.27 (-28%)

The results also show that decreasing the particle size of OPS enhanced the tensile strength for both percentages of OPS. For OPS concrete with 25% of sand replacement, OPSC S25 gained the highest splitting tensile strength with a strength reduction of 12%, while the OPSC L25 achieved the lowest splitting tensile strength and highest strength reduction of about 25%. OPS concrete with 50% sand replacement demonstrated a similar pattern. Hence, it shows that higher splitting tensile strength can be achieved when a smaller particle size of OPS is used in concrete.

Flexural Strength

The flexural strength of different concrete mixes is presented in Figure 9. The results show that replacing sand with OPS decreased the flexural strength of concrete, and increasing the OPS percentage caused a further reduction. A reduction of about 8.6%–24.5% and 28.9%–44.0% are recorded when 25% and 50% of OPS were included, respectively, as presented in Table 3 above. Although OPSC S50 has double the amount of sand replacement than OPSC S25, the strength reduction is three times higher, 28% and 8.6%, respectively. At the same time, the flexural strength reduction of OPSC M50 is 39% which is two times lower than OPSC M25 of 17%. The strength reduction is due to the weak interfacial bond between the binder and the OPS when a higher percentage of OPS is included in the mixture. As a result, flexural load-initiated cracks in the weaker location at the interfacial zone, resulting in flexural failure.

From the aspect of the OPS particle sizes, the results indicate that decreasing the particle size of the OPS increased the flexural strength by 21% and 27.23% for OPS with 25% OPS and 50% OPS concrete, respectively, for concrete samples prepared with 25% OPS, the highest value of flexural strength is attained by OPSC S25, which is 4.20 MPa,

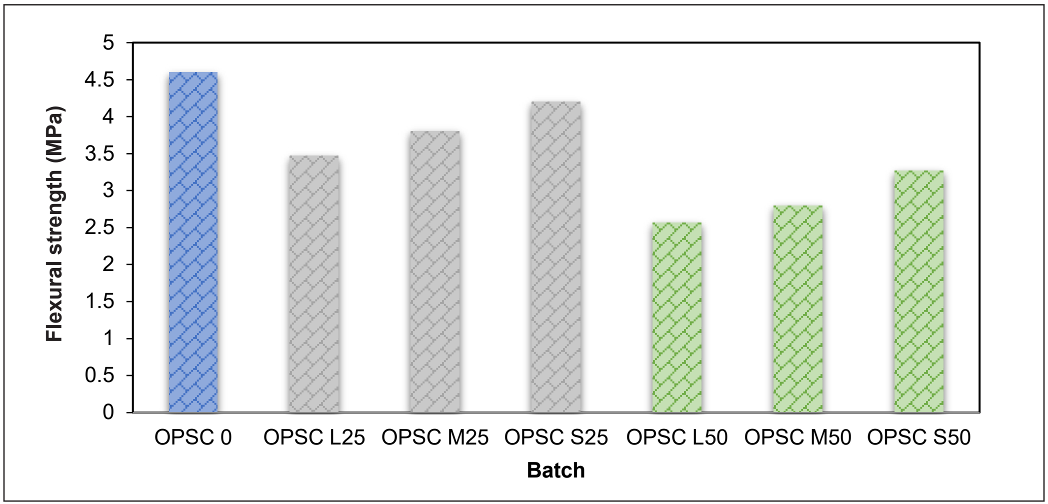

Figure 9. Average flexural strength at 28 days

while OPSC L25 achieved the lowest flexural strength, with a value of 3.47 MPa. OPS concrete with 50% sand replacement demonstrated a similar trend. The smaller particle of OPS in concrete can bond more effectively with the other concrete materials, which in turn aids in increasing the concrete flexural strength for resisting the applied tension. Thus, the smaller particle sizes of OPS are suitable for replacing sand in concrete as it does not reduce flexural strength.

Ultrasonic Pulse Velocity (UPV)

Ultrasonic Pulse Velocity (UPV) test is conducted to evaluate the quality of concrete, including its uniformity and the presence of cracks. Figure 10 displays the average UPV readings of specimens at 28 days. The results show that all the mixes are good quality concrete with UPV values between 3650m/s–4099m/s (Awal & Mohammadhosseini, 2016). Using OPS to replace the sand has decreased the UPV values of the samples. The replacement of sand with 25% of fine OPS (OPSC S25) produces an insignificant impact on the UPV results of less than 6%. Hence, it shows that decreasing the particle size of OPS impacts compactness positively and increases the UPV values to a certain percentage. OPSC S25 and OPSC M25 attained UPV of 4288m/s and 4245m/s, respectively, which are very close to the control sample.

However, further increases in the OPS percentage to 50% decreased the UPV values. This reduction in velocity is often attributed to the presence of microcracks in the samples, which decrease the homogeneity of the concrete. Besides, the porous features of OPS aggregate that are unable to create a good bond with the binder for the development of a highly packed concrete structure contribute to the reduction of UPV readings. The lack

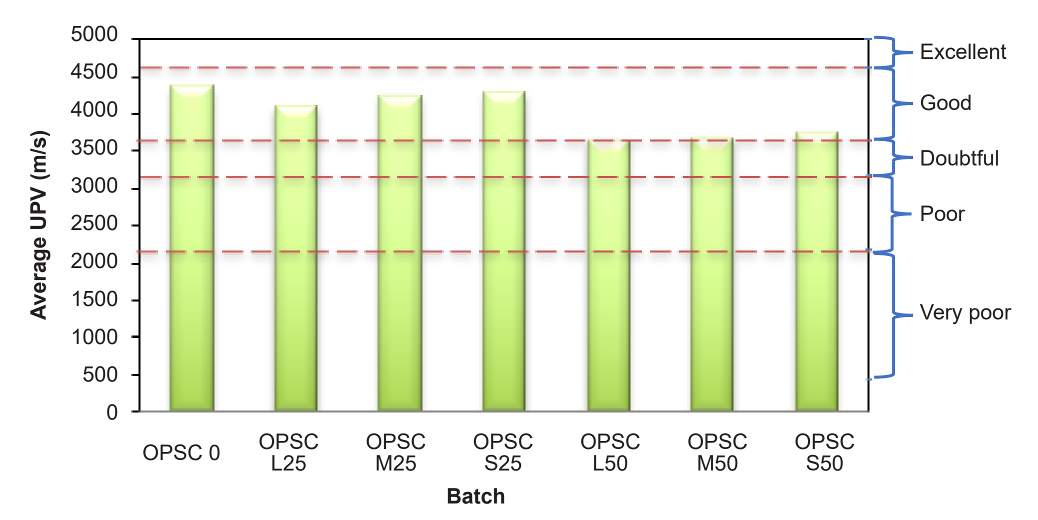

Figure 10. Average UPV of concrete at 28 days

of a strong interlocking action results in the formation of voids has resulted in a reduced pulse travel rate of UPV. Figure 11 displays the correlation between compressive strength and UPV, showing an average coefficient (R^2) of 0.89.

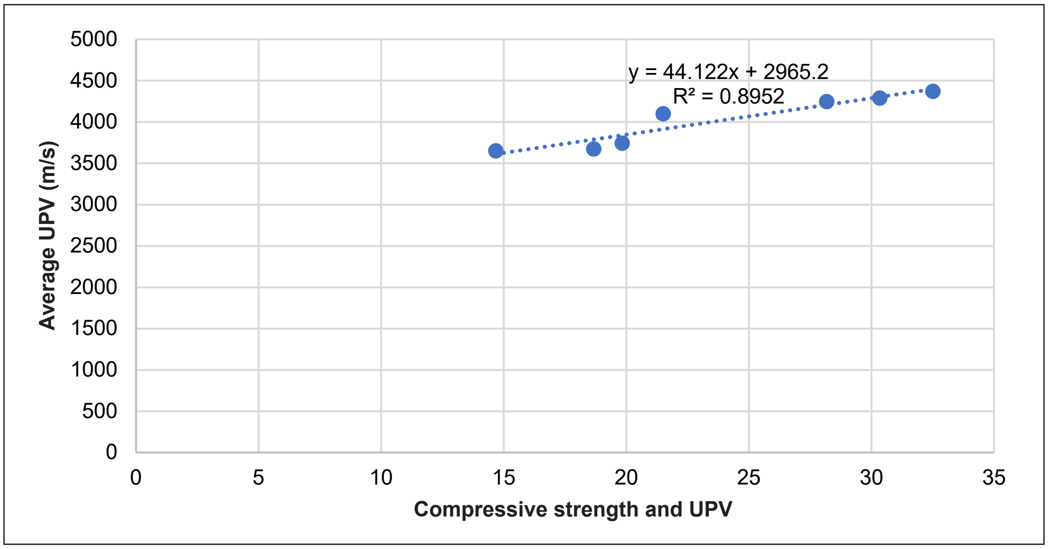

Figure 11. Relationship between compressive strength and UPV

Rebound Number

The other NDT test for concrete is the rebound hammer, tested to evaluate the concrete uniformity and quality in terms of its surface hardness at 28 days. The findings are illustrated in Figure 12. The OPS concrete displayed a lower rebound number than the control sample. Besides, the rebound number of OPSC concrete with 25% sand replacement ranges from 24 to 29, while samples with 50% OPSC range from 18 to 23.

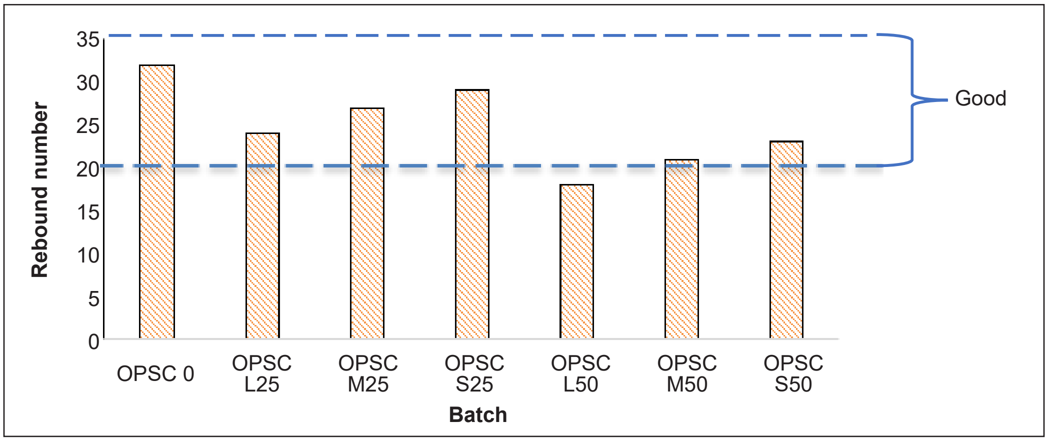

Figure 12. Average rebound number of concretes at 28 days

When smaller particle sizes of OPS are used, concrete density is higher, producing higher surface hardness concrete, i.e., rebound number. It is also observed that smooth surfaces of OPS affected the bonding between the cement matrix and OPS, which increased the porosity and reduced the surface hardness, i.e., the rebound number of concretes. The results show that all mixes attained higher than 20, an average rebound number accepted for structural application, except OPSC L50, which is 18.

The correlation of rebound number, UPV, and compressive strength is illustrated in Figure 13. The rebound number exhibits a positive relationship with compressive strength and UPV. It is also observed that the concrete compressive strength evaluated through the rebound hammer test is lower than the compressive strength measured through the compressive strength test. The percentage difference between the compressive strength values measured through the rebound hammer test and the compressive strength test is shown in Table 4. The differences between the compressive strength values measured from

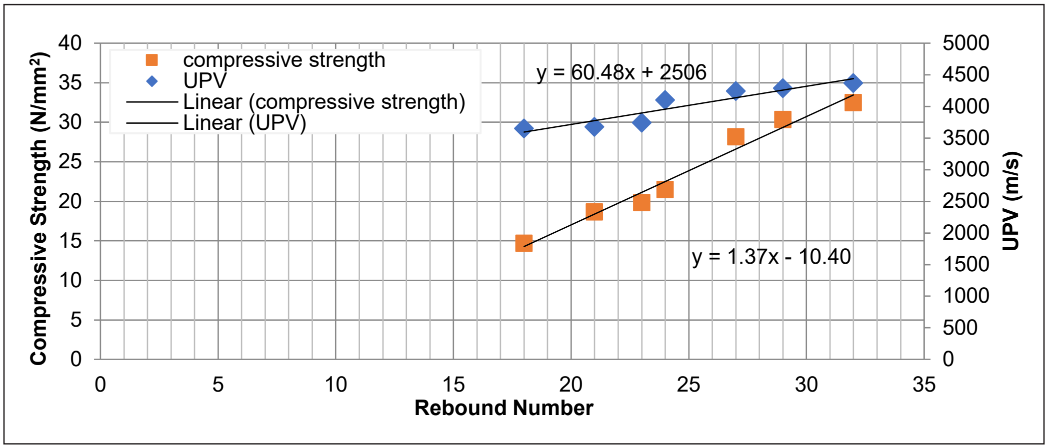

Figure 13. Correlation of rebound number with compressive strength and UPV

Table 4
Percentage difference of the compressive strength measured through rebound hammer test and compressive strength test

Batch	Average compressive strength measured from rebound hammer test (N/mm²)	Average compressive strength measured from compressive strength test (N/ mm²)	Percentage difference between both tests (%)
OPSC 0	30.33	32.50	6.67
OPSC L25	18.67	21.50	13.16
OPSC M25	23.66	28.17	16.01
OPSC S25	27.66	30.33	8.80
OPSC L50	<15	14.67	-
OPSC M50	15.67	18.67	16.07
OPSC S50	18.00	19.83	9.23

both tests range from 6.67% to 16.07%. The average compressive strength of concrete estimated through the rebound hammer correlation curves is lower than its actual value. However, the rebound hammer test still serves as a quick method to assess the concrete compressive strength, where concrete with a higher rebound number indicates that the concrete has a higher surface hardness. Hence, it can resist a higher amount of compressive force without failure.

Water Penetration Depth

The strength of concrete predominantly relies on the water capacity to infiltrate the solid microstructure, also known as permeability (Manjunath et al., 2019). The findings of water penetration depth under the pressure of the OPSC 0, concrete with 25% and 50% of OPS after 28 and 56 days are presented in Figure 14. All concrete show a similar trend: the water penetration depth increases from the 28th to the 56th day. The comparison of values indicates that the lowest penetration depth is obtained in the control specimens, and the penetration depth increases with increasing the percentage of OPS.

At 28 days, the control sample OPSC 0 and OPSC S25 obtained the lowest penetration depth of 31mm and 33mm, respectively. As the OPS replacement percentages increased, the water penetration depth increased. Higher percentages of OPS are associated with larger interconnected pores that produce a high surface area and allow more water penetration, and this effect is observed to be more severe with increasing time. Khan et al. (2016) found a similar phenomenon for concrete containing OPS, where increasing the OPS percentage from 10% to 40% as coarse aggregate replacement increased the water absorption of the concrete from 1.48% to 4.75%.

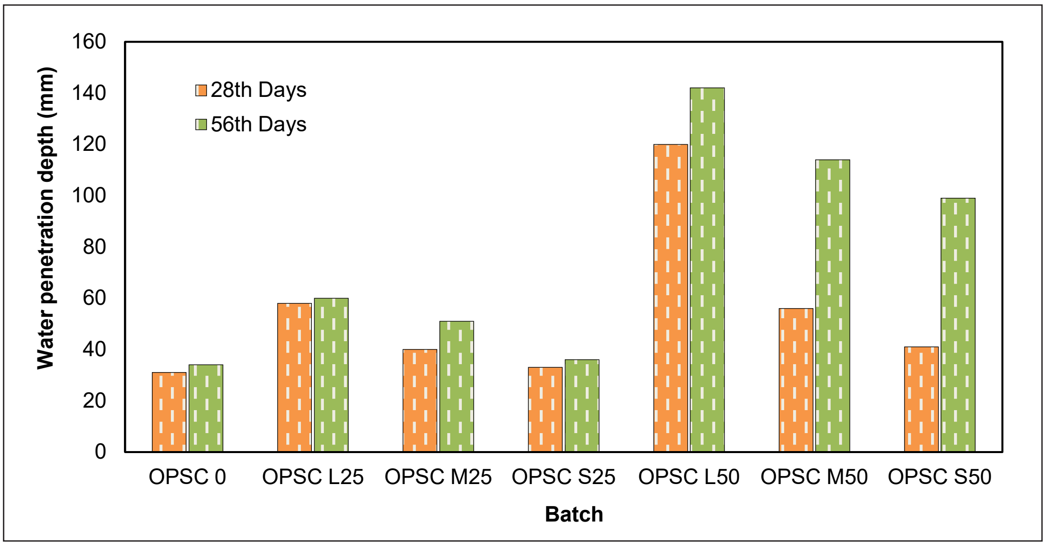

Figure 14. Water penetration test at 28 days and 56 days

In terms of OPS particle size, decreasing the particle size of OPS leads to better results in terms of water penetration. For the 25% replacement of OPS, the values of depth obtained for the sizes OPSC S25, OPSC M25, and OPSC L25 are 33mm, 40mm, and 58mm, respectively, while for the 56th day, the depths were 36mm, 51mm, and 60mm respectively. It could be attributed to the enhanced packing of OPS concrete with finer particle size. The 50% replacement of sand with OPS shows poor bonding between OPS and the matrix, allowing more water to penetrate the sample. It also witnesses more voids forming between the particles and cement matrix, hence providing a higher level of water permeability, as shown in Figure 14.

Sorptivity Test

One of the essential characteristics that determine the durability of concrete is the sorptivity (rate of water absorption), which refers to the ability of concrete to absorb and transmit water and other fluids by capillarity action. The sorptivity results after 28 and 56 days are displayed in Figures 15 and 16, respectively.

The results demonstrated that concrete samples prepared with OPS showed a higher water absorption rate than the control sample. Besides, the mixes prepared with 25% OPS exhibited lower water absorption than that with 50% OPS at the same grading, which aligns with the findings obtained from the water permeability test. The sorptivity levels for both produced a slight increase trend when time increased. Mannan and Ganapathy (2002) observed a similar pattern: the OPS mixes showed higher water absorption capacity than the control sample. The authors concluded that this behavior is due to the high absorption capacity of OPS particles, which increased the porosity of the concrete sample.

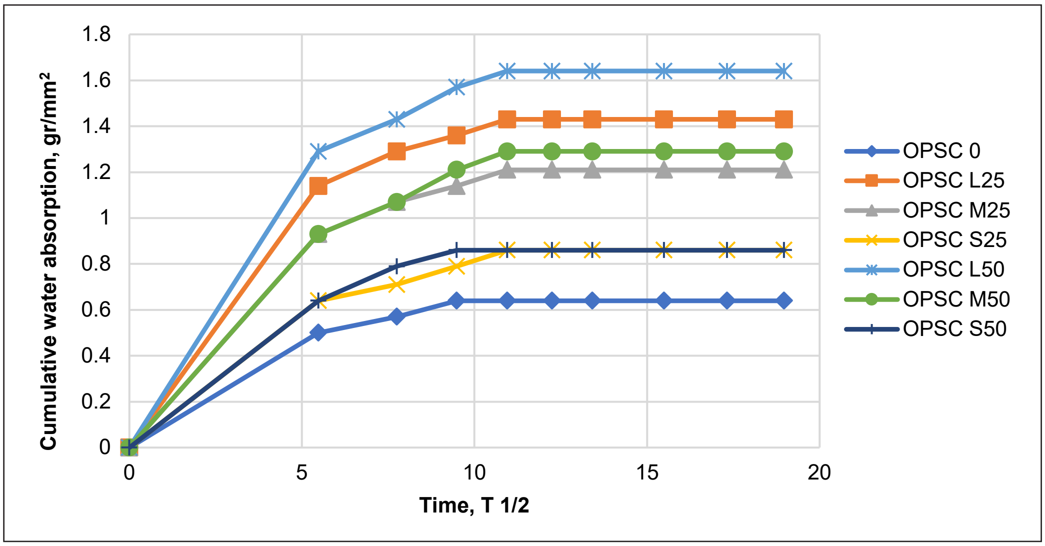

Figure 15. Water absorption versus square root of time at 28 days

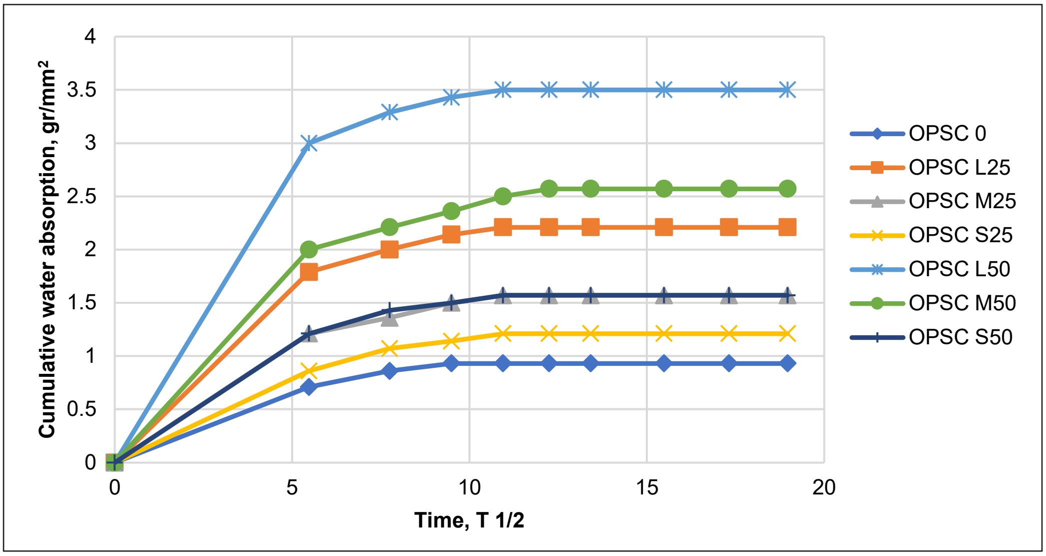

Figure 16. Water absorption versus square root of time at 56 days

The sorptivity level for OPSC M25 and OPSC L25 is higher than that of OPSC S25. It shows that when the size range increases, the sorptivity level also increases. It is similar to the results by Teo et al. (2007). According to Figure 16, the rate of water absorption at 56 days was similar to the results of 28 days for 25% and 50% OPS replacements. The sorptivity level for all mixes slightly increased until 120 minutes and remained constant afterward. The sorptivity level for OPS concrete with larger particle sizes was greater than those with smaller particles for both percentages of OPS. The lowest value of sorptivity level was achieved by using finer particles of OPS at both ages.

Rapid Chloride Permeability Test

The RCPT findings of concrete mixtures are shown in Figure 17. The chloride resistance of concrete decreased when the sand was partially replaced by the OPS, especially with using 50% of OPS. It is due to the increase in the internal connectivity of voids and capillary porosity in concrete produced with OPS.

Decreasing the particle size of OPS for both percentages showed about a 13% decrease in the total charge passed through the samples. OPSC S25, OPSC M25, and OPSC L25 produced a charge of 2593, 2684, and 2729 coulombs, respectively. A similar trend has also been observed for 50% OPS concrete. This result indicates that the smaller particles of OPS have lower permeability because the matrix became well connected and produced more compact concrete, so the current passed through the concrete decreased. While for OPSC L25, the current increased because it contains high levels of porosity. The level of chloride ions in concrete depends on the internal pore structure (Joshi & Chan, 2002). Factors such as mixed design, construction methods, and hydration conditions can increase the pores in concretes. As discussed earlier in slump test results, the lowest quality of concrete consists of more pores and porosity levels. Therefore, a bigger range of 600µm–4.75mm size observed a high level of chloride permeability.

All the concrete mixtures used in this research are classified as moderate chloride ion permeability concrete (Akid et al., 2021). From the studies by Stanish et al. (1997), the lower the quality of concrete, the greater the current passed at a given voltage to the concretes. Thus, this shows the greater heat energy produced in the lowest quality concrete, which consists of the OPS range for a larger size of 600µm–4.75mm.

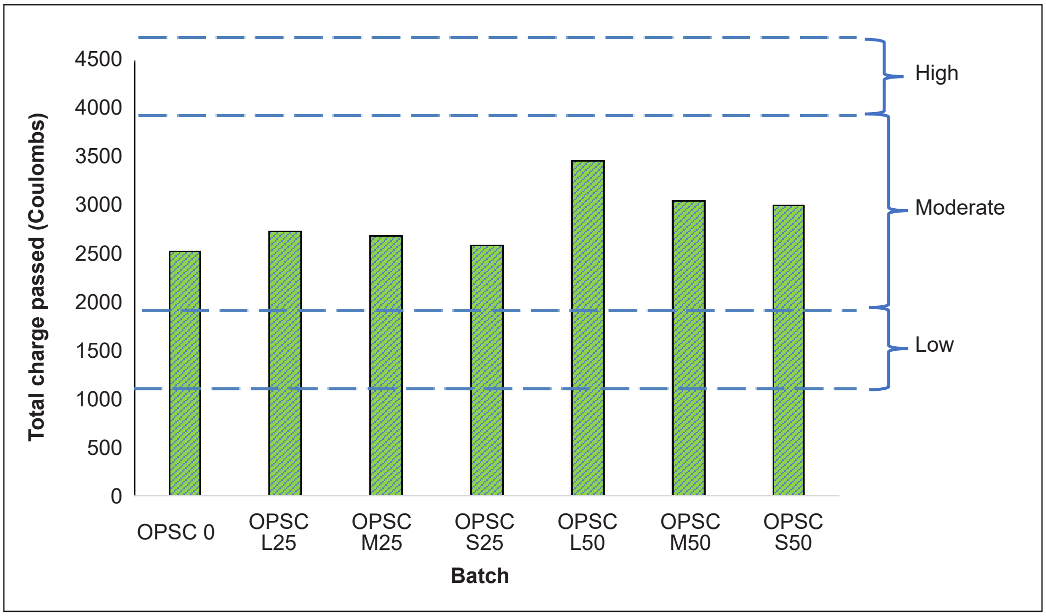

Figure 17. RCPT results of concrete mixes

CONCLUSION

Based on the experimental investigation, the following conclusion can be derived:

1. The partial replacement of the sand with the OPS decreased the workability of the concrete. Moreover, this reduction was higher for the samples containing larger particle sizes of OPS.
2. Increasing the OPS percentages and its particle size decreased the density of the concrete. OPS concrete with 0% and 25% sand replacement can be classified as normal weight concrete (NWC), while OPS concrete with 50% sand replacement is categorized as lightweight concrete (LWC). A higher density is achieved when a smaller particle size of OPS is used.

3. OPS concrete has a lower compressive strength than that of the control samples. However, the reduction in the strength can be overcome by including finer OPS particles due to the better compaction of the samples. OPSC S25 mix achieved a compressive strength of 30.33 MPa at 28 days, which was very close to the strength of the control sample.
4. The partial replacement of the sand with the OPS reduced the performance of concrete under the flexural and tensile loads. However, decreasing the particle size of the OPS increased the tensile and flexural strength by 18% and 17.38%, respectively, for OPS by 25% OPS. OPSC L50 achieved the lowest concrete tensile and flexural strengths of 1.5 and 2.57 MPa, respectively.
5. The UPV results indicate that all OPS mixes are characterized as good quality concrete with UPV values between 3650m/s–4099m/s.
6. The concrete with bigger particles with higher OPS percentage has more penetration depth. The sorptivity level also increased gradually when the dosage and size range increased.
7. All the OPS concretes are classified as moderate chloride ion permeability in 28 days. Decreasing the particle sizes and percentages of OPS improved the chloride resistance, and the lowest chloride permeability was achieved by using 25% OPS with a particle size of less than 600µ.

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REFERENCES

Akid, A. S. M, Hossain, S., Munshi, M. I. U., Elahi, M. M. A., Sobuz, M. H. R., Tam, V. W. Y., & Islam, M. S. (2021). Assessing the influence of fly ash and polypropylene fiber on fresh, mechanical and durability properties of concrete. *Journal of King Saud University - Engineering Sciences*, *33*, 1-11. https://doi.org/10.1016/j.jksues.2021.06.005

Abbas, A. G. N., Aziz, F. N. A. A., Abdan, K., Nasir, N. A. M., & Huseien, G. F. (2022). A state-of-the-art review on fibre-reinforced geopolymer composites. *Construction and Building Materials*, *330*, Article 127187. https://doi.org/10.1016/j.conbuildmat.2022.127187

Alengaram, U. J., Mahmud, H., & Jumaat, M. Z. (2010). Comparison of mechanical and bond properties of oil palm kernel shell concrete with normal weight concrete. *International Journal of Physical Sciences*, *5*(8), 1231-1239.

ASTM C 805-02. (2002). *Standard test method for rebound number of hardened concrete C 805.* United States: American Society for Testing and Material. https://www.academia.edu/14787775/Standard_Test_Method_for_Rebound_Number_of_Hardened_Concrete

ASTM C1202. (2012). *Standard test method for electrical indication of concrete's ability to resist chloride ion penetration*. American Society for Testing and Materials https://doi.org/10.1520/C1202-12.2

ASTM C1585-13. (2013). Standard test method for measurement of rate of absorption of water by hydraulic cement concretes. *ASTM International*, *41*(147), 1-6. https://doi.org/10.1520/C158513.2

ASTM C597-09. (2010). *Standard test method for pulse velocity through concrete*. *Annual Book of ASTM Standards*. American Society for Testing and Materials. https://www.studocu.com/row/document/dogu-akdeniz-universitesi/civil-engineering/kupdfnet-astm-c-597-02-ultrasonic-pulse-velocity/36387906

Awal, A. S. M. A., & Mohammadhosseini, H. (2016). Green concrete production incorporating waste carpet fiber and palm oil fuel ash. *Journal of Cleaner Production*, *137*, 157-166. https://doi.org/10.1016/j.jclepro.2016.06.162

Babafemi, A. J., & Olusola, K. O. (2012). Influence of curing media on the compressive strength of Palm Kernel Shell (PKS) concrete. *International Journal of Recent Research and Applied Studies*, *13*(1), 180-185.

BS EN 12390-3. (2009). *Testing hardened concrete - Part 3 : Compressive strength of test specimens*. https://www.thenbs.com/PublicationIndex/documents/details?Pub=BSI&DocID=288816

BS EN 12390-5. (2009). *Testing hardened concrete - Part 5 : Flexural strength of test specimens*. https://kupdf.net/download/bs-en-12390-5-2009-part-5-flexural-strength-of-test-specimens_58caa120dc0d60ab1033902f_pdf

BS EN 12390-6. (2009). *Testing hardened concrete - Part 6 : Tensile splitting strength of test specimens*. https://pdfcoffee.com/bs-en-12390-6-2009-testing-hardened-concrete-part-6-tensile-splitting-strength-of-test-specimens-pdf-free.html

BS EN 12390-8. (2009). *Testing hardened concrete - Part8: Depth of penetration of water under pressure*. British Standard. https://pdfcoffee.com/bs-en-12390-8-3-pdf-free.html

Guan, W., Qi, Q., Zhang, Z., & Nan, S. (2020). Effect of sand particle size on microstructure and mechanical properties of gypsum-cemented similar materials. *Materials*, *13*(3), 1-16. https://doi.org/10.3390/ma13030765

Huda, M. N., Jumat, M. Z. Bin, & Islam, A. B. M. S. (2016). Flexural performance of reinforced oil palm shell & palm oil clinker concrete (PSCC) beam. *Construction and Building Materials*, *127*, 18-25. https://doi.org/10.1016/j.conbuildmat.2016.09.106

Joshi, P., & Chan, C. (2002). Rapid chloride permeability testing. *Concrete Construction - World of Concrete*, *47*(12), 37-43.

Karakoç, M. B., Türkmen, I., Maraş, M. M., Kantarci, F., & Demirboğa, R. (2016). Sulfate resistance of ferrochrome slag based geopolymer concrete. *Ceramics International*, *42*(1), 1254-1260. https://doi.org/10.1016/j.ceramint.2015.09.058

Khan, M. M. H., Guong Wei, L., Deepak, T. J., & Nair, S. (2016). Use of oil palm shell as replacement of coarse aggregate for investigating properties of concrete. *International Journal of Applied Engineering Research*, *11*(4), 2379-2383.

Lim, S. K., Tan, C. S., Chen, K. P., Lee, M. L., & Lee, W. P. (2013). Effect of different sand grading on strength properties of cement grout. *Construction and Building Materials*, *38*, 348-355. https://doi.org/10.1016/j.conbuildmat.2012.08.030

Maghfouri, M., Shafigh, P., & Aslam, M. (2018). Optimum oil palm shell content as coarse aggregate in concrete based on mechanical and durability properties. *Advances in Materials Science and Engineering*, *2018*, Article 4271497. https://doi.org/10.1155/2018/4271497

Manjunath, R., Narasimhan, M. C., & Umesha, K. M. (2019). Studies on high performance alkali activated slag concrete mixes subjected to aggressive environments and sustained elevated temperatures. *Construction and Building Materials*, *229*, Article 116887. https://doi.org/10.1016/j.conbuildmat.2019.116887

Mannan, M. A., Alexander, J., Ganapathy, C., & Teo, D. C. L. (2006). Quality improvement of oil palm shell (OPS) as coarse aggregate in lightweight concrete. *Building and Environment*, *41*(9), 1239-1242. https://doi.org/10.1016/j.buildenv.2005.05.018

Mannan, M. A., & Ganapathy, C. (2004). Concrete from an agricultural waste-oil palm shell (OPS). *Building and Environment*, *39*(4), 441-448. https://doi.org/10.1016/j.buildenv.2003.10.007

Mannan, M. A., & Ganapathy, C. U. (2002). Engineering properties of concrete with oil palm shell as coarse aggregate. *Construction and Building Materials*, *16*, 29-34. https://doi.org/10.1016/S0950-0618(01)00030-7

Mo, K. H., Alengaram, U. J., Jumaat, M. Z., & Yap, S. P. (2015). Feasibility study of high volume slag as cement replacement for sustainable structural lightweight oil palm shell concrete. *Journal of Cleaner Production*, *91*, 297-304. https://doi.org/10.1016/j.jclepro.2014.12.021

Mo, K. H., Yeoh, K. H., Bashar, I. I., Alengaram, U. J., & Jumaat, M. Z. (2017). Shear behaviour and mechanical properties of steel fibre-reinforced cement-based and geopolymer oil palm shell lightweight aggregate concrete. *Construction and Building Materials*, *148*, 369-375. https://doi.org/10.1016/j.conbuildmat.2017.05.017

Momoh, E. O., & Osofero, A. I. (2019). Behaviour of oil palm broom fibres (OPBF) reinforced concrete. *Construction and Building Materials*, *221*, 745-761. https://doi.org/10.1016/j.conbuildmat.2019.06.118

Muthusamy, K., Zulkepli, N. A., & Mat Yahaya, F. (2013). Exploratory study of oil palm shell as partial sand replacement in concrete. *Research Journal of Applied Sciences, Engineering and Technology*, *5*(7), 2372-2375. https://doi.org/10.19026/rjaset.5.4667

Nadh, V. S., Krishna, C., Natrayan, L., Kumar, K. M., Nitesh, K. J. N. S., Raja, G. B., & Paramasivam, P. (2021). Structural behavior of nanocoated oil palm shell as coarse aggregate in lightweight concrete. *Journal of Nanomaterials*, *2021*, Article 4741296. https://doi.org/10.1155/2021/4741296

Olanipekun, E. A., Olusola, K. O., & Ata, O. (2006). A comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates. *Building and Environment*, *41*(3), 297-301. https://doi.org/10.1016/j.buildenv.2005.01.029

Qasem, A. A., Almekhlafi, M. A., & Yahaya, F. M. (2021). The effect of palm oil fuel clinker powder and cockleshell powder as cement replacement on durability properties of the concrete mortar. *IOP Conference Series: Earth and Environmental Science*, *682*(1), Article 012037. https://doi.org/10.1088/1755-1315/682/1/012037

Rahman, F. F., Prakoso, W. A., Tjahjono, E., Sentosa, B. O. B., & Orentilize, M. (2020). Load-displacement response of oil palm shell concrete compressive test using digital image correlation. *IOP Conference Series: Earth and Environmental Science*, *498*(1), 012037. https://doi.org/10.1088/1755-1315/498/1/012037

Stanish, K. D., Hooton, R. D., & Thomas, M. D. (1997). *Testing the chloride penetration resistance of concrete : A literature review*. Transportation Research Board. https://trid.trb.org/view/690568

Sutherland, W. J., Barnard, P., Broad, S., Clout, M., Connor, B., Cote, I. M., Dicks, L. V., Doran, H., Entwistle, A. C., Fleishman, E., Fox. M., Gaston, K. J., Gibbons, D. W., Jiang, Z., Keim, B., Lickorish, F. A., Markillie, P., Monk, K. A., Pearce-Higgins. J. W., … & Ockendon, N. (2017). A 2017 horizon scan of emerging issues for global conservation and biological diversity. *Trends in Ecology and Evolution*, *32*(1), 31-40. https://doi.org/10.1016/j.tree.2016.11.005

Teo, D. C. L., Mannan, M. A., & Kurian, V. J. (2006). Structural concrete using oil palm shell (OPS) as lightweight aggregate. *Turkish Journal of Engineering and Environmental Sciences*, *30*(4), 251-257.

Teo, D. C. L., Mannan, M. A., Kurian, V. J., & Ganapathy, C. (2007). Lightweight concrete made from oil palm shell (OPS): Structural bond and durability properties. *Building and Environment*, *42*(7), 2614-2621. https://doi.org/10.1016/j.buildenv.2006.06.013

Ting, T. Z. H., Rahman, M. E., & Lau, H. H. (2020). Sustainable lightweight self-compacting concrete using oil palm shell and fly ash. *Construction and Building Materials*, *264*, Article 120590. https://doi.org/10.1016/j.conbuildmat.2020.120590

Tripathi, M., Sahu, J. N., Ganesan, P., Monash, P., & Dey, T. K. (2015). Effect of microwave frequency on dielectric properties of oil palm shell (OPS) and OPS char synthesized by microwave pyrolysis of OPS. *Journal of Analytical and Applied Pyrolysis*, *112*, 306-312. https://doi.org/10.1016/j.jaap.2015.01.007

UNEP. (2019). *Sand and sustainability: Finding new solutions for environmental governance of global sand resources.* United Nations Environment Programme. https://wedocs.unep.org/20.500.11822/28163