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Comparing the effects of oil palm kernel shell and cockle shell on properties of pervious concrete pavement

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Abstract

Nowadays, pervious concrete pavement is one of the best materials used in construction industry as a top layer of permeable pavement system to control the storm water at source. In addition, increasing production of waste materials, increased the interest in utilising the waste materials for environmental and technical benefits. Therefore, this paper compared the effect of using two different sizes of oil palm kernel shell (OPKS) and cockleshell (CS) as partial replacement of natural coarse aggregate on properties of pervious concrete pavement. Thirteen mixtures were made, in which 6.30-mm natural gravel was replaced with 0, 25, 50 and 75% of 6.30-mm and 4.75-mm of both shells. The relationships between the properties of pervious concrete mixtures was also determined. The replacement of OPKS and CS as the natural aggregate decreased the compressive strength, while the angular shape of both shells caused higher void content and permeability as compared to those of control pervious concrete. On the other hand, pervious concrete containing CS showed better properties than those of incorporating OPKS. Apart from that, strong relationships between density, void content, permeability, compressive strength values indicated that they can be used as a pervious concrete quality control tests for prediction of properties of pervious concrete pavement before placement in the field.

Keywords: Pervious concrete pavement; Void content; Permeability; Cockleshell; Palm oil kernel shell

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1. Introduction

The effective management of by-product waste materials plays an important role in increasing environmental sustainability. One of the strategies in waste management is the utilisation of by-product waste materials in the construction industry to reduce the landfill of waste materials. Moreover, with the application of waste materials, more sustainable, clean and green construction could be achieved [1]. In addition, most of the raw materials used in concrete production are natural aggregates, and generally the materials are excavated from mines and river beds or dredged from sea shelves [2]. These activities have resulted in severe damage to the environment, including disruption of the ecosystem and contamination of soil, air and water [3]. Therefore, the construction industry encourages the incorporation of sustainability in production issues with the

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application of solid waste materials as aggregate in concrete [4–6]. In addition, it was indicated that by reusing waste materials could also ensure waste conservation, and subsequently, decrease waste disposal in the involved sectors. Two of the waste materials, which were successfully utilised as coarse aggregate in conventional concrete, were oil palm kernel shell (OPKS) and cockle shell (CS). OPKS is a waste product obtained from oil palm fruits during the production of palm oil [7,8]. Malaysia produces over four million tonnes of OPKS annually [8,9], and the country is expected to grow five million hectares of oil palm trees by the year 2020 [10]. Many researchers have previously investigated the properties of OPKS as aggregate in the production of lightweight concrete. In the said studies, they managed to achieve compressive strength ranging from 13 to 30 MPa [11–13]. Olanipekun et al. [15] showed that by increasing OPKS, the compressive strength of concrete decreased. This was due to the lower specific gravity (1.17–1.62) and a much higher water absorption ratio (14–33%) of OPKS in comparison to those of natural aggregates [7,9]. Furthermore, Alengaram et al. [15] reported that the angular and rough edges of OPKS were responsible for lower workability, while higher water absorption of OPKS was a result of the existence of many pores in the shells. However, Shafigh et al. [16] stated that OPKS could be replaced as a lightweight natural aggregate to produce high strength lightweight concrete with a compressive strength of up to 48 MPa at 28 days. This is due to the small size of OPKS and superplasticiser. Islam et al. [17] utilised both OPKS and palm oil fuel ash (POFA) as aggregate and cement replacement respectively to produce lightweight concrete. They concluded that using 10% POFA attained the most optimum performance in terms of the sustainability of the concrete containing OPKS, which was according to the evaluation of the cost and eco-efficiencies of the concrete.

According to the Department of Fisheries Malaysia, 57,544 tonnes of cockles were harvested along the west coast of Peninsular Malaysia. In addition, it was reported that the retail value of cockles in Malaysia was estimated to be at over USD 32 million [18]. Boey et al. [18] also indicated that the active and lucrative industry has resulted in a significant amount of waste shells. Moreover, left untreated and dumped irresponsibly, CS may produce unpleasant odour [19]. Several researchers have previously investigated the effects of replacing natural coarse aggregates on concrete with seashells by-products. Muthusamy and Sabri [20] reported that the replacement of CS as coarse aggregates were able to produce good quality concrete due to their hardness property. However, higher cement paste would be required to obtain the desired workability at higher percentage replacement of CS, owing to the angularity of the shells. In their study, the maximum compressive strength obtained was 34.8 MPa at 20% CS substitution. On the other hand, Cuadrado-Rica et al. [23] indicated that the application of crushed queen scallop shells as aggregate substitution could result in the decrease of mechanical properties. They also reported that the replacement could potentially increase the porosity of concrete, resulting from an increase of entrapped air in the concrete. Moreover, the concrete could also exhibit low workability due to the shells' size, shape and texture [20]. In another study, Nguyen et al. [25] investigated the effects of partial replacement of natural coarse aggregate with crushed crepidula seashells of 2–4 mm and 4–6.3 mm (20 or 40% by mass) on the properties of pervious concrete. They reported that pervious concrete paver containing 40% of crepidula shell (2–4 mm) could achieve 97% of the compressive strength demonstrated by the control pervious concrete (CPC). They concluded that the permeability of the pervious concrete increased with the increasing amount of the seashell used, as a result of the porosity of the seashells. However, to the author's best knowledge, there are currently no reports of the use of CS as the partial coarse aggregate replacement in pervious concrete paver.

In this paper, the effects of OPKS and CS as a partial replacement of natural coarse aggregate on the properties of pervious concrete, were investigated. The production of pervious concrete pavement is a unique and successful strategy to help both the environmental issues and sustainable development. Based on the literature search carried out, there are currently no studies investigating the effects of OPKS and CS on the properties of pervious concrete. On a related note, the aim of this study was to replace OPKS and CS (0, 25, 50 and 75%) with two different sizes (6.30-mm, 4.75-mm) as natural coarse aggregate in pervious concrete. The effects of replacing coarse aggregate with OPKS and CS on fresh and hardened properties of pervious concrete, such as density, void content, permeability as well as compressive strength were investigated and compared against each other and the CPC. In addition, the relationship between properties of pervious concrete mixtures was also analysed.

2. Specimen and preparation

2.1. Materials

The cement used in this study was Ordinary Portland Cement (OPC) type I. To achieve a system with interconnection voids in the pervious concrete, the selection of single-sized aggregates is necessary [23,24]. The details of the aggregates are listed in Table 1. In this study, crushed limestone (LS) with a grain size of 6.30-mm (passed through a 9.5 mm sieve and retained on a 6.30 mm sieve) was used as the natural coarse aggregate. LS presented a specific gravity of 2.7 kg/m^3 and water absorption of 1.8%.

In addition, OPKS and CS were used as a replacement of natural coarse aggregate. In this study, OPKS was collected from a local palm oil producing mill located in Johor, a southern state of Malaysia. On the other hand, CS were obtained from a local market located in the south coast of Malaysia, and were crushed before they were used. Subsequently, both OPKS and CS were sieved and divided

Table 1
Physical properties of waste and natural aggregates.

Characteristics	Waste aggregates				Natural aggregate	
	CS		OPKS		LS	Sand
	CS1	CS2	OPKS1	OPKS2		
Gradation (mm)	6.30–9.50	4.75–6.30	6.30–9.50	4.75–6.30	6.30–9.50	–
Bulk specific gravity (SSD)	2.09	2.64	1.29	1.30	2.7	2.62
Water absorption (%)	1.8	2.5	24.73	25.62	1.8	7.4
Dry rodded density (kg/m^3)	1408	1420	631	656	1475	–

into two different size categories, namely (OPKS1, CS1) 6.30-mm (passed through a 9.50 mm sieve and retained on a 6.30 mm sieve) and (OPKS2, CS2) 4.75-mm (passed through a 6.30 mm sieve and retained on a 4.75 mm sieve), as illustrated in Fig. 1. Following that, they were washed and air dried in the laboratory. The purpose of washing both OPKS and CS was to remove oil and dirt.

2.2. Mixture proportions

Placement or compaction method plays an important role towards the properties of pervious concrete [25–27]. For this study, the rod with diameter of 0.95 cm was used in equal blows of 25 per layer, for three layers and 10 blows by a 2.5 kg Proctor hammer, which falls 30 cm for each three layer was used for all mixtures.

The mixture proportions used in this study are listed in Table 2. Each mixture proportion was designated with a specific code. The first labels represented the types of coarse aggregates used. ‘CPC’, ‘SPC’ and ‘KPC’ represented control, cockle shell and oil palm kernel shell pervious concretes respectively. The second labels, ‘1’ and ‘2’, referred to the size of the coarse aggregates used, big and small respectively. Finally, the third labels, ‘0’, ‘25’, ‘50’ and ‘75’, indicated the percentage of waste aggregate added in terms of the weight percentage of the natural coarse aggregate proportion, which were calculated according to the specific gravity of each waste materials. All batches were designed with the purpose of investigating their density, void content, permeability as well as compressive strength. Both water cement ratio (w/c) and sand content were fixed at 32% and 10% (wt.% of the coarse aggregate) respectively [28].

2.3. Experimental details

The density of the fresh samples was tested according to ASTM C1688 [31]. On the other hand, the density and void content of the hardened samples were tested based on ASTM C1754 [32] using the volumetric method. Previously to determine the water permeability coefficient of pervious concrete, several researchers have used falling-head test [24,31]. In this study, water permeability coefficient was determined following Darcy’s law, as shown in Eq. (1):

$$K = \frac{A_{tube} \times L}{A \times t} \times \ln\left(\frac{h_1}{h_2}\right) \tag{1}$$

where K (mm/s) is the water permeability coefficient, A and A_{tube} (mm^2) are the areas of the cross-sections of the sample and tube, L (mm) is the length of the sample and t (s) represents the time required for water to fall from an initial water level ($h_1 = 260$ mm) to a final water level ($h_2 = 60$ mm). Fig. 2 shows the device for the falling-head water permeability test.

The cylindrical specimens for compressive strength tests were dried in room temperature for about two hours and then capped with sulphur capping compound at both ends in accordance to ASTM C617 [32]. This step was taken to fill up any voids and level both ends of the cylinder

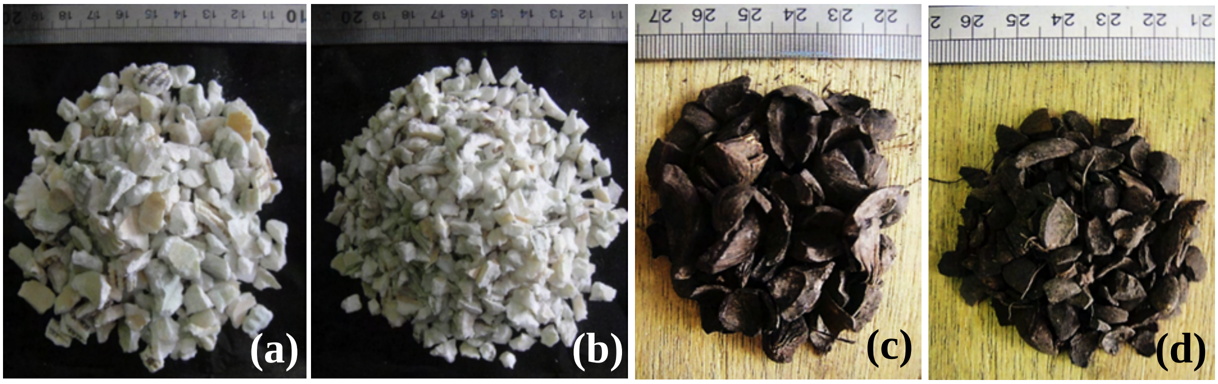

Fig. 1. Particle shapes of aggregates: (a) CS1, (b) CS2, (c) OPKS1 and (d) OPKS2.

Table 2
Mixture proportion of pervious concrete.

Mix	Cement (kg/m^3)	Water (kg/m^3)	Coarse aggregate (kg/m^3)			Sand (kg/m^3)
			LS	CS	OPKS	
CPC	339.5	107.54	1313.8	–	–	139.0
SPC1-25	339.5	107.54	985.4	348.4	–	139.0
SPC1-50	339.5	107.54	656.9	696.8	–	139.0
SPC1-75	339.5	107.54	328.5	1045.2	–	139.0
SPC2-25	339.5	107.54	985.4	348.4	–	139.0
SPC2-50	339.5	107.54	656.9	696.8	–	139.0
SPC2-75	339.5	107.54	328.5	1045.2	–	139.0
KPC1-25	339.5	107.54	1094.9	–	157.6	139.0
KPC1-50	339.5	107.54	729.9	–	315.3	139.0
KPC1-75	339.5	107.54	365.0	–	472.9	139.0
KPC2-25	339.5	107.54	1094.9	–	157.6	139.0
KPC2-50	339.5	107.54	729.9	–	315.3	139.0
KPC2-75	339.5	107.54	365.0	–	472.9	139.0

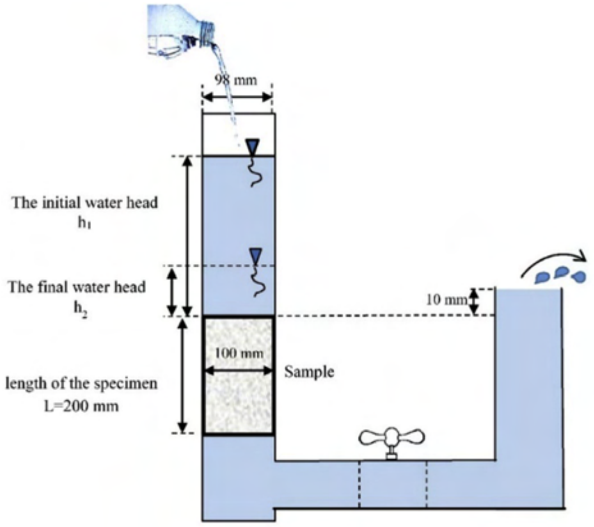

Fig. 2. Scheme of falling-head water permeability test.

specimens. The splitting tensile strengths were tested according to ASTM C496 [35].

3. Test results and discussion

3.1. Density

Fig. 3 shows the effects of OPKS and CS on the density of pervious concrete. In addition, one standard deviation for the density of three pervious concrete cylinders, which belonged to the same mixture, was represented by the error bars. It was found that the density of the pervious concrete mixtures decreased significantly as the amount of OPKS in the pervious concrete increased. This reduction was expected due to the lower specific gravity of OPKS compared to the natural coarse aggregate. The results showed that there was a significant reduction of approximately 29% for the density of the KPC2-75 mixture in comparison with that of the CPC. Additionally, in contrast to KPC2-25, KPC2-75 reported a reduction of 25%. Overall, the lowest density was observed in KPC1-75, which reduced about 30% in comparison to the CPC sample. For the mixtures containing CS, the density was almost similar to that of the control mixture, and this was not surprising, given that the specific gravity of CS was almost similar to that of LS. However, by increasing CS, the density of the mixtures decreased slightly, due to the angular shape of CS, which caused the void content of the mixtures to increase. The density of the SPC1-75 mixture showed 5% decrease compared to that of SPC1-25. According to Fig. 3, the density of all SPC2 and KPC2 mixtures was higher than that of the SPC1 and KPC1 mixtures respectively. This indicated that by decreasing the size of both OPKS and CS, the density of pervious concrete could be increased. This was probably due to OPKS and CS being small enough that they were able to fit into the voids, and thus decreased the void content in comparison to that of the control mixture. In addition, it might be due to the specific gravity of the small particles of waste materials (OPKS1 and CS1), which was higher compared to the bigger particles (OPKS2 and CS2).

The density results showed that the pervious concrete with OPKS and CS could be classified as lightweight concrete with a density ranging from 1314 to 1929 kg/m^3. This range of density was lower than that of the conventional concrete (approximately 2400 kg/m^3). Nonetheless, this reduction in density is desirable for paving structures, such as concrete bridges and concrete blocks.

3.2. Void content and water permeability

With the application of volumetric method, the void content was ascertained. Fig. 4 illustrates the void area fractions where one standard deviation for the void content of three pervious concrete specimens, which belonged to the same mixture, was illustrated by the error bars. It can be seen that the void content increased as the percentage of waste also increased. For instance, there was an increase of 2, 4 and 20% for the void content of SPC1-25, SPC1-50 and SPC1-75 respectively in comparison to that of CPC.

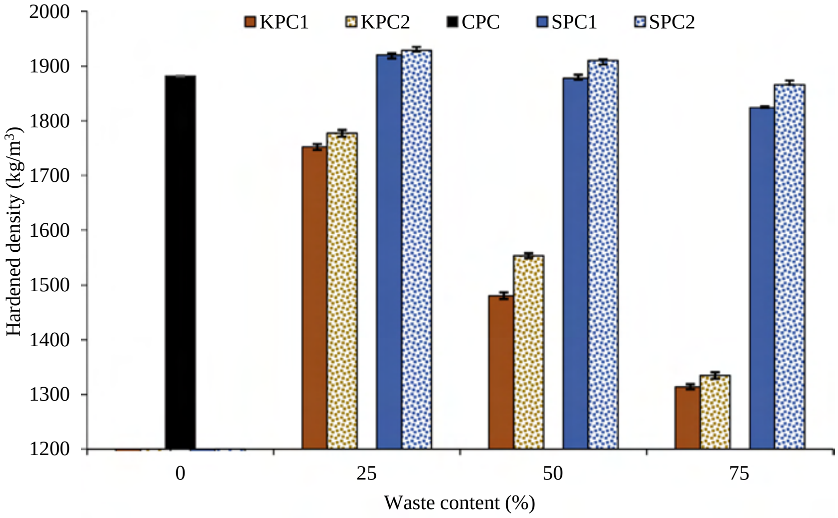

Fig. 3. Density of pervious concrete mixtures contains OPKS and CS.

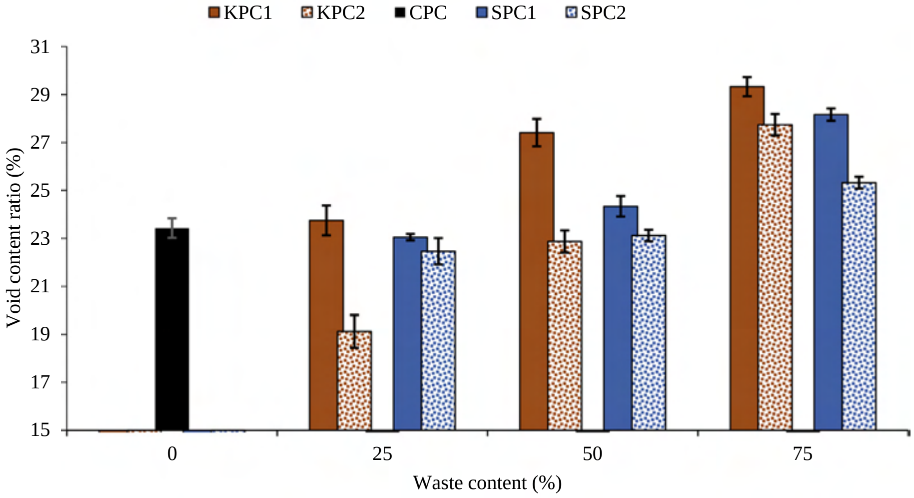

Fig. 4. Void content of pervious concrete mixtures.

This could be due to the angular shape of CS, which decreased the compactness of all SPC1 mixtures, and subsequently, disturbed the granular arrangement of the pervious concrete. Nguyen et al. [25] reported comparable findings, in which the void content increased with increasing percentage of crushed crepidula seashells.

The void content of mixtures containing the bigger sized OPKS, including KPC1-25, KPC1-50 and KPC1-75, increased about 1, 17 and 25% compared to that of CPC at the age of 28 days. From the results shown in Fig. 4, it could be concluded that the void content of the mixtures with OPKS was higher than that of with CS. This could be due to the high water absorption of OPKS particles, which absorbed more water during the mixing process, and thus entrapping air on its surface, which then caused the void content of the KPC1 mixtures to increase. The highest void content was obtained by KPC1-75.

The mixtures containing the smaller sized waste materials (OPKS2 and CS2) showed lower void content than the mixtures with the bigger sized waste materials (OPKS1 and CS1). This might be due to the smaller sized OPKS and CS were able to fit into the voids, and thus decreased the void content.

The main purpose of pervious concrete is to obtain a proper connected void content so as to allow water to pass through it easily. Fig. 5 shows the effects of OPKS and CS on the water permeability of the pervious concrete mixtures. The influence of waste materials on the water permeability seemed to be similar to that of the void content of the pervious concrete mixtures. Therefore, it was expected that by increasing the percentage of waste materials replacement as the natural coarse aggregate, the water permeability of pervious concrete mixtures would also increase due to the escalated void content. The range of water per-

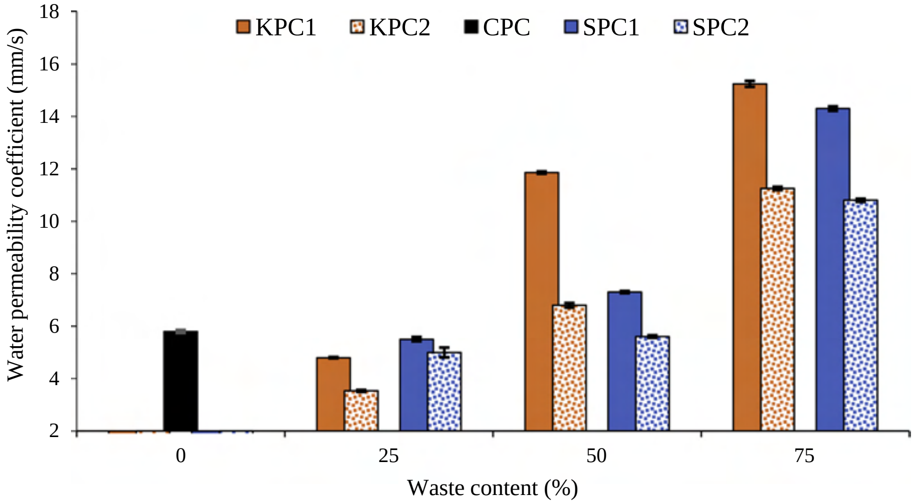

Fig. 5. Water permeability coefficient of pervious concrete mixtures.

meability coefficient of the pervious concrete mixtures was between 3.5 and 15.2 mm/s. This result was almost similar to the typical range of water permeability, which was between 2 and 12 mm/s, as reported by several researchers [23,34,35]. Furthermore, Nguyen et al. [25] reported lower water permeability when using crushed crepidula seashells in pervious concrete, with a range of 3–8.4 mm/s. This could be due to smaller sized coarse aggregate, 4–6.3 mm, was used for their pervious concrete specimens, which reduced the void content and permeability, in comparison to the 6.3–9.5 mm coarse aggregate used in this study.

3.3. Compressive strength

Compressive strength test was performed on the hardened samples after 28 days of curing. As illustrated in Fig. 6, the compressive strength of the pervious concrete mixtures decreased as the percentage of waste materials replacement increased. For instance, there was a reduction of 20, 25 and 38% for the compressive strength of SPC1-25, SPC1-50 and SPC1-75 respectively in comparison to that of CPC. As previously discussed, this was caused by the angular shape and heterogeneous structure of the CS particles, which led to reduced compactness and increased void content (Figs. 6 and 7). Similar findings was reported by Nguyen et al. [25] in regard to the structure of crepidula seashells.

On the other hand, the compressive strength of the mixtures containing OPKS1, including KPC1-25, KPC1-50 and KPC1-75, decreased about 27, 52 and 58% compared to that of CPC at the age of 28 days. The results showed that the compressive strength for the KPC mixtures was lower than the SPC mixtures. The entrapped air on the surface of the OPKS particles led to a reduction in the bonding area matrix. Furthermore, as stated before the cement paste in the pervious concrete was very thin, and thus it was not able to fully bond with the OPKS particles. However, with natural coarse aggregate (LS), this was not a significant issue. As the load was applied to KPC during the strength test, micro cracks formed at the weak interface, between the cement paste and OPKS, due to stress focus. This resulted in the failure of continuous load application. Again, this might be due to the angular shape of the

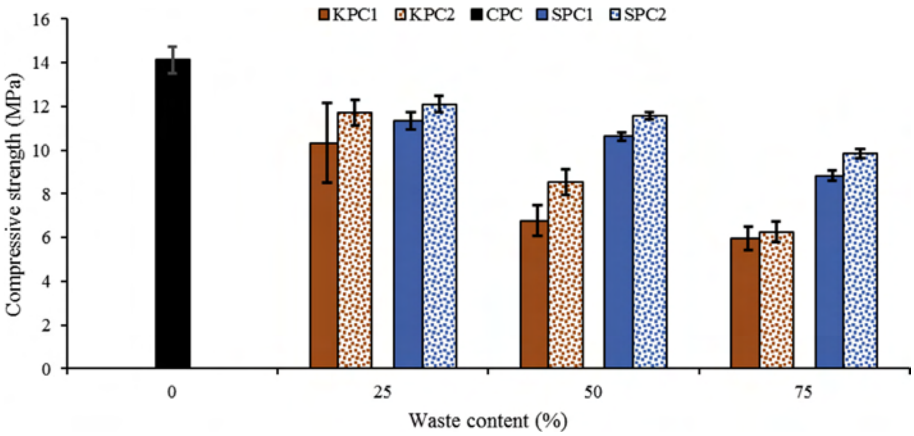

Fig. 6. Compressive strength of pervious concrete mixtures at 28 days.

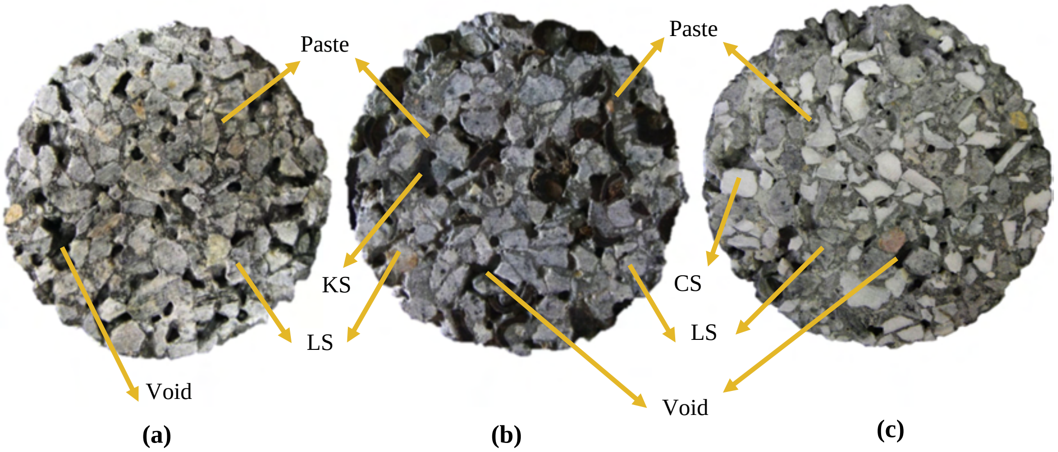

Fig. 7. Structural arrangement of the pervious concrete matrix (a) with natural aggregate (LS); (b) with OPKS and (c) with CS.

crushed CS, which in turn decreased the compactness of the KPC mixtures.

Moreover, referring to Fig. 6, it could be concluded that the mixtures, which contained the smaller sized waste materials (OPKS2 and CS2), showed higher compressive strength than the mixtures containing the bigger sized waste materials (OPKS1 and CS1). This could be a result of the small parts of both OPKS and CS being able to fit into the voids, which then decreased the void content, and at the same time, increased the compressive strength of the mixtures. Furthermore, by decreasing the size of both OPKS and CS, the surfaces, which could be coated with cement paste, increased and resulted in better bonding between the cement paste and smaller coarse aggregate.

3.4. Relationship between properties of pervious concrete mixtures

3.4.1. Relationship between density and void content

The relationship between density and void content is shown in Fig. 8. The R^2 value was 0.79 and 0.97 for KPC and SPC mixtures, respectively. The value demonstrated good confidence in the relationship. The results of this study suggested that density and void content were directly related to each other in the pervious concrete mixtures incorporating CS and OPKS, as shown in Eqs. (2) and (3):

For KPC mixture:

$$D = -46.306 \times V + 2694.5 \tag{2}$$

For SPC mixtures:

$$D = -18.531 \times V + 2340.2 \tag{3}$$

where, D is density (kg/m3) and V is void content (%).

It can be seen that for all mixtures containing OPKS and CS, the density decreased with the increase of void content up to 30%. As shown in Fig. 8, the specimens incorporating OPKS had lower predicted density than those containing CS, at the same void content. This could be due to lower specific gravity of OPKS that that of CS.

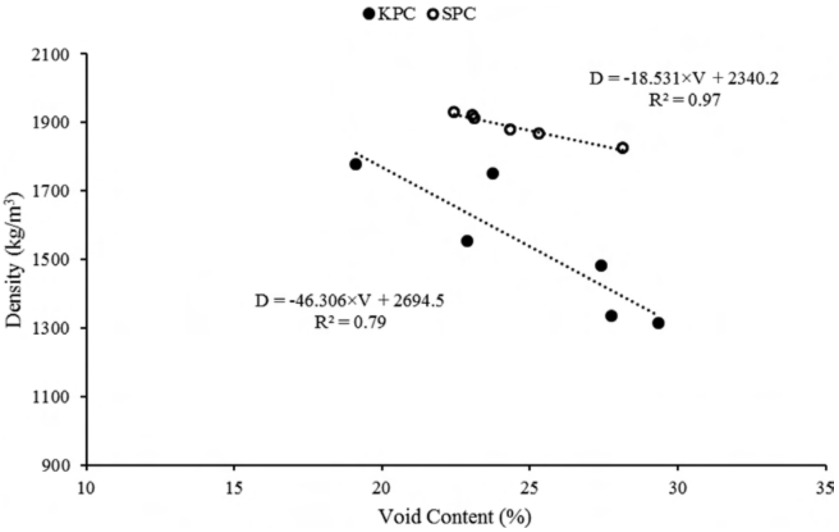

Fig. 8. Relationship between density and void content.

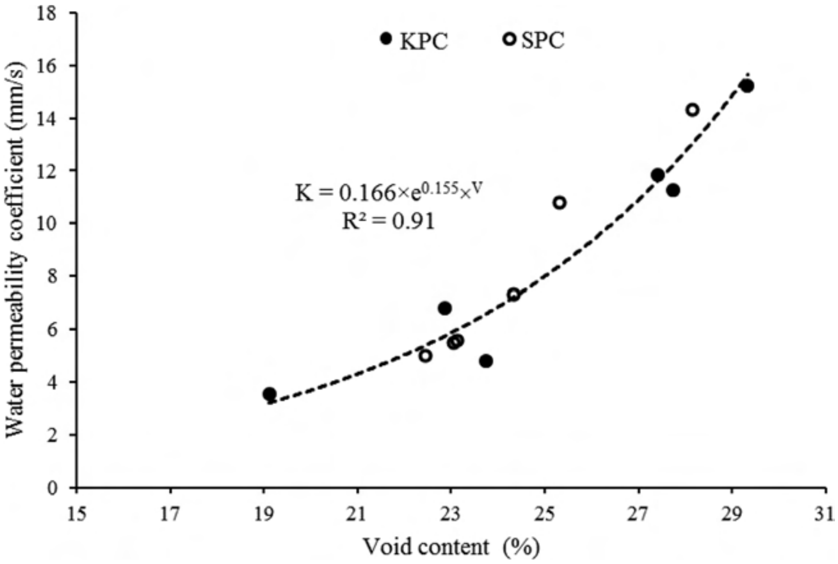

Fig. 9. Relationship between the void content and water permeability.

3.4.2. Relationship between the void content and water permeability

The relationship between the void content and water permeability coefficient using linear regression method is presented in Fig. 9. It was concluded that there was a good relationship between both variables. The R^2 value, which indicates the amount of the total change in the related variables, and is explained by a regression equation, was 0.91. The value demonstrated good confidence in the relationship. The results of this study suggested that both void content and water permeability were directly related to each other in the pervious concrete mixtures incorporating CS and OPKS. In addition, it could be concluded that as void content increases, so does water permeability, as shown in Eq. (4):

$$K = 0.166 \times e^{0.155} \times V \tag{4}$$

where K is water permeability coefficient (mm/s) and V is void content (%).

3.4.3. Relationship between compressive strength and void content

The relationship between 28-day compressive strength and void content of all pervious concrete mixtures is illustrated in Fig. 10. In fact, the compressive strength decreased with the increment of void content. The R^2 value was 0.89 and 0.96 for KPC and SPC mixtures, respectively. The value demonstrated good confidence in the correlation. The results of this study indicated that compressive strength and void content were directly related to each other in the pervious concrete mixtures incorporating CS and OPKS, as shown in Eqs. (5) and (6):

For KPC mixture:

$$Fc = -0.586 \times V + 22.929 \tag{5}$$

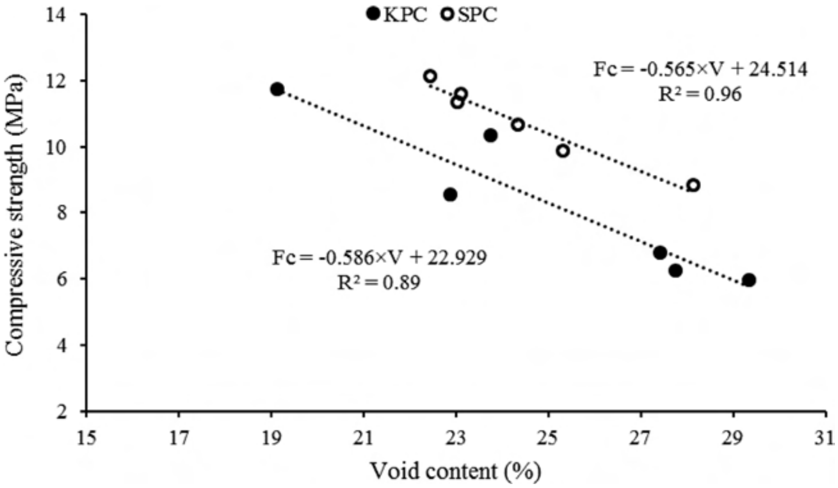

Fig. 10. Relationship between compressive strength and void content.

For SPC mixtures:

$$F_c = -0.565 \times V + 24.514 \quad (6)$$

where, F_c is compressive strength (MPa) and V is void content (%).

As shown in Fig. 10, the specimens incorporating OPKS had lower predicted compressive strength than those containing CS, at the same void content. This could be due to higher water absorption and lower stiffness of OPKS that those of CS.

4. Conclusion

In this paper, the effects of oil palm kernel shell (OPKS) and cockle shell (CS), on the properties of pervious concrete mixtures were compared. In addition, the relationship between the properties of pervious concrete pavement is analysed. The utilisation of OPKS and CS in pervious concrete mixture was able to address the demand of preserving a cleaner environment and producing pervious concrete pavement in light traffic roads and parking lots.

Based on the experimental results and observations made, the following conclusions could be drawn:

1. The replacement of both OPKS and CS as the natural coarse aggregate reduced the density of the pervious concrete. This was due to the shape and lower specific gravity of the waste materials, especially OPKS, which was almost 50% lighter than limestone (LS). In accordance with the requirements of ASTM C90, both oil palm kernel shell pervious concrete (KPC) and cockle shell pervious concrete (SPC) could be classified as lightweight concrete.
2. Both void content and water permeability significantly escalated with the increase of OPKS and CS, owing to the angular shape of the waste materials. Smaller particles of OPKS and CS produced lower void content and permeability compared to that of the control pervious concrete (CPC). This was probably due to the smaller parts were able to fit into the pores, and thus reduced the void content. Pervious concrete containing CS produced lower void content and permeability in comparison with pervious concrete incorporating OPKS.
3. The compressive strength of pervious concrete decreased as the content of both OPKS and CS increased, owing to escalated void content. However, the values obtained were still within the satisfactory range for pedestrians' pathways, light traffic roads and parking lots.
4. In addition, strong relationships between density, void content, permeability, compressive strength values indicated that they can be used as a pervious concrete quality control tests for prediction of properties of pervious concrete pavement before placement in the field.

To summarise, the findings and observations of this study suggested that pervious concrete incorporating OPKS and CS could be used with satisfactory engineering properties in the construction of light traffic road pavements, parking lots, pedestrians' pathways and other similar applications. However, it was recommended that future studies be carried out to investigate the durability of pervious concrete containing OPKS and CS.

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