Study of Permeability Characteristics of Open Graded Friction Courses Used in Wearing Courses

K.Umasangar[1] and W. K. Mampearachchi[2]
Department of Civil Engineering, University of Moratuwa, Sri Lanka

ABSTRACT : Open graded friction course (OGFC) has been used by several countries since 1950. While many countries report good performance, some countries have stopped using OGFC due to unacceptable performance and/or lack of adequate durability. High permeability is one of the important characteristics of the OGFC mixtures. There is a high possibility of fail the ordinary OGFC mixtures in tropical countries due to heavy dust content in the environment. In the absence of proper, maintenance standard of roads, there is high potential of clogging of dust in OGFC layers. So, there is a need of an improved mix design procedure to help highway agencies in successful use of OGFC.
The primary objectives of this study were to evaluate the permeability characteristics of OGFC in the laboratory with various gradations and recommend a proper testing method to evaluate the performance of the OGFC mixes. Typical permeability measures (void ratio, porosity) do not indicate the pore sizes and pore distribution and pore connectivity of the mixtures. An experimental procedure has been proposed to measure the permeability under both laminar and turbulent flow conditions. Three gradations used in a previous study were analysed in the experimental setup proposed in the study. Analysis of the test results of the mixtures showed a comparison of the mixture designs with respect to the pore size and the number of pores which can be used as OGFC mixture design parameter in future.

Key Words: open graded friction course, OGFC, mix design,

1. INTRODUCTION

Open friction courses are a type of pavement that has been built across the United States since the 1950's. These mix design contain a large portion of coarse aggregate, creating a pavement with a relatively high percentage of air voids, and generally have high asphalt content. This aggregate structure provides a higher degree of friction as well as permeability in the surface layer of the pavement. This permeability further improves frictional behavior during wet weather while reducing the dangers of splash and spray and hydroplaning due to increased drainage from the pavement surface. In addition, open friction courses are generally quieter than typical pavements. There has been a wide range of experience with open friction courses in different regions. While a large majority of countries have experimented with these pavements, there is a large split over whether they will continue to be built.

2. BACKGROUND

Evaluating the drainage capacity of porous layers based on porosity itself is convenient, but could be in adequate and misleading (Tan et al., 1999, Kuang et al., 2011). Porosity is a measure of voids. It is a general an indicator use in the industry to measure the permeability of a mixture. It is also commonly used as a control parameter in the mixture design to predict the performances of the finished pavement.

However, various experimental studies have proved that pavements with similar porosities may have significant differences in permeability value. The falling-head outflow tests conducted by Neithalath et al. (2010) showed that permeability values differed by more than 100% for porous concrete specimens with similar porosities. Summanasooriya & Neithalath (2011) measured the intrinsic permeability of lab-cast pervious concrete samples designed for similar porosities using two different proportioning methods and observed large variations between the two approaches due to the difference in pore connectivity. Based on the numerous existing studies, it can be concluded that besides porosity, many other factors are also influential to drainage properties of porous pavements, such as pore size distribution, tortuosity of capillaries, pore surface properties and pore connectivity.

Since limited research works are available to investigating the influence of pore structure on the permeability of porous pavements, this study attempts to approach the problem numerically with the practical results. The influence of pore size and no of pores on permeability of the pavement throughout the service life are to be evaluated through the practical results.

3. OBJECTIVES

The primary objective of this study is to evaluate the laboratory performance of OGFC mixtures by analyzing hydraulic performance and to develop a

1 Former Student 2 Professor e-mail : wasanthak@uom.lk

relationship between the pore size and number of pores through hydraulic performance of the mixtures.

4. NEED FOR THE RESEARCH

In the research of Influences of pore size on the permeability and skid resistance of porous pavement by(Zhang, Fwa , 2013), a computational pore network model (Table 1)was proposed and concluded that permeability increases with the pore size.

Table 1 - Parameter of pore network models

Porosity (ø) %	Pore size (x) mm	Pore spacing (y) mm
20	2.0	7.0
	3.0	10.4
	4.0	13.9
	5.0	17.4
	6.0	20.9

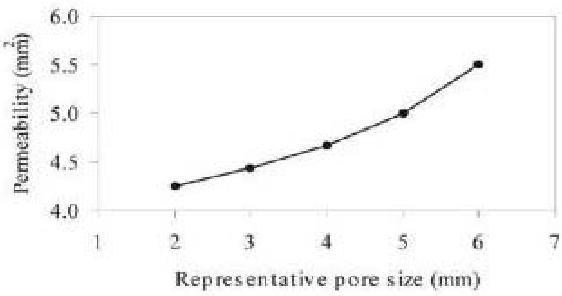
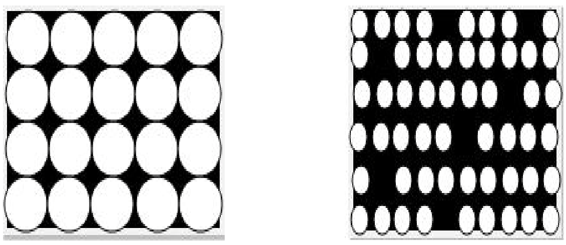


Figure 1–Relationship between the Permeability and pore size

Following hypothesis needs to be tested to verify the finding of model and application of the model finding in the mixture designs.;

- Porosity is not a representation of the interconnected pores of a mixture. So, it does not indicate the permeability of a mixture.
- Differentiate the permeability characteristics of mixtures with high numbers of small pores and less number of large pores.



Sketch 1 **Sketch 1**

Figure 2 - Plan views of pore distribution of samples

Assume the permeability of samples shown in Figure 2 (Sketch 1 and 2) is same. However, pore distribution in Sketch 1is better than the sketch 2 for a road environment since pore distribution in Sketch 1 will have less clogging and needs low maintenance during operation. Durability of the sketch 1 mixture is higher than that of the sketch 2. Obviously, there is a need of improved testing method and analysis procedure to recommend a suitable gradation for OGFC.

4. EXPERIMENTAL PLAN AND PROCEDURES

4.1. Sample preparation

In the study, mixes were prepared with the coarsest gradation (3 gradations in Table 2) which were used in the research of Automated determination of the optimum binder content of open- graded friction course mixtures using digital image processing by Gunaratne and Pernia(2015). Mixes were prepared using Penetration grade 60-70 asphalt binder with the percentage of Optimum Bitumen Content (OBC)used in the same research and samples were compacted with 50 gyrations using super pave gyratory compactor available at advance bituminous testing laboratory. Table 2 shows the gradation of selected samples and average OBC used in the previous research (Table 1 of (Gunaratne, M. and Pernia, Y, 2015)

Table 2 - OGFC gradation used for the study

size	mix A	mix B	mix C
19mm	100	100	100
12.5mm	95	96	96
9.5mm	74	70	71
4.75mm	20	23	15
2.36mm	8	10	8
1.18mm	6	5	6
600µm	4	4	5
300µm	4	3	4
150µm	4	3	3
75µm	3.4	2.5	2.3
OBC	5.5%	5.3%	5.3%

4.2.Permeability test

The permeability of mixes with different gradations was tested with a constant head method under various pressure conditions. There is no existing apparatus available for asphalt samples testing for permeability in laboratory. An apparatus was developed to test

1 Former Student 2 Professor e-mail : wasanthak@uom.lk

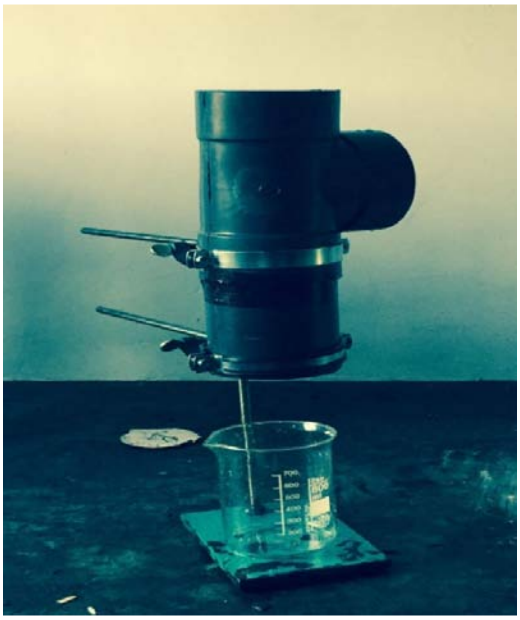


Figure 3 – Permeability apparatus

100mm diameter asphalt samples. However, available PVC conduit sizes are 110mm and 90mm. So, PVC conduit of 110mm diameter was selected and perimeter of the samples was sealed using double sided tape and brought up to the size of the PVC pipe. Further, samples were sealed with epoxy to avoid any gap between pipe and the sample. Top end of the PVC
pipe was extended to maintain constant head of 70mm, 130mm& 150mmusing a T joint. Figure 3 shows the Apparatus prepared for testing a sample for a selected head.

Using this apparatus test was carried out for three different pressure heads by supplying water through the top part of the apparatus and waited until constant flow and then collected the water in the bottom jar for 1 minute and the volume was measured. This procedure was carried out for each sample under three pressure heads.

5. RESULTS AND ANALYSIS

5.1. Results

The test was carried out for the three samples under three different pressure heads; 70mm, 130mm & 150mm. Average flow reading (average of three readings) for a selected pressure head was measured Flow rate vs pressure head data are presented in Figure 5.
A series of constant head outflow test simulations were conducted under different hydraulic heads. Water flow through the specimen changes from laminar to turbulence with the increase of the pressure difference as shown in the Figure 4.

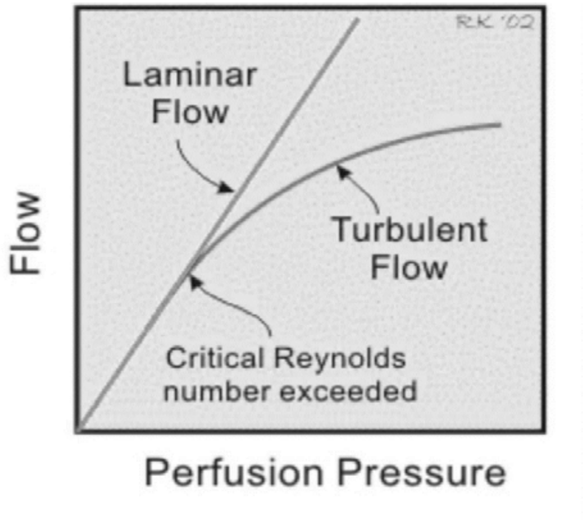


Figure 4 Flow vs Pressure distributio

Under the assumption of flow through the porous media is same as flow through the pipe. The Poiseuille's law equation can be used for laminar flow condition and Darcy's formula can be used for turbulent flow condition. Equation 1 and 2 shows the equations for laminar and turbulent flow respectively. Figure 5 shows the graphical presentation of the flow verses pressure curve for the three-gradation used in the study. It can be seen that all three mixtures have a laminar and turbulent flow conditions. Gradient of the flow verses pressure curves of three mixtures are not identical. The mixture A and the mixture C samples had the low and high gradient respectively. Gradient of the mixture C was between mixture A and B.

Laminar flow

$$Q = \frac{\pi \Delta p r^4}{8 \eta L} \quad \textbf{Equation 1}$$

Turbulent flow

$$Q^2 = \frac{4\pi^2 \Delta p r^5}{8 \rho f L} \quad \textbf{Equation 2}$$

Where is:
Δp - Pressure drop;
η - Viscosity;
L - Pipe length;
ρ - Density;
Q -Volume flow rate;
F - Friction coefficient

For the analysis, the structure of the porous is defined as number of pores= M_x and pore radius=r_x. Here x indicates the sample name (number).

MIX A&MIX B considers for the comparisons of laminar flow conditions and application of equation 1 for mixture A and mixture B is shown in equation 3 and 4 respectively

1 Former Student 2 Professor e-mail : wasanthak@uom.lk

Laminar region,

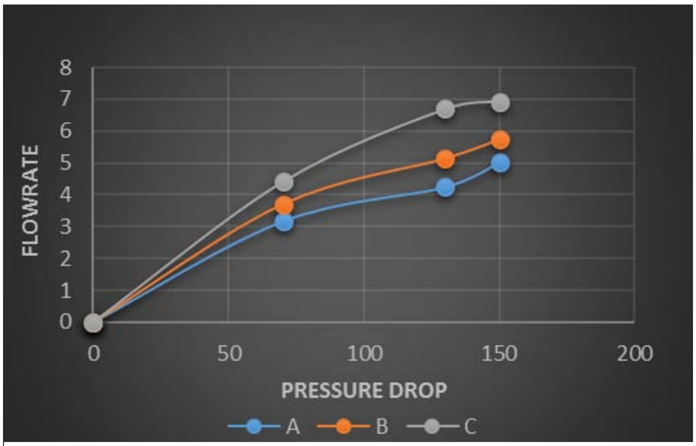


Figure 7 - Flow rate vs. Pressure drop

At hydraulic head of 25mm

$$Q_{LA} = M_A \frac{\pi \Delta p {r_A}^4}{8\eta L_A} = 1.12$$ **Equation 3**

$$Q_{LB} = M_B \frac{\pi \Delta p {r_B}^4}{8\eta L_B} = 1.297$$ **Equation 4**

Application of mixture properties (A and B) for turbulent region is shown in Equation 5 and 6, Equation 7 was derived from equation 3 and 4.
At the hydraulic head of 140mm

$$Q_{TA} = M_A \sqrt{\frac{4\pi^2 \Delta p {r_A}^5}{8\rho f L_A}} = 4.83$$ **Equation 5**

$$Q_{TB} = M_B \sqrt{\frac{4\pi^2 \Delta p {r_B}^5}{8\rho f L_B}} = 5.649$$ **Equation 6**

$$\frac{Q_{LA}}{Q_{LB}} = \frac{M_A {r_A}^4}{M_B {r_B}^4} = 0.864$$ **Equation 7**

Equation 8 was derived from equation 5 and 6

$$\frac{Q_{TA}}{Q_{TB}} = \frac{M_A {r_A}^{5/2}}{M_B {r_B}^{5/2}} = 0.855$$ **Equation 8**

rom the equation 7 and 8

$$\frac{{r_A}^{3/2}}{{r_B}^{3/2}} = 1.01$$

$$\frac{r_A}{r_B} = 1.0$$

Results indicates that pore sizes of the sample A and sample B is same but the variation of the permeability only depends on the number of pores in the sample. In this analysis, pores considered have connectivity from top to bottom of the samples and facilitate for water flow through the mixture.

6. CONCLUSION

Large pore size in OGFC pavement increases the effectiveness of the permeability. The flow and pressure head relationship of the three-selected gradation showed that permeability variation only depend on the number of pores and the pore sizes of the three gradations. In this study, a new testing method and a mixture analysis have been proposed. The new testing method can be used to compare the distribution of pore sizes and number of pores in two mixtures. Limited number of samples have been prepared and tested in the laboratory. Therefore, this experiment should be conducted for different gradations and mixtures. The connectivity of the pores was assumed in this study and it needs to be validated. Further, the finding of this research needs to be validated by performance testing in future.

7. References

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1 Former Student 2 Professor e-mail : wasanthak@uom.lk