Permeability and Mechanical Properties of Pervious Concrete Curb with Different Aggregate Sizes

C. N. A. Lian, M. H. Jamal, and Z. Ibrahim

Abstract Pervious concrete is an environmentally friendly material that can be a feasible option in solving urban drainage problems and mitigating climate change. This research aims to evaluate the mechanical and hydraulics properties of pervious concrete with different aggregate sizes and propose the acceptable aggregate size for road curb. Pervious concrete mixes are prepared with single-sized aggregates (4.75, 8, 12.5 and 16 mm) with constant aggregate cement and water-cement ratios. Furthermore, a series of tests were conducted in this study, such as compressive strength, porosity, and permeability. The experimental result showed that the size of coarse aggregate affects the strength and permeability of the specimens. The permeability and porosity decrease as the aggregate size increases. The smaller aggregate size is beneficial to increase the 28 days compressive strength of pervious concrete. Linear regression relationships were developed to establish relationships between porosity and compressive strength and porosity and permeability. The obtained result showed that the aggregate size of 8 mm performed better than the others in all assessments and could be applied on pervious concrete curb.

Keywords Pervious concrete · Road curb · Permeability · Compressive strength · Porosity · Aggregate size

1 Introduction

Rapid urbanization has risen in impervious surfaces such as highways and roofs, dramatically altering the normal hydrological cycle in urban areas [11, 25, 35]. The

C. N. A. Lian (✉) · M. H. Jamal · Z. Ibrahim
Department of Hydraulics and Hydrology, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai, Malaysia
e-mail: nipi@graduate.utm.my

M. H. Jamal
e-mail: mhidayat@utm.my

Z. Ibrahim
e-mail: zulkfe@utm.my

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impact of these changes is related to hydrological and environmental problems, including flash floods due to exceeded discharge capacity of the existing stormwater drainage system [27]. Stormwater drainage system comprises many linking structure such as street gutter and inlet which collect access stormwater from the street and convey it to the underground drainage system. Unfortunately, even though the drainage system has been provided with those inlets, it is still less efficient to remove stormwater on the road surface. Some systems are not fully utilized because of some factors such as clogging the inlet opening by debris [14, 17], the uncertainty design leads to oversize or undersize of the inlet [16, 37] and inappropriate inlet spacing and location [15]. Poorly managed runoff on impervious surfaces will produce some undesirable conditions, such as water spread and ponding onto the roadway which leads to hydroplaning [42]. These conditions will negatively affect vehicle performance and create safety hazards [12, 38], thereby increasing the probability of traffic stagnation and road accidents.

Although various ways have been done to increase the effectiveness of inlets, flood problems still occurred. Among various strategies, pervious concrete pavement technology has been widely used all over the world. Pervious concrete is recognized among the best management practice (BMP) by Environmental Protection Board [7]. This technology provides a solid structure for allowing rainwater to infiltrate naturally into the ground, recharging aquifers and reducing stormwater runoff [47]. Pervious concrete also has been developing in many applications as paving roads, sidewalks and non-structural components [30].

Pervious concrete is a composite with the same essential components as standard concrete engineered to have a large porosity between 15 and 35% [7, 11, 23, 41] and permeability ranging between 1.4 to 12.2 mm/s [20, 44]. Pervious concrete is a combination of Portland cement, coarse aggregate, and water, with or without a limited volume of fine aggregate. Pervious concrete has excellent drainage properties and high noise absorption characteristics [21, 31] due to its high porosity, critical attributes of a quality pavement. Pervious concrete mixtures may have densities ranging from 1600 to 2000 kg/m^3 [33, 40] with the typical compressive strength in the range of 2.8 to 28 MPa [7, 28, 39]. Pervious concrete's poor strength affects the structure's stability and durability because of its vulnerability to frost loss and chemical tolerance. Because of its poor strength, previous concrete has limited application in constructing high traffic highways and low load structures [26]. Porous concrete should achieve maximum function by having efficiency criteria in delivering greater mechanical capabilities while accommodating the porosity of the concrete [8, 19].

Usually, pervious concrete comprises single aggregates in sizes ranging from 19–9.5 mm to obtain sufficient pores in the concrete [7]. However, several studies have used aggregate sizes ranging from 9.5 to 2.36 mm are provided to enhance the strength of PC [11, 29, 43]. Studies conducted by Deo and Neithalath [13], Nguyen et al. [32] have used coarse aggregates with sizes ranging from 16 to 2.35 mm to improve the strength properties. Usage of minor aggregate exhibited compressive and flexural strength, meanwhile, larger aggregate resulted in greater permeability and porosity [9, 19, 45].

Nevertheless, not all areas are capable of providing a pervious concrete road because of its constraints such as expensive cost, less expertise and complicated design [10, 46]. Therefore, the use of pervious concrete technology can be applied for the road curb as an alternative solution, which can provide high permeability compared to the concrete curb to support urban stormwater drainage facilities. Also, by installing a pervious concrete curb on the roadside, the stormwater was supposed to have the self-draining capacity to penetrate the side surface of the porous landscape without relying on the quality and position of the inlet. Thus, this pervious curb would provide as part of the stormwater collection scheme aside from serving as a lane delineation.

The main objective of this study is to evaluate the suitable pervious concrete properties for road curb application. Therefore, several pervious concrete mixes with different aggregate sizes were produced for testing. This information is essential to understand the pervious concrete properties that achieved the standards required to produce road curbs.

2 Materials

The primary experimental materials used are Ordinary Type 1 Portland cement, gravel aggregate and water. In this study, pervious concrete specimens were proportioned using four sizes of coarse aggregate, namely 4.75, 8, 12.5 and 16 mm procured from one distinct source of the quarry. The physical properties of coarse aggregate were measured according to BS EN 1097-6 [4] specification and given in Table 1. The grading was conducted by sieve analysis standard BS EN 12,620 [3] to obtain the size of coarse aggregate. The coarse aggregates are well graded as their sizes are within the grading limit graphically represented in Fig. 1. The polymer adhesive and rice husk ash were used as a binder in the mixture to increase the strength of pervious concrete. A sulphonated naphthalene polymers-based superplasticizer was also applied to the mix to increase the workability of concrete.

Table 1 Physical properties of aggregate

Properties	4.75 mm	8 mm	12.5 mm	16 mm
Water absorption (%)	4.8	4.8	1.3	1.0
Specific gravity	2.3	2.5	2.6	2.7
Bulk density (kg/m^3)	1240	1308	1277	1260

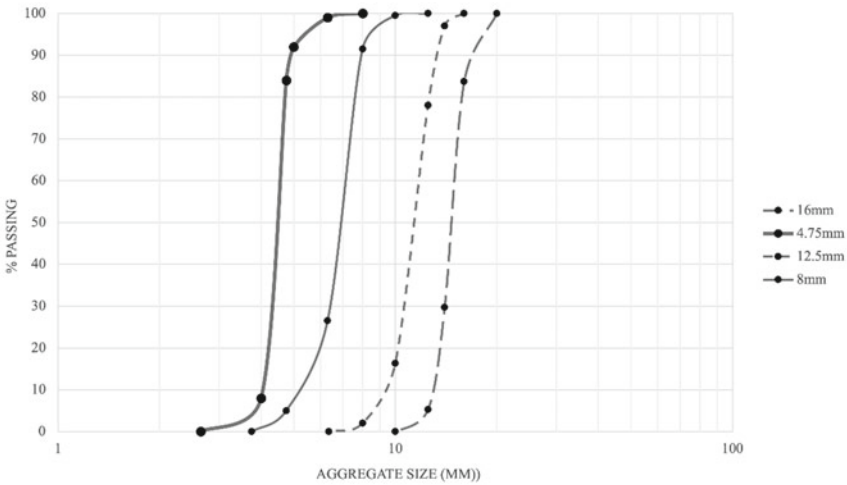

Fig. 1 Particle size distribution curve of aggregate

Table 2 Pervious concrete mix design proportion

Aggregate size (mm)	w/c ratio	a/c ratio	Cement (kg/m^3)	Water (litre)	Superplasticizer (%)	Rice husk ash (%)	Adhesive polymer (%)
4.75	0.4	4	395	158	0.3	5	5
8	0.4	4	395	158	0.3	5	5
12.5	0.4	4	395	158	0.3	5	5
16	0.4	4	395	158	0.3	5	5

2.1 Concrete Mix Design

The pervious concrete mixture, according to Chandrappa and Biligiri [10] is dependent on structural parameters such as a/c ratio, aggregate size, w/c ratio, and aggregate gradation. The a/c ratio, cement content, and w/c ratio values were chosen based on local material properties and trial and error method following the guideline by ACI [7]. The final pervious concrete mix proportion is shown in Table 2.

2.2 Specimen Preparation and Testing

The standard procedure for making and curing cubes was followed according to established [7]. All of the ingredients of pervious concrete consist of cement, coarse aggregate and admixtures, were first weighed as per mix design proportion. The

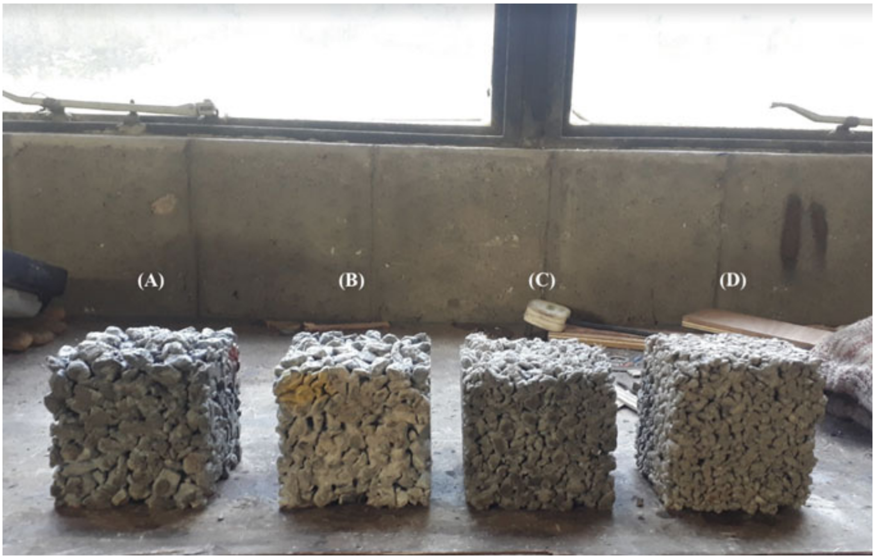

Fig. 2 Pervious concrete cube sample **A** CA20 mm **B** CA16 mm **C** CA8 mm **D** CA4 mm

ingredients were blended for at least two minutes with the aid of a revolving drum mixer to achieve homogeneity of the mixture. The steps are followed by adding the measured amount of water to produce a uniform paste for binding the aggregates together. Finally, the superplasticizer was added altogether with remaining water in the pervious concrete mixture for about another minute, which depended on the workability of the fresh concrete mixture. The concrete mix was compacted using steel tamping rodding in three layers, each of 25 blows, accompanied by vibration on a vibrating table for 2 s to provide proper layer finishing. According to ACI [7], there is no specific requirement for laboratory compaction prepared for pervious concrete sample. After 24 h, the specimens were demolded and placed in a water tank at room temperature for 28 days of water curing. The outcomes of all mixes are shown in Fig. 2.

2.3 Porosity Test

The porosity test was conducted after of 28 days cured specimens and calculated based on Eq. (1) determined by **ASTM C1754,** which is shown below:

$$P = 1 - \frac{m_{1-}m_2}{V.\rho_\omega} \times 100 \tag{1}$$

where, P is the porosity, m_1(kg) is the dry sample mass of the oven, m_2(kg) is the sample mass of water saturation, ρ_ω (kg/m^3) is the density of water, and V(m^3) is the total sample volume.

2.4 Permeability Test

A constant head test was designed in the laboratory to evaluate the water permeability of the samples. The ACI [7] recommends the constant head permeability test because it meets the Darcy Law theorem [36]. The value permeability coefficient, k of specimens directly from Darcy's law is determined by Eq. (2).

$$\mathrm{k} = \frac{QL}{hAt} \tag{2}$$

where K is the permeability coefficient of the sample (mm/s), Q is the volume of water flow between time (m^3/s), L is the length of the sample (mm), A is the top cross-sectional area of the specimen (mm^2), h is the water head differences (mm), and t is the time measured (s).

2.5 Compressive Strength Test

The compressive strength was tested at 7 days and 28 days after curing, according to BS EN 12390-3 [5] using an automatic compression machine with a loading speed of 3000kN. The compression loaded to failure at a constant rate of 3 kN/s [6, 34] and the maximum load was recorded. The average compressive strength of three samples is taken to perform for each mix proportion. The compressive strength of the specimen was calculated by using Eq. (3).

$$f_i = \frac{P}{A} \tag{3}$$

3 Result and Discussion

The effects of size aggregate of 4.75, 8, 12.5 and 16 mm, were investigated in this result. The density, porosity, water permeability, and compressive strength tests conducted on this sample are summarized in Table 3. Compressive strength was tested at 7 and 28 days. Porosity and permeability tests were carried out for 28 days.

Table 3 Summary of the test value

Aggregate size (mm)	Porosity (%)	Permeability (mm/s)	Compressive strength on 7 days (Mpa)	Compressive strength on 28 days (Mpa)
4.75	30	7.42	3.7	4.4
8	32	12.54	3.5	4.3
12.5	33	13.37	2.9	4.2
16	35	16.43	2.3	3.4

3.1 Porosity

Porosity is the most dependent parameter for invaluable concrete mixes, and therefore, its evaluation of the sample is a requirement in this study. Table 3 shows the results for each sample measured to calculate the porosity. The average void content from smallest to largest size was estimated at approximately 30%, 32%, 33% and 35%, respectively as in Fig. 3. As expected, the largest aggregate size of 16 mm has to produce the highest porosity value up to 35%. The smallest aggregate size of 4.75 mm has contributed the lowest porosity in 30%. The higher porosity occurs due to the inclusion of larger sized aggregates that may have induced more interconnected macropores and possess the largest void spaces within the sample. In other words, the porosity of pervious concrete is closely related to its voids structure. The porosity value of the samples was also found to be in the range of 35 to 30%, which is consistent with the recommended porosity values for pervious concrete mixes [7] and [30].

3.2 Compressive Strength

The size of the aggregates has a significant impact on the compressive strength of pervious concrete. Table 3 show that for 28 days compressive strength of pervious concrete was between 3.4 to 4.4 Mpa. The mixture produces a 4.75 mm aggregate size with the highest compressive strength, followed by 8 mm, 12.5 mm, and 16 mm, respectively. Figure 4 showed a decrease in compressive strength as coarse aggregate size increased. This variation in compressive strength values can be attributed to the increasing amount of voids inside the samples, which play an essential role in determining the strength of pervious concrete mixes. The presence of pore structure in the concrete has a decisive effect on the strength of concrete. Furthermore, it can also be observed that its specific surface area decreases when the aggregate size increases. Hence, the contact points between the aggregates decrease, which makes the strength of the concrete low. The reduction of strength is also because the mixture is free from fine aggregate, and the cement paste coating is the primary source of the compressive strength. Similar result was also observed and well-explained in another

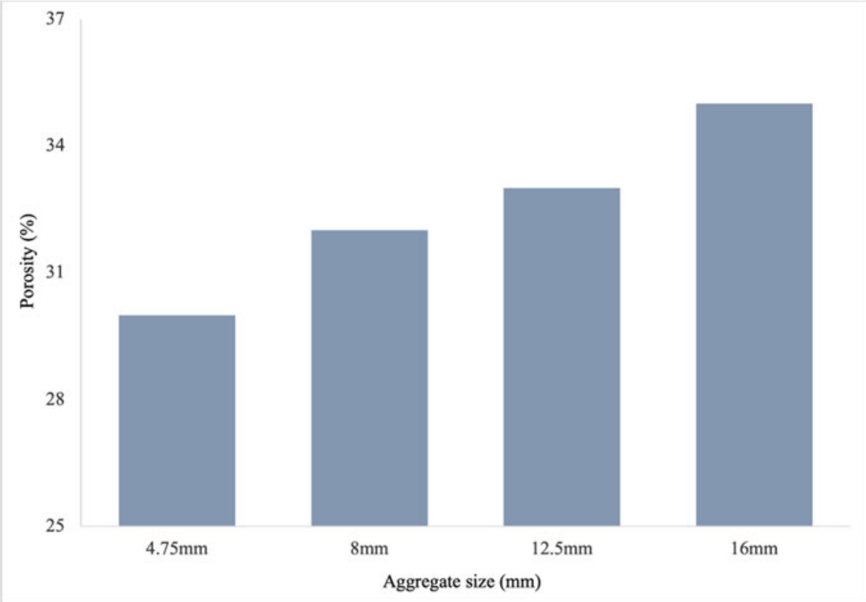

Fig. 3 Porosity of pervious concrete with different coarse aggregate sizes

research [19, 22]. Furthermore, as expected, the 28 days compressive strength were higher than those of 7 days, as the pervious concrete matured. It means strength is directly proportional to time. Therefore, the 28 days compressive strength of all the tested mixes was within the generally acceptable range, which is the compressive strength of conventional pervious concrete is usually lower than 20 MPa. These values also fall within the values stipulated by ACI [7], which is 2.8–28 Mpa. For pervious concrete used as pavement materials, the compressive strengths are restricted from 3.5 to 28 MPa [40, 48]. Therefore, the studied mixes also conform to the compressive strength requirement for curbs application.

The influence of porosity on compressive strength is shown in Fig. 5. As seen in Fig. 5, compressive strength decreases linearly with increasing porosity values. The R^2 value of 0.847 shows a good correlation between compressive strength and porosity. The results verify the generally accepted rule that porosity and compressive strength are inversely related.

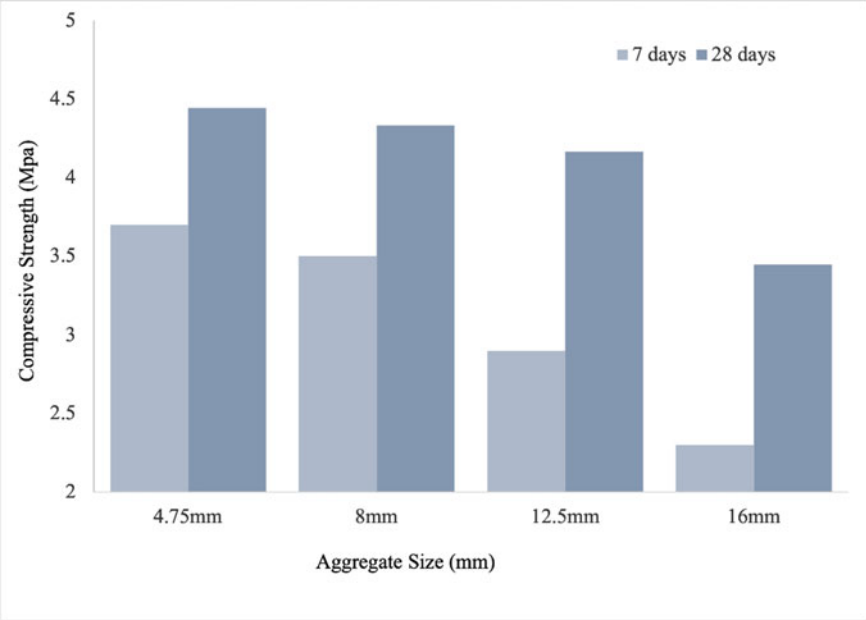

Fig. 4 Compressive strength of pervious concrete with different coarse aggregate sizes

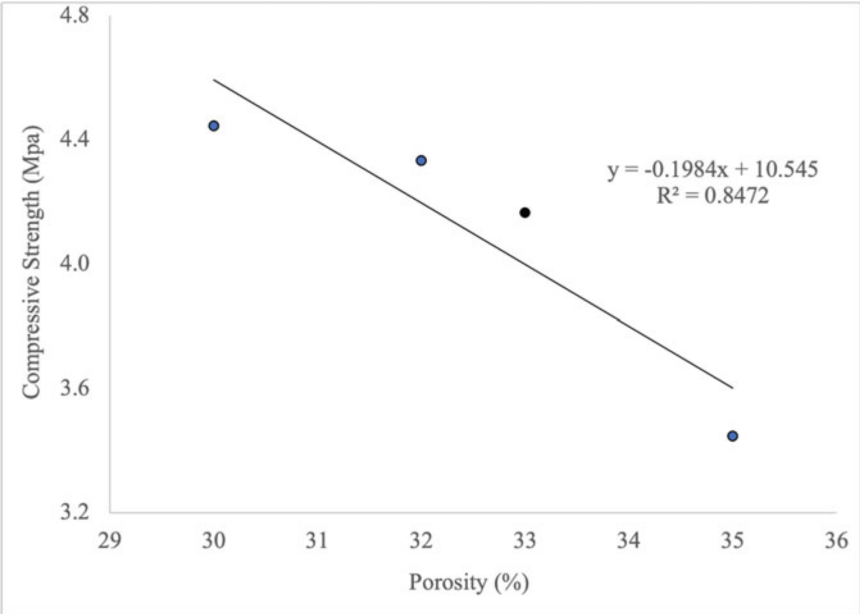

Fig. 5 Relationship between porosity and compressive strength of pervious concrete

3.3 Permeability

Permeability is a critical property in the successful functioning of permeable concrete systems. The permeability of pervious concrete greatly depends on the aggregate size. According to Table 3, the average permeability coefficient for each mix is 16.43 mm/s for size 16 mm, 13.37 mm/s for size 12.5 mm, 12.54 mm/s for size 8 mm and 7.42 mm/s for 4.75 mm, respectively. The permeability coefficient of all samples increases as the aggregate size increases as shown in Fig. 6. As aggregate size increases, bulk density decreases, the contact point between aggregate and cement paste decrease, internal pore diameter increases, pore tortuosity decreases, and more attached pores emerge within, resulting in an improvement in permeability coefficient. A similar result was also observed in Li et al. [24]. Regarding the permeability performance, it was found that all the mixtures had coefficient permeability values obtained between 7 mm/s to 17 mm/s, which is within the acceptable specification of ACI [7].

The relationship between permeability and porosity is a power function following a Cozeny Karmen model. Figure 7 shows permeability as a function of porosity. The significant linearity indicates that the porosity of pervious concrete strongly influences permeability. As the porosity increases, the permeability increases correspondingly, which more void allows more water to sip through the porous concrete. The study used Eq. (3) to estimate permeability with an adjusted R^2 value of 0.9636.

$$k(mm/s) = 1.76x + 44.9$$

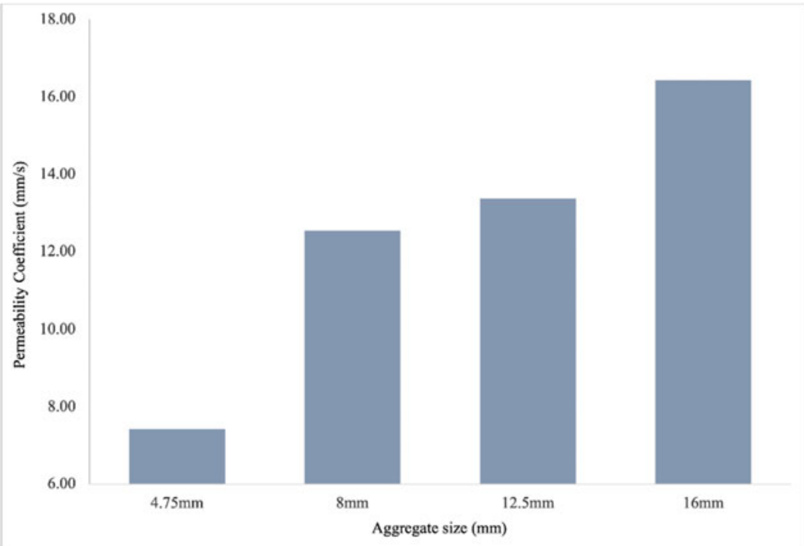

Fig. 6 Permeability of pervious concrete with different coarse aggregate sizes

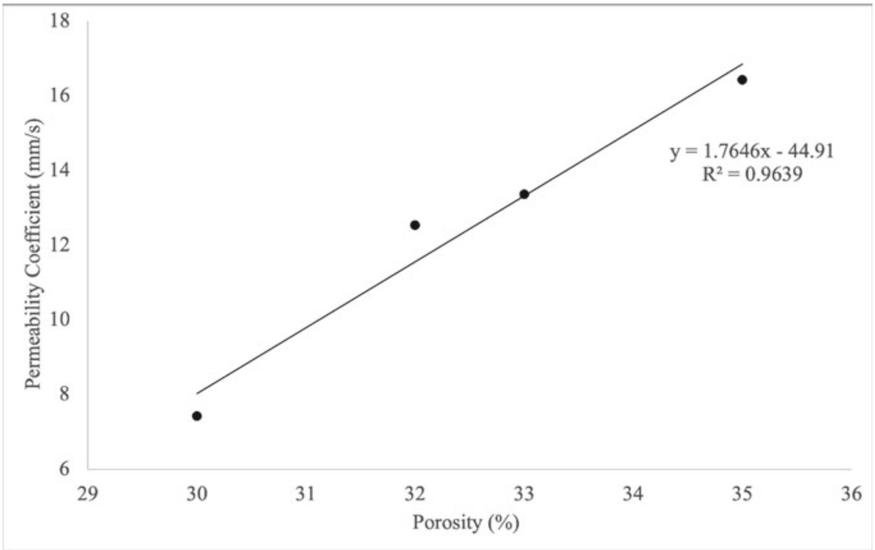

Fig. 7 Relationship between porosity and permeability of pervious concrete

4 Conclusion

An experimental investigation was conducted to examine the influence of aggregate size on pervious concrete's mechanical and permeability characteristics. The study investigated the porosity, compressive strength and water permeability. Based on observed data in this study, the following conclusions have been discussed.

The overall pervious concrete curb performance was chosen based on standard properties requirements and practicality on site. The recommendations were based on the 15 to 25% standard requirement for porous concrete according to porosity property. The selection for permeability characteristics is based on the acceptance criterion, ranging between 1.4 to 12.2 mm/s. For compressive strength, the mixtures should develop compressive strengths in the range of 3.5 to 28 MPa, suitable for a wide range of applications. Based on the overall performance of the static test, all the results were achieved the requirement guidelines by ACI [7]. which applies for the low load structural application as walkways. The aggregate size of 8 mm was considered the most optimum and appropriate size that can satisfy the permeability coefficient of 12.54 mm/s, the porosity of 32% and the compressive strength of 4.3 Mpa.

For the practically on-site, the selection of 8 mm aggregate size can produce a finer texture curb surface which is more aesthetically pleasing for the product. Otherwise, using a larger aggregate size would not be advisable due to the rougher surface and low strength provided. The mixture using 4.75 mm is also not recommended because of low voids and permeability characteristics. Furthermore, the size of 8 mm is also more practical to apply as it has much availability by the local supplier.

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