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Performance of Pervious Concrete Containing Kenaf *(Hibiscus cannabinus L.)* Fibres

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Abstract

The present study investigates the feasibility of adding kenaf fibres *(Hibiscus cannabinus L.)* in pervious concrete. Pervious concrete is a special concrete designed to possess large quantity of voids for water permeability. Kenaf fibres is selected to be added into the concrete mixture due to the exceptional engineering properties apart from being locally available. The fibres is added at 0%, 0.1% and 0.3% by weight of cement to produce three different batches of concrete mixtures. The density, porosity, constant head water permeability and compressive strength were investigated. Experimental results showed that the permeability is directly proportional to the porosity of the concrete specimens. Maximum porosity of 40% is recorded, corresponds to the maximum water permeability of 6.3L/min. Addition of kenaf fibres at an increasing quantity however caused agglomeration of cement paste, kenaf fibres and the aggregate particles that affect the voids distribution and the compressive strength. Nonetheless, the concrete continue to show steady increment in compressive strength with respect to the testing age where highest strength of 6.8MPa is observed for control mix, followed by 5.8MPa and 4.7MPa, respectively for concrete of 0.1% and 0.3% fibres addition. Considering water permeability as the key feature of pervious concrete, addition of kenaf fibres in the concrete is feasible and could be applied at locations where excessive loadings are unlikely. Therefore, the study can be further extended to reduce the high voids content whilst increasing the compressive strength.

Keywords

Pervious concrete, kenaf fibres, porosity, constant head water permeability, compressive strength

Introduction

A pervious concrete, shown in Figure 1 is a special concrete designed to contain vast amount of voids in the concrete mixture itself. Unlike conventional concrete which is normally dense graded, the pervious concrete is open graded, with a remarkable interconnected voids which forms a mini channel to transmit water. Such feature is extremely important for developing countries in many parts of the world including Malaysia that is the common victim of flooding, partly due to the increase of the impervious surfaces contributed by the bituminous and concrete pavements. The pervious concrete is a unique and latest technology used to meet the ongoing green environmental trend. The use of pervious concrete as road paving materials can capture the stormwater, allowing the downwards movement of water into the soil hence recharge the groundwater. This is considered to be the best stormwater management practice as recognised by the US Environmental Protection Agency (EPA).

Figure 1: Texture of pervious concrete, containing large amount of voids to allow water permeability

Pervious concrete is also referred to as permeable concrete or no-fines concrete. The first use of pervious concrete was dated back as early as the post-World War II, documented by Offenberg (2008). Since then, it has becoming popular worldwide for engineering applications. These includes particularly pervious concrete pavements for highways, low volume roads, parking lots, hydraulic structures, drainage, sound barrier, tennis courts and walkways in garden for pedestrian and bicyclist (ACI 522, 2010; Tennis et al., 2004)

The main constituents of pervious concrete are predominantly coarse aggregates, which is mixed under a water to binder ratio of approximately 0.2 to 0.45. The most important characteristics of pervious concrete is the percentage voids and the capability to transmit water – the permeability. Typically, between 15% and 25% voids are achieved in the hardened concrete, and that the water permeability is approximately 200 L/min/m^2, although they can be much higher (Tennis et al. 2004). Due to the presence of the voids, the strength performance of pervious concrete is relatively low compared to conventional concrete. Nonetheless, sufficient strength for various engineering applications is readily achieved. Studies of literature indicated that the strength performance of pervious concrete generally lies in the range of 3.5MPa to 28MPa (Obla, 2010), primarily believed to be a result of different mixture designs and materials used in the pervious concrete. Considering the open graded nature of the mixture, water permeability should be the main specification requirement instead of the strength performance.

The present study is considered as a pioneer study that focuses on incorporating natural fibres in pervious concrete to enhance the properties of the concrete, hence to decide on the feasibility of adding kenaf fibres in pervious concrete. Kenaf (*Hibiscus cannabinus L.*) fibres are selected to be used in this study as it is locally available apart from being having exceptional engineering property like tensile strength, described by Ramesh (2016). Kenaf fibres were added at different percentages to produce different batches of pervious concrete that are to be investigated for density, porosity, permeability and the compressive strength.

Methodology

Tasek brand ordinary Type I Portland cement for general use was used as the binder to produce the pervious concrete. The coarse aggregates are quarried granites of 14mm stockpiles with a specific gravity of 2.64 supplied by local quarry. The aggregates from the stockpiles were selected to be used without selecting the size in conjunction to promote simplicity and to investigate the practicality of stockpiles aggregates towards the performance of the pervious concrete produced. Sieve analysis on the randomly collected stockpile aggregates reveals that the stockpile contains approximately 85% of aggregate particles greater than 4.75mm and the remaining being particles size of less than 4.75mm. Sand were deliberately omitted to allow the pervious concrete to possess more voids content. The kenaf fibres added into the pervious mixture were obtained from the National Kenaf and Tobacco Board of Malaysia fixed at a length of 20mm. Prior to the addition, there is no any form of chemical treatment being carried out on the kenaf fibres. The materials used were shown in Figure 2.

(a) 20mm kenaf fibres

(b) 14mm stockpile aggregates

Figure 2: The materials used in the study.

Three pervious concrete batches were produced with kenaf fibres addition levels of 0%, 0.1%, and 0.3% by mass of cement. The aggregate to cement ratio for all the concrete batches were fixed at 4.5 in which 1350kg/m^3 is the coarse aggregate content and cement content is fixed at 300kg/m^3. Such mixture proportion corresponds to the materials proportion suggested by ACI 522 (2010). The water to cement ratio was kept at 0.32 to ensure sufficient workability of the pervious mixture which is assessed through the rolling ball test as documented elsewhere (Tennis et al., 2010). Triplicate specimens were produced throughout and the average of three results is documented herein.

The fresh pervious concrete mixture were thoroughly mixed in an uncontrolled laboratory environment using a drum mixer and that the specimens were casted in standard cylindrical moulds of 200mm height and 100mm diameter. All the specimens were carefully compacted by hand tamping to avoid potential segregation that can affect the voids distribution and the permeability. Specimens were demoulded after being allowed to harden for 24 hours, which then later subjected to water curing until the respective testing ages.

Within the scope of this study, the compressive strength test is performed on the 7th and 28th days of age in accordance to ASTM C39. The porosity is examined on 7th and 28th days using the ASTM C1754 and constant head permeability test is tested on 28th days on the specimens using a non-standard method documented by Aoki (2009). The schematic diagram of the constant head permeability test setup is shown in Figure 3.

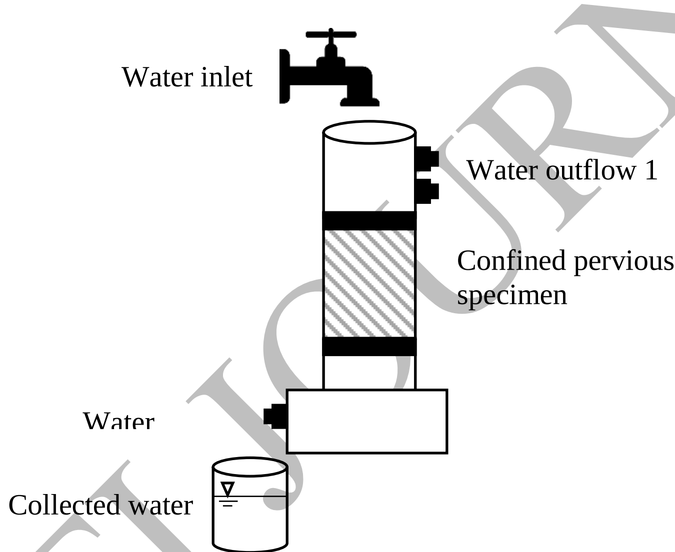

Figure 3: Schematic diagram of constant head permeameter used in this study

Results

Density

Figure 4 shows the density of the hardened cylinder pervious concrete specimen of different kenaf fibres addition at the age of 7th and 28th days. In general, the average density of the pervious concrete produced is approximately 1780kg/m^3. The density shows a steady decreasing trend with the amount of kenaf fibres added. It is also noticed that with kenaf fibres added, the density of the pervious concrete is relatively lower compared to the control specimens. Such variations could be associated to the varying degree of compaction when more and more kenaf fibres are added. Increasing amount of kenaf fibres restricts movement of aggregates during the compaction that eventually results in lower density. A difference of density at an approximate 60kg/m^3 was observed for pervious concrete specimens with 0.30% kenaf fibres addition. Such difference is primarily believed to be inattentive specimen handling during measurements that can caused detached of aggregate particles from the specimens.

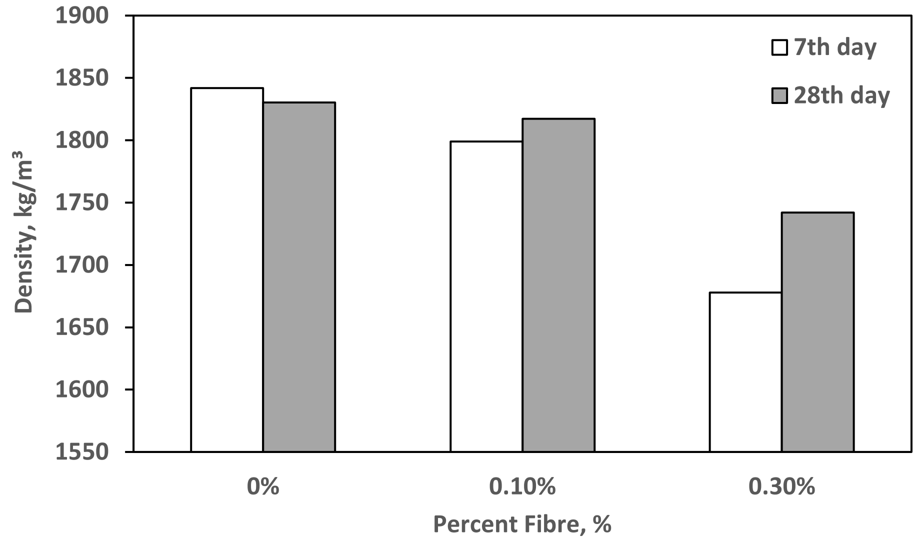

Figure 4: Density of pervious concrete at different age and kenaf fibres addition.

Porosity

Porosity of the three different batches of pervious concrete is shown in Figure 5. The average porosity of the specimens is approximately 33%. It is noticed from the findings that the percentage of pores for a given pervious concrete batch have very limited changes with respect to the testing age of the pervious concrete specimens. This is expected considering that hardened pervious concrete restricts any movements of the aggregates orientation, hence affecting the original void content initially formed during the compaction works. Nonetheless, it is worthwhile to note that porosity of the specimens increased with the addition of kenaf fibres.

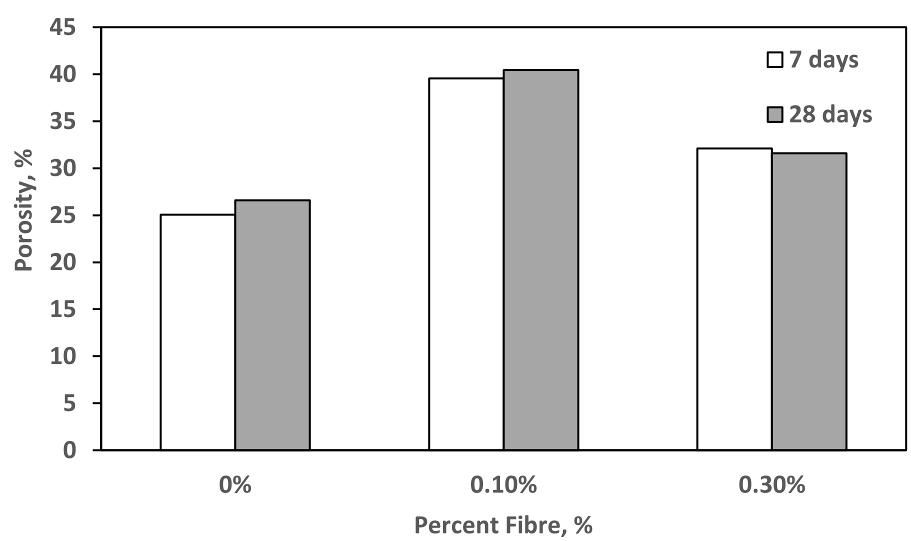

Figure 5: Porosity of pervious concrete at different age and kenaf fibres addition.

Water Permeability

The water permeability of the different batches of pervious concrete with different percentage of kenaf fibres added is presented in Figure 6. The measured water head during the testing is 50mm. On average, the range of water permeability of the pervious concrete is between 5.4 L/min to 6.3 L/min for a standard surface area of the 100mm diameter specimen. Addition of kenaf fibres significantly improved the water permeability of the pervious concrete specimen regardless of the quantity of the fibres added. Independent of the kenaf fibres added, the findings principally revealed the water permeability of the pervious concrete to be exceptional and capable to be accepted for public use where pervious medium is required for water transmission.

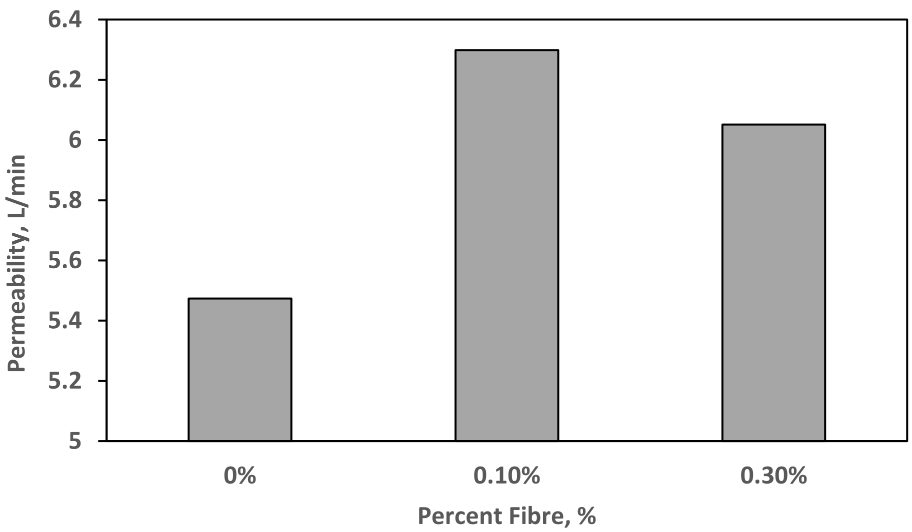

Figure 6: 28th day permeability of pervious concrete added with different kenaf fibres content

Relationship between porosity and permeability for pervious concrete

Figure 7 shows the relationship between the permeability and porosity of pervious concrete with kenaf fibres addition for all the specimens tested at 28th days. The analysis returns a fairly strong linear relationship between the permeability and porosity properties exhibits by the pervious concrete as described by the R-squared value of 0.61.

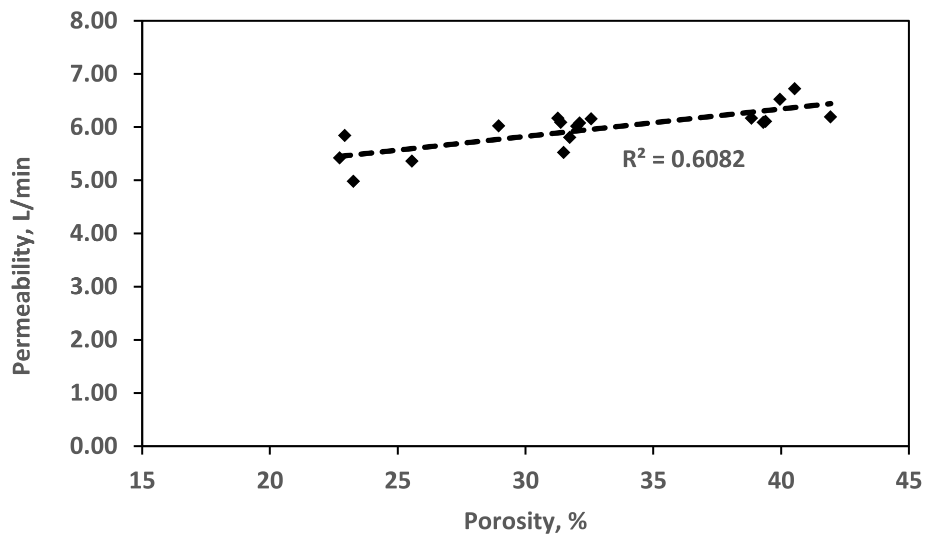

Figure 7: Linear relationship between permeability and porosity of pervious concrete containing kenaf fibres

Compressive strength of pervious concrete

Figure 8 illustrates the compressive strength of the pervious concrete mixture at the different testing age. It is noted that compressive strength of pervious concrete shows a distinct increment of strength from 7th to 28th days due to the hydration process between cement and water in developing the overall concrete strength. Generally, the specimens show an increment of 1MPa to 1.5MPa in compressive strength between the 7th and 28th days. However, adding kenaf fibres in pervious concrete shows no sign of contribution towards the compressive strength of pervious concrete especially when the quantity of kenaf fibres added is becoming more. Considering that water permeability as the key requirement for pervious concrete, the addition of kenaf fibres in pervious concrete could be still accepted. Under such consequence, the application of such mixture will have to be restricted at areas where excessive loadings is unlikely.

Relationship between porosity and compressive strength for pervious concrete

Figure 9 shows the relationship between the compressive strength of pervious concrete and the porosity at the 28th days. A second order polynomial relation of R-squared value 0.57 is recorded. Theoretically, the relationship of compressive strength and porosity should be a linear relationship. However, addition of kenaf fibres in the pervious concrete has changed the aggregate orientation inside the concrete and hence the porosity (shown in Figure 5) that give rise to the polynomial relationship between compressive strength and porosity of pervious concrete. As such, the second order polynomial relation in Figure 9 is limited to within the scope of this work only.

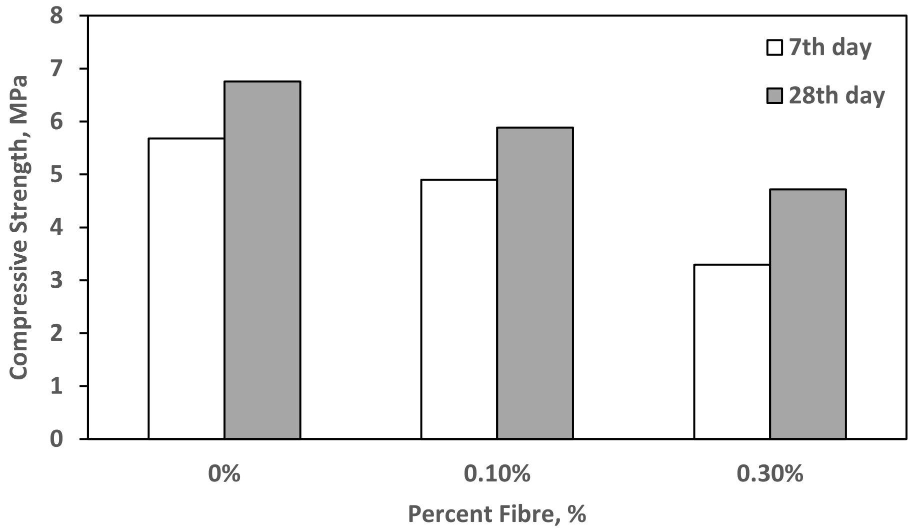

Figure 8: Effect of kenaf fibres addition on the compressive strength of pervious concrete

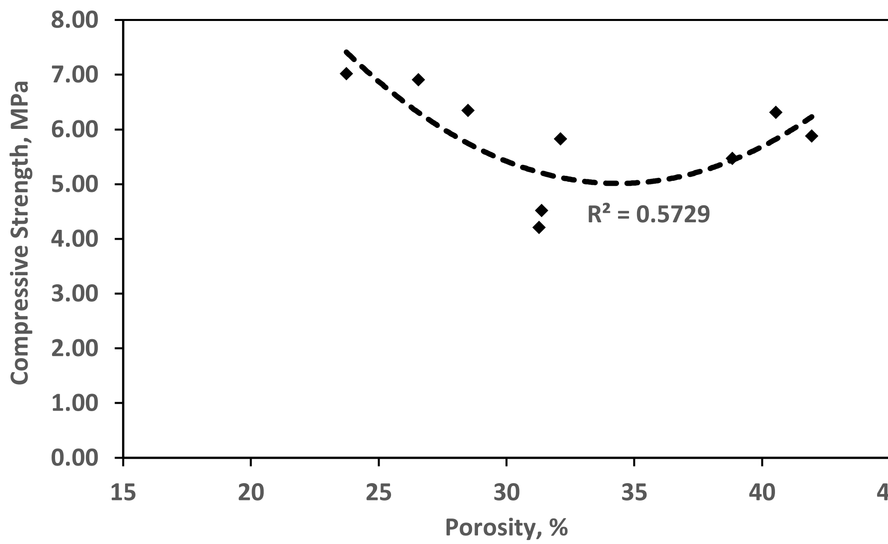

Figure 9: Relationship of compressive strength and porosity of pervious concrete

Discussion

The present study investigates the feasibility of adding kenaf fibres in pervious concrete. Considering the density, porosity, permeability and compressive strength test that were being carried out, there exist a non-uniform relationship between the four parameters tested. Porosity and permeability exhibits an expected linear relationship, indicating higher water flow when there exists more voids in the pervious concrete. As for compressive strength and porosity, a second order polynomial relationship is identified. An ideal condition would be a linear relationship between the two parameters that shows an increased in compressive strength with a reduction of voids, or vice versa. Such observation is most likely to be associated to the continuous addition of kenaf fibres and the hand tamping compaction method adopted in casting the pervious concrete. Continuous addition of kenaf fibres into the concrete mixtures leads to the agglomeration of cement paste and the aggregate particles when the fibres began to entangle, probably due to the length of the fibres itself. Such phenomenon is presented in Figure 10. The agglomeration destroyed the aggregate orientation, resulting in an uneven compaction of the specimens that in the end affected the porosity of the overall mixture. At the same time, the kenaf fibres added is capable of absorbing the water used for the mixing of pervious concrete. Such phenomenon prevents the proper hydration process of cement and water, especially when more fibres are added, resulting in a reduction of compressive strength of pervious concrete, presented in Figure 9 even though the voids content is much lower. Despite showing a relatively low compressive strength (approximately 6MPa) with 0.10% of kenaf fibres added, existing literatures reveals different application for pervious concrete of such nature at areas where excessive loadings is unlikely.

Figure 10: Presence of kenaf fibres produced agglomeration of cement paste, fibres and aggregate particles, affecting the aggregate orientation and void distribution.

Conclusions and Recommendations

Three pervious concrete mixtures made with 0%, 0.1% and 0.3% of kenaf fibres addition were investigated for its properties. The density, porosity, water permeability and compressive strength were determined. The 28th day compressive strength obtained were in the range of 4.7MPa to 6.8MPa. High porosity of 26% to 40% leads to high water permeability of 5.5 to 6.3 L/min. Based on the results obtained in this study, linear relationship between porosity and permeability were identified regardless of the quantity of fibres added. Agglomeration of cement paste and aggregates particle due to the addition of kenaf fibres has affected the aggregates and the voids orientation that yielded a non-linear relationship of compressive strength and porosity. Nonetheless, the results showed that the most important property of pervious concrete – the water permeability was not significantly reduced in the presence of kenaf fibres. It is therefore concluded that addition of kenaf fibres in pervious concrete is feasible and worth to be investigated further. As of that, several recommendations are made to improve the study. It is recommended to chemically treat the kenaf fibres and to reduce the length from 20mm to 10mm in order to avoid the entangling of fibres, hence reducing the agglomeration. Since there exist a 40% voids at 0.1% of kenaf fibres addition, modification on the mix design can be done to further reduce the voids and anticipating for higher compressive strength. Finally, it is also recommended to extend the study to examine the efficiency of kenaf fibres in pervious concrete to act as a primary absorbent for treating runoff water circulating through the medium.

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