International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 2 No. 5, May, 2012

# Evaluation of Structural Performance of Pervious Concrete in Construction

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## ABSTRACT

The permeability and strength of pervious concrete depend on the particle sizes and proportions of the constituent materials of which the concrete is made of. In this paper, structural property and permeability of pervious concrete made with different coarse aggregate sizes is presented. For the different aggregate/cement ratio used in this study, coarse aggregate size 9.375 mm has higher compressive strength values compared to those made from 18.75 mm aggregate size while 18.75 mm aggregate size had higher permeability value compared to that of 9.38 mm. The average specific gravity of the two aggregates sizes used was 2.7.

Aggregate/cement ratio of 6:1, 8:1 and 10:1 respectively were used to produce three different batches of fresh concrete using 18.75mm aggregate size and same ratios were used for 9.375mm coarse aggregate size to produce another three different batches. In each case, aggregate/cement ratio of 6:1 gave the highest compressive strength compared to other aggregate/cement ratio of 8:1 and 10:1. The highest compressive strength obtained was 8.2N/mm$^2$ and 10.8N/mm$^2$ respectively for 18.75mm and 9.375mm coarse aggregate sizes. These values fall within the values stipulated by ACI 552R-10 (2.8N/mm$^2$-28 N/mm$^2$). It was found that the aggregate/cement ratio of 10:1 produced pervious concrete of higher co-efficient of permeability of 3.12x10$^{-3}$cm/sec and 3.89x10$^{-3}$cm/sec for aggregate size 9.375mm and 18.75mm respectively.

**Keywords:** *pervious concrete, permeability, compressive strength, aggregate size, porosity*

## 1. INTRODUCTION

Pervious concrete which is also known as the no-fines, porous, gap-graded, and permeable concrete and enhance porosity concrete has been found to be a reliable storm water management tool (Mary, 2010). By definition, pervious concrete is a mixture of gravel or granite stone, cement, water, little to no sand (fine aggregate) with or without admixtures. When pervious concrete is used for paving (Figure 1), the open cell structures allow storm water to filter through the pavement and into the underlying soils. In other words, pervious concrete helps in protecting the surface of the pavement and its environment.

As stated above, pervious concrete has the same basic constituents as conventional concrete that is, 15% -30% of its volume consists of interconnected void network, which allows water to pass through the concrete. Pervious concrete can allow the passage of 3-5 gallons (0.014 - 0.023m$^3$) of water per minute through its open cells for each square foot (0.0929m$^2$) of surface area which is far greater than most rain occurrences. Apart from being used to eliminate or reduce the need for expensive retention ponds, developers and other private companies are also using it to free up valuable real estate for development, while still providing a paved park.

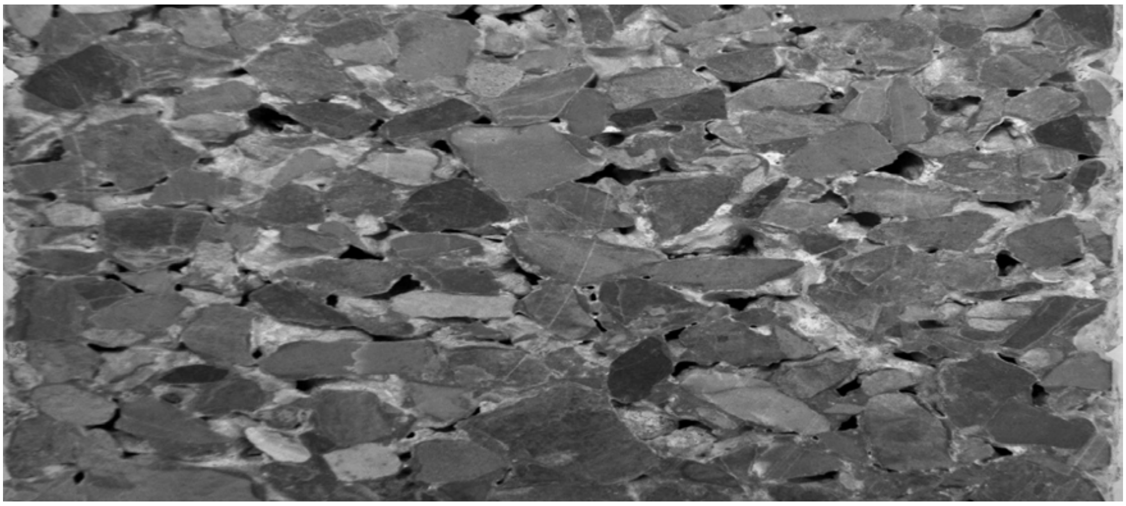

**Figure 1: Polish surface of a pervious concrete pavement (Source: Mary et al, 2010)**

Pervious concrete is also a unique and effective means to address important environmental issues and sustainable growth. When it rains, pervious concrete automatically acts as a drainage system, thereby putting water back where it belongs. Pervious concrete is rough textured, and has a honeycombed surface, with moderate amount of surface ravelling which occurs on heavily travelled roadways (Concrete network, 2009). Carefully controlled amount of water and cementitious materials are used to create a paste (Dan, 2003). The paste then forms a thick coating around aggregate particles, to prevent the flowing off of the paste during mixing and placing. Using enough paste to coat the particles maintain a system of interconnected voids which allow water and air to pass through. The lack of sand in pervious concrete results in a very harsh mix that negatively affects mixing, delivery and placement. Also, due to the high void content, pervious concrete is light in weight (about 1600 to 1900kg/$m^3$). Pervious concrete void structure provides pollutant captures which also add significant structural strength as well. It also results in a very high permeable concrete that drains quickly.

Pervious concrete can be used in a wide range of applications, although its primary use is in pavements (Vimy et al, 2009) which are in: residential roads, alleys and driveways, low volume pavements, low water crossings, sidewalks and pathways, parking areas, tennis courts, slope stabilisation, sub-base for conventional concrete pavements etc.

Pervious concrete system has advantages over impervious concrete in that it is effective in managing run-off from paved surfaces, prevent contamination in run-off water, and recharge aquifer, repelling salt water intrusion, control pollution in water seepage to ground water recharge thus, preventing subterranean storm water sewer drains, absorbs less heat than regular concrete and asphalt, reduces the need for air conditioning. Pervious concrete allows for increased site optimization because in most cases, its use should totally limit the need for detention and retention ponds, swales and other more traditional storm water management devices that are otherwise required for compliances with the Federal storm water regulations on commercial sites of one acre or more. By using pervious concrete, the ambient air temperature will be reduced, requiring less power to cool the building. In addition, costly storm water structures such as piping, inlets and ponds will be eliminated. Construction scheduling will also be improved as the stone recharge bed will be installed at the beginning of construction, enhancing erosion control measures and preventing rain delays due to harsh site conditions (Vimy et al, 2009).

Apparently, when compared to conventional concrete, pervious concrete has a lower compressive strength, greater permeability, and a lower unit weight (approximately 70% of conventional concrete). However, pervious concrete has a greater advantage in many regards. Nevertheless, it has its own limitations which must be put in effective consideration when planning its use. Structurally when higher permeability and low strength are required the effect of variation in aggregate size on strength and permeability for the same aggregate cement ratio need to be investigated.

## 2. AIM OF THE STUDY

The aim of this study is to evaluate the structural performance of pervious concrete in civil engineering construction. To achieve this, the effects of varying the aggregate size on the porosity, compressive strength and specific gravity of pervious concrete were studied. The study covers the simple use of pervious concrete as pavement material in the construction of pedestrian walkways and parking lots.

## 3. SIEVE ANALYSIS OF COARSE AGGREGATE

Using a stack of sieves (BS410), the samples of the coarse aggregates used were graded into two main particle sizes, mainly sample A of 18.75mm and sample B of 9.375mm. The result of the test is as shown in Figure 2 and Figure 3 respectively for samples A and B

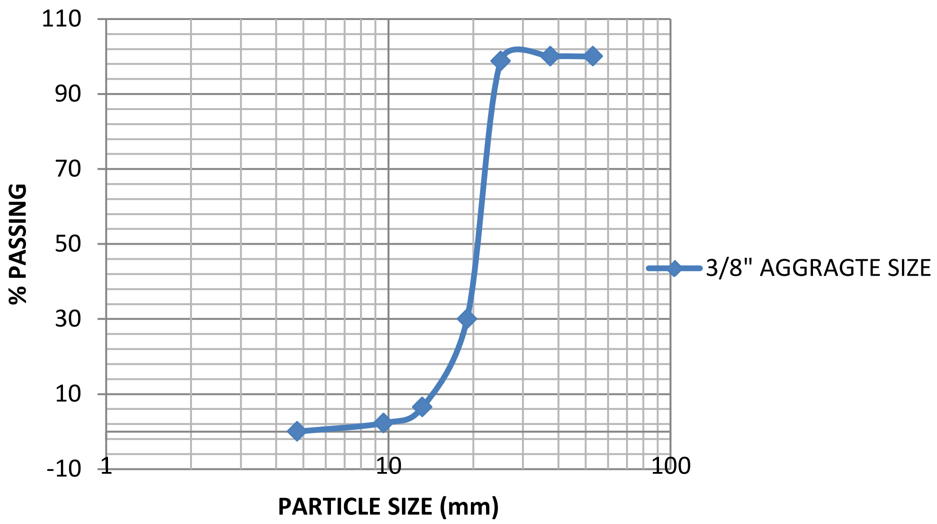


**Figure 2: Gradation Curve for 9.375 mm Aggregate Sizes**

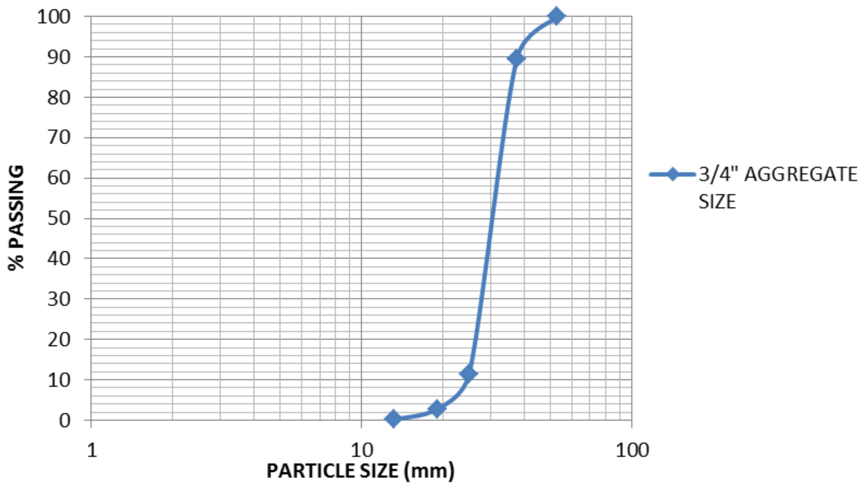


**Figure 3: Gradation Curve for 18.75 mm Aggregate Sizes**

## 4. PREPARATION OF TEST SPECIMEN

Three batches of test specimen were produced from each of the aggregate size representing aggregate cement ratios of 6:1, 8:1 and 10:1 with no fines in the mixes. The materials were batched by weight as in Table 3.

As earlier stated, two different sizes of coarse aggregate (crushed stone or granite) were used in this study. The sizes are 3/8-inch (9.375mm) and 3/4-inch (18.75mm) granite. The specific gravity test carried out on the two aggregate sizes gave average value of 2.7. For the two aggregate sizes, the mix proportions were done by weight. From each of the batches, 8 of 150mm concrete cubes were taken. The mix proportioning are as shown in Table 3.

**Table 3: Mix Proportion by weight of Aggregate and Cement**

| Ratio | Weight of aggregate (kg) | Weight of cement (kg) | Volume produced ($m^3$) |
|---|---|---|---|
| 6:1 | 37.5 | 6.25 | 0.025 |
| 8:1 | 50.0 | 6.25 | 0.029 |
| 10:1 | 62.5 | 6.25 | 0.033 |

The batched materials are thoroughly hand-mixed with water so as to obtain uniform and homogenous pervious concrete. Water/cement ratio of 0.4 was added to form a cement paste, ACI 211.3R (2002) stipulates that the ratio should be between 0.35 and 0.45. A total of 24 cubes were produced for each aggregate size for different mix ratio of 6:1, 8:1 and 10:1 of coarse aggregate and cement.

## 5. COMPRESSIVE STRENGTH TEST

The aim of the test is to determine the compressive strength of pervious concrete. The test was carried out in accordance with BS1881-108: 1983 and ACI 522R-10. The cubes were tested for compressive strength (Figure 4) at specify ages of 7, 14, 21 and 28 days of curing. The compressive strength of pervious concrete is calculated thus:

$$\text{Compressive strength} = \frac{crushing\ load\,(kN)}{area\ of\ cube\,(m^2)} \qquad \ldots\ldots\ldots.1$$


Pervious concrete cube

**Figure 4: Compression Testing Machine (Controls Milano-Italy, range: 0 – 1500 kN)**

The compressive strength of the pervious concrete increases with increase in age and as the aggregate/cement ratio reduces as observed in Table 4 and 5. Also, the compressive strength of the 3/8'' aggregate is greater than that of 3/4'' for the same age and aggregate/cement ratios as shown in tables 4 and 5.

**Table 4: Compressive Strength at age 7, 14, 28, 21 days for 6:1, 8: 1 and 10:1 Aggregate/Cement ratio and aggregate size of ¾"**

| Age (Days) | Water/Cement ratio | Aggregate/Cement ratio | Average Compressive Strength ($KN/m^2$) |
|---|---|---|---|
| 7 | 0.4 | 6:1 | 3.333 |
| 14 | | | 5.722 |
| 21 | | | 6.833 |
| 28 | | | 8.200 |
| 7 | 0.4 | 8:1 | 2.222 |
| 14 | | | 4.111 |
| 21 | | | 4.445 |
| 28 | | | 5.111 |
| 7 | 0.4 | 10:1 | 2.000 |
| 14 | | | 2.956 |
| 21 | | | 3.667 |
| 28 | | | 4.333 |

**Table 5: Compressive Strength at age 7, 14, 28, 21 days for 6:1, 8: 1 and 10:1 Aggregate/Cement ratio and aggregate size of 3/8"**

| Age (Days) | Water/Cement ratio | Aggregate/Cement ratio | Average Compressive Strength ($kN/m^2$) |
|---|---|---|---|
| 7 | 0.4 | 6:1 | 5.778 |
| 14 | | | 8.815 |
| 21 | | | 9.777 |
| 28 | | | 10.810 |
| 7 | 0.4 | 8:1 | 3.481 |
| 14 | | | 4.444 |
| 21 | | | 5.852 |
| 28 | | | 8.074 |
| 7 | 0.4 | 10:1 | 3.407 |
| 14 | | | 3.852 |
| 21 | | | 4.593 |
| 28 | | | 7.185 |

Aggregate/cement ratio of 6:1, 8:1 and 10:1 had compressive strength of 29%, 18% and 15% respectively of $28N/mm^2$ which is the maximum value stipulated by ACI 552R-10 on 28th day of curing for aggregate size 3/4" and also supported by Ann (2005). In addition, for the same aggregate cement ratio(6:1,8:1and 10:1) the compressive strength of the concrete were found to be 39%, 29% and 26% of the value stipulated by ACI 552R-10 which is 28 $N/mm^2$ for aggregate size 3/8".

Conclusively, the A/C of 6:1 had the highest value of compressive strength and aggregate size 3/8" produced the best results.

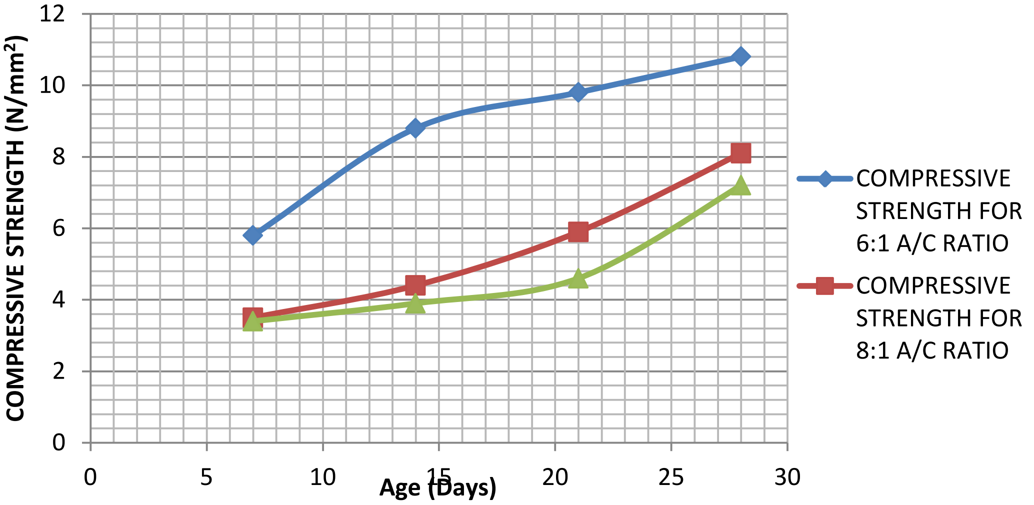


**Figure 5: Compressive Strength of Pervious concrete of 3/8'' Aggregate size at different Aggregate-Cement Ratio**

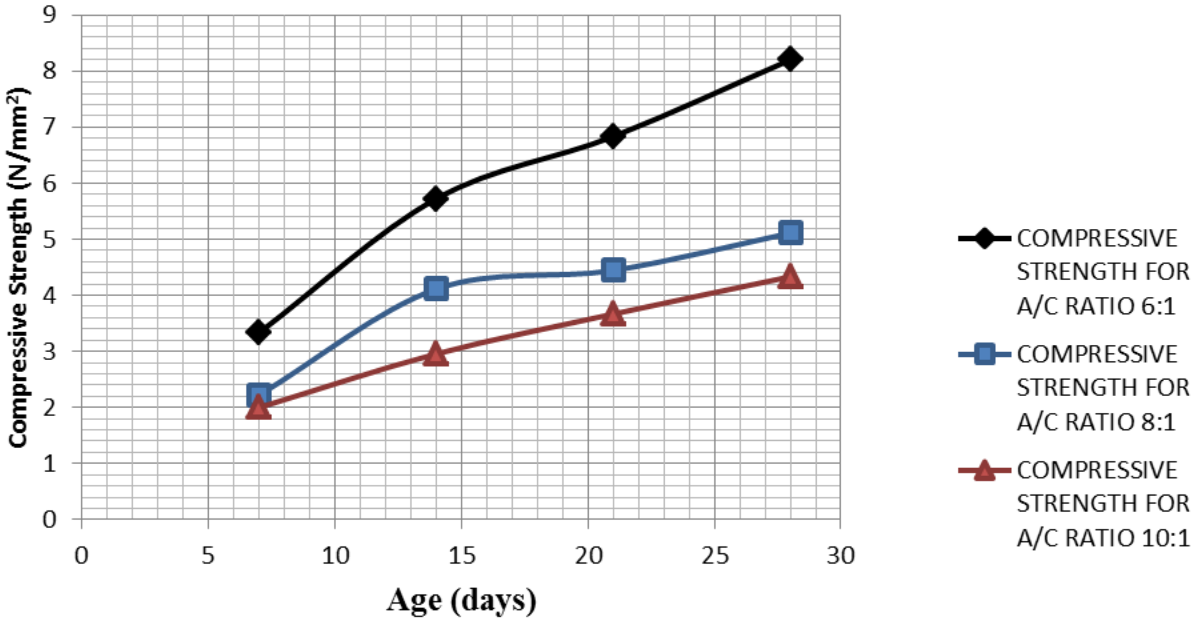


**Figure 6: Compressive Strength of Pervious concrete of 3/4" Aggregate size at different Aggregate-Cement Ratio**

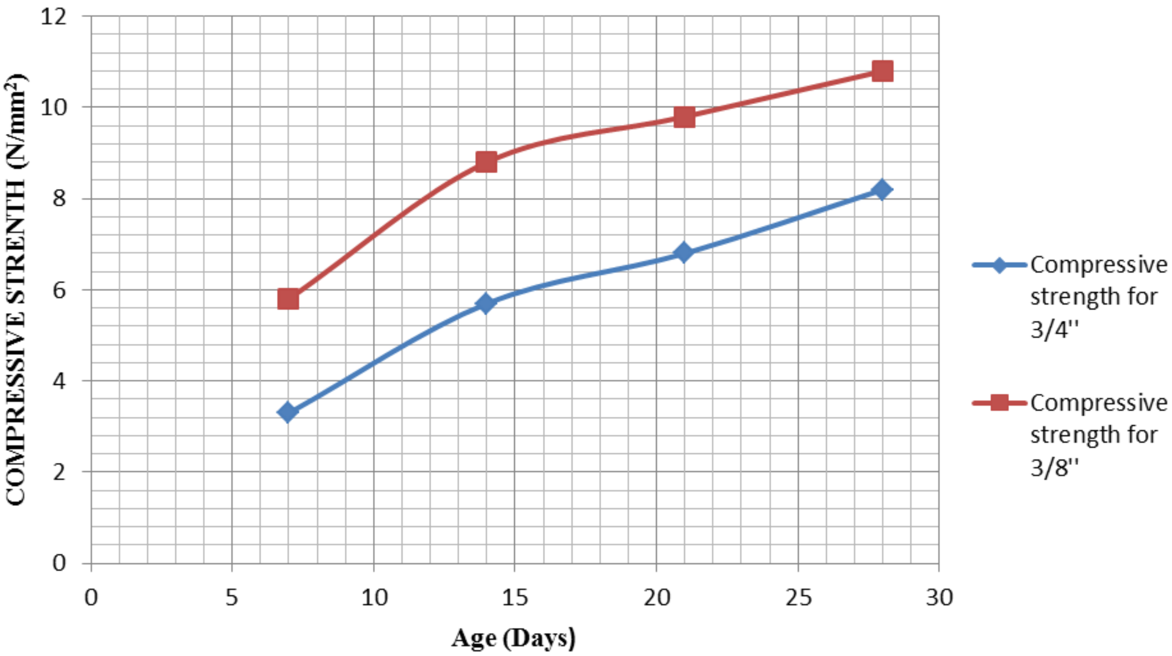


**Figure 7: Comparison between ¾" and 3/8" Compressive Strength for 6:1 Aggregate/Cement ratio**

## 6. PERMEABILITY TEST

The permeability of pervious concrete was determined using a falling head permeability set up Figure 8. Water was allowed to flow through the sample, through a connected standpipe which provides the water head. Before starting the flow measurement, the samples were wrapped with polythene inside the cylinder. Then the test started by allowing water to flow through the sample until the water in the standpipe reached a given lower level. A constant time of 5secs was taken for the water to fall from one head to another in the standpipe. The standpipe was refilled and the test was repeated when water reached a lower level as shown in Figure 8. The permeability of the pervious concrete sample was evaluated from the expression given below:

$$K = 2.303\, {aL}/{A} (t_2 - t_1) \log\left( {h_1}/{h_2} \right) \ldots\ldots\ldots\ldots\ldots 2$$

Where:

A = the sample cross section area

A = the cross section of the standpipe of diameter (d) = 0.95cm$^2$

L = the height of the pervious concrete sample

$(t_2 - t_1)$ = change in time for water to fall from one level to another (5secs.)
$h_1$= upper water level
$h_2$= Lower water level
D= diameter of sample (10.5cm)
d= diameter of standpipe (1.1cm)

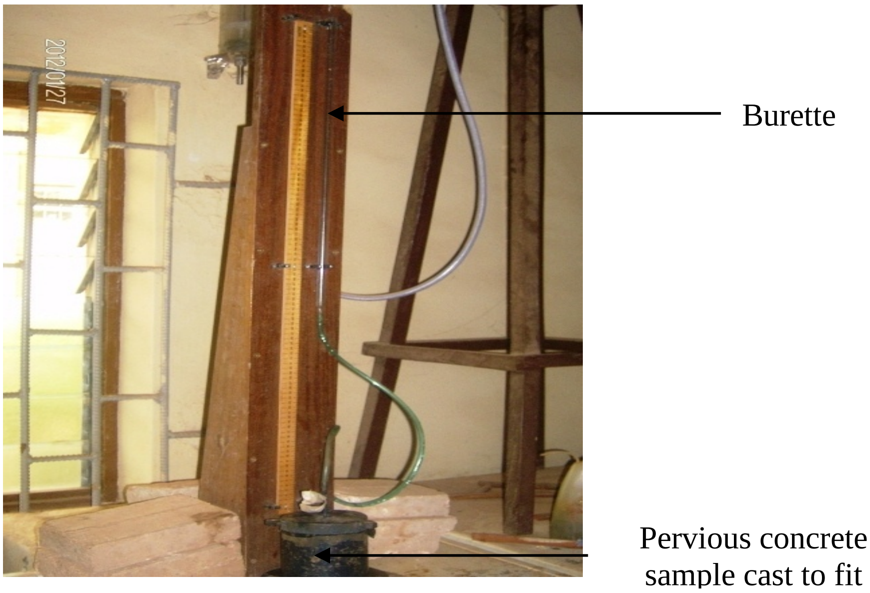


**Figure 8: Falling head permeability set up**

**Table 6: Permeability result for 3/4" aggregate size and A/C Ratio of 6:1**

| Time (sec) | Height (cm) | Co-efficient of Permeability K (cm/sec.) x $10^{-3}$ |
|---|---|---|
| 0.0 | 100.0 | - |
| 5.0 | 89.8 | 2.36 |
| 10.0 | 79.8 | 2.59 |
| 15.0 | 68.3 | 3.42 |
| 20.0 | 58.3 | 3.48 |
| 25.0 | 48.0 | 4.27 |
| | | Average K= 3.224 |

**Table 7: Permeability result for 3/4" aggregate size and A/C Ratio of 8:1**

| Time (sec) | Height (cm) | Co-efficient of Permeability K (cm/sec.) x $10^{-3}$ |
|---|---|---|
| 0.0 | 95.0 | 2.70 |
| 5.0 | 84.0 | 3.14 |
| 10.0 | 72.8 | 3.56 |
| 15.0 | 61.9 | 4.30 |
| 20.0 | 50.9 | 5.41 |
| 25.0 | 39.8 | Average K= 3.852 |

**Table 8: Permeability result for 3/4" aggregate size and A/C Ratio of 10:1**

| Time (sec) | Height (cm) | Co-efficient of Permeability K (cm/sec.) x $10^{-3}$ |
|---|---|---|
| 0.0 | 100.0 | - |
| 5.0 | 88.4 | 2.71 |
| 10.0 | 76.6 | 3.15 |
| 15.0 | 64.7 | 3.71 |
| 20.0 | 52.9 | 4.43 |
| 25.0 | 41.3 | 5.44 |
| | | Average K= 3.89 |

**Table 9: Permeability result for 3/8" aggregate size and A/C Ratio of 6:1**

| Time (sec) | Height (cm) | Co-efficient of Permeability K (cm/sec.) x $10^{-3}$ |
|---|---|---|
| 0.0 | 90 | - |
| 5.0 | 83.7 | 1.60 |
| 10.0 | 77.6 | 1.66 |
| 15.0 | 71.6 | 1.77 |
| 20.0 | 65.4 | 1.99 |
| 25.0 | 59.3 | 2.15 |
| | | Average K= 1.83 |

**Table 10: Permeability result for 3/8" aggregate size and A/C Ratio of 8:1**

| Time (sec) | Height (cm) | Co-efficient of Permeability K (cm/sec.) x $10^{-3}$ |
|---|---|---|
| 0.0 | 90.0 | - |
| 5.0 | 82.0 | 2.05 |
| 10.0 | 73.8 | 2.32 |
| 15.0 | 65.8 | 2.52 |
| 20.0 | 57.7 | 2.89 |
| 25.0 | 49.5 | 3.37 |
| | | Average K= 2.63 |

**Table 11: Permeability result for 3/8" aggregate size and A/C Ratio of 10:1**

| Time (sec) | Height (cm) | Co-efficient of Permeability K (cm/sec.) x $10^{-3}$ |
|---|---|---|
| 0.0 | 70 | - |
| 5.0 | 62.9 | 2.35 |
| 10.0 | 55.7 | 2.67 |
| 15.0 | 48.5 | 3.04 |
| 20.0 | 41.5 | 3.43 |
| 25.0 | 34.4 | 4.12 |
| | | Average K= 3.12 |

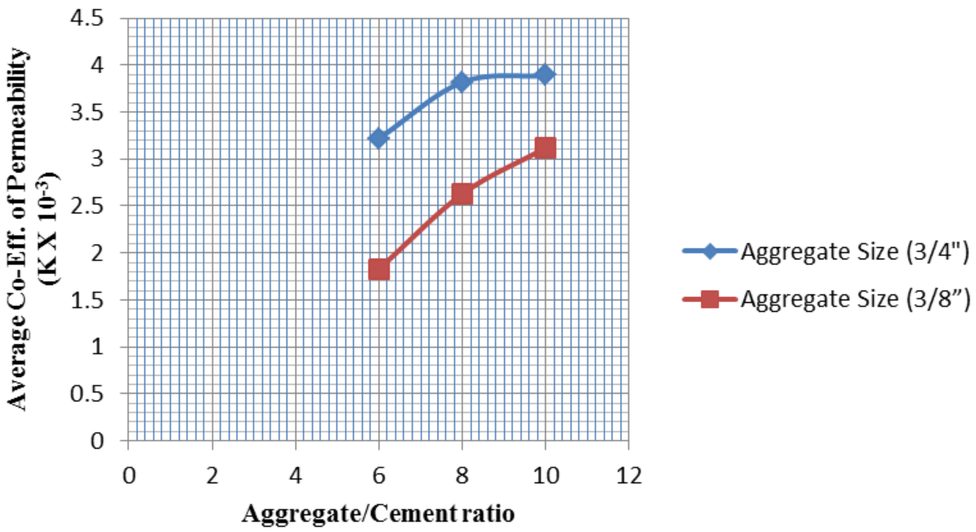


**Figure 9: Variation of average values of K with A/C ratio for ⅜" and ¾" aggregate sizes**

## 7. DISCUSSION OF RESULTS

- The Specific gravity of the coarse aggregate used for 18.75mm and 9.375mm of 2.7 is in agreement with the range of values stipulated by ACI 552-R10
- Pervious concrete made from coarse aggregate size 9.375mm had compressive strength value of 39% compared to that of 18.75mm which is 29% of the maximum value of strength stipulated by ACI 552-

R10 (i.e. 28N/$mm^2$) for aggregate cement ratio A/C 6:1.

- As shown in Figure 9, and Tables 6 – 11, the aggregate/cement ratio of 10:1 produced pervious concrete of higher co-efficient of permeability of $3.12x10^{-3}$cm/sec and $3.89x10^{-3}$cm/sec for aggregate size 9.375mm and 18.75mm respectively.

## 8. CONCLUSIONS

- The smaller the size of coarse aggregate should be able to produce a higher compressive strength and at the same time produce a higher permeability rate.

- The mixtures with higher aggregate/cement ratio 8:1 and 10:1 are considered to be useful for a pavement that requires low compressive strength and high permeability rate.

- Finally, further study should be conducted on the pervious concrete pavement produced with these material proportions to meet the condition of increased abrasion and compressive stresses due to high vehicular loading and traffic volumes.

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