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Properties of quiet pervious concrete containing oil palm kernel shell and cockleshell

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ABSTRACT

Nowadays, the significant increase in noise has become a major problem in urban areas. Using pervious concrete pavement is recommended to reduce the noise. Unfortunately, standard materials used to produce pervious concrete are not completely environmental friendly. As a result, many researchers have devoted their attention towards identifying eco-friendlier substitutions to be used in the manufacturing of pervious concrete. In this respect, this current paper discussed the efficiency of two different sizes of oil palm kernel shell (KS) and cockle shell (CS) as partial replacement of natural coarse aggregate for sound absorption of pervious concrete. Thirteen mixtures were made, which replaced 6.30 mm limestone with 0, 25, 50 and 75% of 6.30 mm and 4.75 mm of both shells. The specimens were cured in a fog room and void content and compressive strength were tested. The replacement of both KS and CS as the natural aggregate decreased the compressive strength, although the range was still acceptable for pervious concrete at 28 days. However, the angular shape of both shells caused high void content. The maximum increase in void content compared to that of the control pervious concrete (CPC) was achieved with the use of 75% of 6.30 mm KS at 28 days. Moreover, by increasing sound absorption with the application of both shells, particularly KS, the concrete could be used as silent road pavement. It was therefore concluded that the use of both KS and CS to produce cleaner and quitter pervious concrete pavement is practical, both mechanically and environmentally.

1. Introduction

Of late, the significant increase in noise has become a major problem in urban areas. The said noise is typically generated from a variety of sources, including various types of vehicles on the road, airplanes, factories and construction sites. Noise exposure does not only impair human hearing capacity, but may also cause certain mental disorders [1]. Therefore, using of pervious concrete pavements have been recommended by Environmental Protection Agency (EPA) of the United State (US) to reduce traffic noise in urban area. Pervious concrete is one of the best materials used in top layer of permeable pavement system. In the past 30 years, pervious concrete has been gradually used in the United States (US), and is among the Best Management Practices (BMPs) recommended by EPA and American Concrete Institute (ACI) [2,3].

Due to the lower durability and strength of pervious concrete compared to normal concrete, the application of pervious concrete is limited to the roads that have light volume traffic [2,3]. However, due to the advantages of pervious concrete, the utilisation and construction properties of pervious concrete have been studied by many researchers [4–6]. The benefits of using pervious concrete are: reduction of downstream flows; reduction of large volumes of surface pollution flowing into rivers; decreasing of urban heat island effect; reducing traffic noise; enhancing safety of driving during raining; and removing heavy metal from stormwater runoff [3,7]. The use of pervious concrete in building site design can also aid in the process of qualifying the building for Leadership in Energy and Environmental Design (LEED) [8].

In pervious concrete, water passes through an interconnected network of voids structure, resulting from the constrained use of fine aggregates, uniform gradation and low water-to-cement ratio

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[3]. Void content of pervious concrete ranging from 20 to 30% is a consequence in a concrete with high drainage rate from 0.25 to 6.1 mm/s [6]. Moreover, typical range for the compressive strength of the pervious concrete are between 2 and 28 MPa [3,6,2].

Previous researches have reported that pervious concrete has the potential to reduce significantly the noise produced by vehicles due to high void content [9–12]. Normal concrete, for example, typically has an absorption coefficient (α) of 0.03–0.05 [13]. Pervious concrete typically has an absorption range from 0.1 (for poorly performing mixtures) to nearly 1 (for mixture with optimal pore volume and size) [3]. This is due to the voids inside the material, which absorbed the sound energy through internal friction. For pervious concrete to effectively absorb sound, 15–25% of connected void content is essential. Meiarashi et al. [14] compared the noise reduction levels of pervious asphalt and normal asphalt pavement. They found that 2–5 dB noise reduction was obtained by pervious asphalt, and concluded that it was crucial to keep the pavement porosity at 20% or higher for noise reduction purpose. In another study, Kim and Lee [15] investigated the effects of three levels of cement flow and five types of aggregates on the mechanical properties and sound absorption level of porous concrete. They observed that the sound absorption of specimens with smaller size was better than that of the control sample. This was because the total void ratios of the specimens were higher when smaller sized aggregates were used. Berengier [16] measured acoustical performance of porous pavement over real road surfaces and compared to theoretical predictions. They found that the microstructural model provided a good physical description of the acoustical properties of porous pavement. This was due to the flow resistivity and the porosity of the material and, to a lesser extent, on the tortuosity. Further, the properties of the pavement are relatively insensitive to pore shape factor.

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 due to the decrease of cost [17]. In addition, most materials used in concrete production are natural aggregates, and a majority of the materials are excavated from mines and river beds or dredged from sea shelves [18]. These activities have resulted in severe damage to the environment, including disruption of the ecosystem and contamination of soil, air and water [19]. Therefore, the construction industry encourages the incorporation of sustainability in production issues with the application of solid waste materials as aggregate in concrete [20–23]. Neithalath et al. [11] reviewed the benefits of using farming waste materials in concrete. They reported that both the reliance on standard materials used to produce concrete and adverse effects on the environment could be reduced with the reuse of farming waste materials in concrete. In addition, it was indicated that the method could also ensure waste conservation, and subsequently, decrease waste disposal in the involved sectors. Moreover, they concluded that by selecting proper farming waste materials, concrete with better performance could be produced. Asdrubali et al. [25] evaluated the acoustic performance of sustainable products made from natural and recycled materials. They concluded that the substitution of conventional sound insulating materials with sustainable ones has significant effects on the impact of all the various phases of the life of the building (construction, operation, end of life). Ibrahim and Razak [26] studied the use of palm oil clinker (POC) as coarse aggregate in the production of pervious concrete. They indicated that with using POC the compressive strength and density of the concrete reduced. However, the coefficient of permeability and porosity increased.

Two of the farming waste materials, which were successfully utilised as coarse aggregate in conventional concrete, were oil palm kernel shell (KS) and cockle shell (CS). KS is a waste product obtained from the production of oil from oil palm trees [27,28]. Malaysia produces over four million tonnes of KS annually [28,29], and the county is expected to grow five million hectares of oil palm trees by the year 2020 [30]. 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 [32]. Boey et al. [32] 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 [33].

In this paper, the effects of KS and CS as a partial replacement of natural coarse aggregate on the properties of especial type of concrete, pervious concrete, was investigated. To the author's best knowledge, there are currently no studies investigating the effects of oil palm kernel shell (KS) and cockle shell (CS) on the noise absorption of pervious concrete. On a related note, the aim of this study was to replace KS and CS (0, 25, 50 and 75%) with two different sizes (6–9 mm and 4–6 mm) as natural coarse aggregate in pervious concrete. The effects of replacing coarse aggregate with KS and CS on void content and compressive strength of pervious concrete were investigated and compared against the control pervious concrete (CPC). In addition, sound absorption coefficient and sound transmission loss were also examined and 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 [3,2]. 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 2.6 kg/m^3 and water absorption of 1.8%.

In addition, KS and CS was used as a replacement of natural coarse aggregate. In this study, KS was collected from a local palm oil producing mill located in Johor, a southern state of Malaysia. On the other hand, CS was obtained from a local market located in the south coast of Malaysia, and were crushed before they were used. Subsequently, both KS and CS were sieved and divided into two different size categories, namely (KS1, CS1) 6.30 mm (passed through a 9.5 mm sieve and retained on a 6 mm sieve) and (KS2, 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 a laboratory. The purpose of washing both KS and CS was to remove oil and dirt. Fig. 2 presents the Scanning Electron Macroscopy (SEM) image of KS and CS particles. It can be seen that the high porous and heterogeneous structure of KS and CS respectively.

2.2. Mixture proportions

Placement or compaction method plays an important role towards the properties of pervious concrete [34]. For this study, the technique of filling in three layers using 25 drops of a 15.9 mm diameter steel rod and 10 drops of a standard Proctor hammer (2.5 kg) for each layer was used from the results of Khankhaje et al. [35].