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Investigation of Durability of Open Graded Friction Courses

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Abstract

Open Graded Friction Courses (OGFC) have many positive attributes due to the porous nature. It allows sun-rays, water, air and dust to go into interior of the OGFC. It accelerates the aging process of asphalt binder, and influences the durability. The permeability varies with the durability of OGFC. OGFC can be clogged due to high dust levels in the tropical climate and will not be functional anymore. The aim of the research is to evaluate the durability, permeability and clogging potential of OGFC. Three different gradations were selected and samples were prepared from those gradations. The Cantabro test was conducted to evaluate the durability. Permeability test was conducted to evaluate drainage characteristics and the clogging potential of OGFC was also tested. The test results indicated that the variability of durability, permeability and clogging potential according to the gradations and bitumen content.

Keywords: Open graded friction courses; Durability; Permeability; Clogging potential;

1. Introduction

An Open Graded Friction Course is defined as a permeable layer of asphalt that integrates a skeleton of a uniform aggregate size with a minimum amount of fines. These OGFC mixes contain a small percentage of fine aggregate which delivers a large number of air voids. The pavement comprises essentially of a single sized coarse aggregate with a high asphalt content. The load is carried by the stones while the asphalt effectuates everything to set up.

The air voids in the OGFC and its stone-on-stone skeleton provide these types of mixtures many positive attributes. The porous nature allows immediate drainage of water from the pavement surface. This leads to give skid resistance and reduces water spray and splash. The visibility of road markings is increased during rain. The voids absorb sound energy as tires roll over the pavement to reduce surface noise.

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In Sri Lanka, dense asphalt is used as pavement material in expressway construction. However, in the wet season, it is observed that vehicles cannot travel in design speed due to lack of visibility and low skid resistance. Many times, drainage capacity exceeds the limit and water film thickness becomes higher. Therefore, studies are being done to use OGFC to the surface pavement in expressway construction in Sri Lanka to reduce the existing problems.

However, sun rays, air and water can more effortlessly penetrate the interior of the OGFC due to its unique characteristic which is presence of large voids that accelerate the aging process of asphalt binder, and influence the durability of the pavement. Meanwhile, the open-graded structure is vulnerable to water damage, resulting in stripping and loss of the surface of the pavement.

Therefore, if a durable OGFC mixture is discovered, it will particularly be useful and valuable for the highway construction field. It was revealed that if the durability of OGFC is increased, there is huge possibility of decreasing the porosity which will decrease the permeability characteristics of OGFC.

Furthermore, the OGFC gets clogged due to high dust levels. The dust level in Sri Lanka is very high as in most of the tropical countries. Also there is no proper maintenance system in Sri Lanka. The Clogging effect can cause the structure to be less permeable and durable.

Therefore, in the discovery of a durable OGFC mixture, not only the strength between bonds but sufficient permeability characteristics and clogging potential should be checked as well.

2. Objectives

The objectives of this research are,

- To assess the durability of OGFC mixtures in the laboratory.
- To assess permeability of OGFC mixtures.
- To assess clogging potential of OGFC mixtures.

3. Background

The durability of OGFC is affected by factors such as aggregate gradation, asphalt content, aging degree of the mixture and layer thickness. Therefore, to investigate the durability of OGFC, how those factors affect the durability of OGFC should be monitored. For that OGFC mixtures should be tested changing those factors. Among these aggregate gradation and layer thickness significantly affect the durability of the OGFC surfaces in general. (Qureshi, N.A.; Farooq, S.H.; Khurshid, Bilal;, 2015)

There are several tests available to evaluate durability of OGFC: Cantabro test, Hamburg wheel-tracking test (HWTT), Overlay test (OT). According to the test results of the (Alvarez, Epps-Martin, Estakhri, & Izzo, 2010), "cantabro test is recommended over the HWTT and OT, to investigate the durability of open graded friction course mixtures. Further it is mentioned that cantabro test has not enough sensitivity when determining the optimum asphalt content."

According to above the method, a more durable OGFC mixture with optimum aggregate gradation, optimum asphalt content and other factors can be determined. However, in a tropical country like Sri Lanka these characteristics may be changed. In the previous research conducted on the durability of OGFC, they have only considered the strength of the bonds between asphalt and aggregate as the durability. Therefore, when durability is increased, there is a huge possibility in the porosity of the OGFC decreasing and causing the decrease in permeability characteristics of OGFC. Also, the OGFC may be clogged because the dust level is very high in tropical countries like Sri Lanka. When it is clogged, it will not be functional any more if the required maintenance are not adopted. Due to limited budget available for maintenance in general, designers should consider level of maintenance in designing the OGFC layers. Hence OGFC should possess not only durability but also the required permeability.

There are mainly two methods of measuring the permeability.

- Constant head method
- Falling head method

Umasangar, K; Mampearachchi, W.K.;. (2016) have conducted permeability test using the constant head method.

Many studies show that the function of OGFC deteriorates rapidly due to reduction in the effective air voids. It is called as clogging. There are two types of clogging,

(1) Particle - related clogging
(2) Deformation – related clogging

Particle-related clogging occurs when the voids or pores of an OGFC mix are clogged by dirt and pollutants such as dust, detritus, tire wear by-products and debris. Deformation-related clogging ascribes reduction in air void content of OGFC mixture to the accumulation permanent or rutting deformation (Chen, J. et al., 2015).

According to research done on Laboratory Evaluation of Clogging Potential of Porous Asphalt Mixtures by Fwa, T.F., Xtan, S.A, Guwe, Y.K. (1999), experiments has shown that in Singapore the local residual soils deposited from dirty wheels and vehicles carrying earth have been a major source of materials contributing to the clogging of porous asphalt layers.

4. Experimental details

4.1. Sample preparation

In this study, three different OGFC gradations used in US were selected from the research done on optimum bitumen content of open graded friction courses by Gunaratne and Pernia (2015) and Study of permeability characteristics of open graded friction courses by K.Umasangar and W.K.Mampearchchi (2016). The percentage of optimum bitumen content (OBC) was used as in the same research. Table 1 shows the selected three gradations and their average OBC. Mixes were prepared using the asphalt binder with a penetration grade of 60/70.

First the aggregates were sieved and separated according to the ranges of sizes in gradation. Then, the required weights of aggregates from different sizes were measured and the necessary quantity of aggregates for samples of mix A, B and C were prepared. The aggregates and required bitumen content were kept in the oven for about four hours at 160°C. Heated aggregate and bitumen were mixed using the bench mixer. Mixed sample was placed in the mould and compacted with 50 gyrations using the superpave gyratory compactor. The diameter of the samples was 150mm and height was 115±5 mm. (Fig. 1)

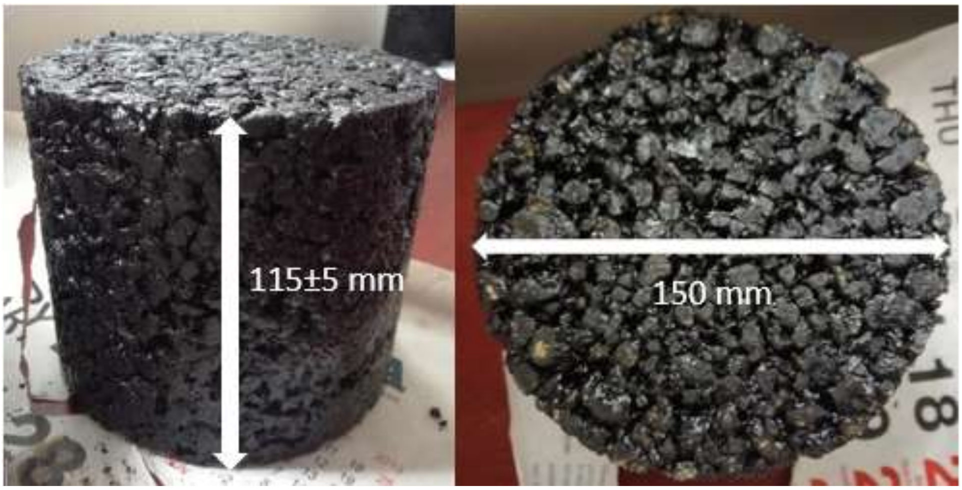

Fig. 1. Dimensions of the OGFC sample

Table 1. OGFC gradations used for the study

Size	Mix A	Mix B	Mix C
19 mm	100	100	100
12.5 mm	95	96	96
9.5 mm	74	70	71
4.75 mm	20	23	15
2.36 mm	8	10	8
1.18 mm	6	5	6
600 µm	4	4	5
300 µm	4	3	4
150 µm	4	3	3
75 µm	3.4	2.5	2.3
OBC	5.50%	5.30%	5.30%

4.2. Permeability test

The permeability of the prepared samples was tested using the constant head method under various pressure conditions. A proper permeability apparatus was developed to measure permeability of 150mm diameter asphalt samples due to the unavailability of such an apparatus in the laboratory. Fig. 2 shows the developed apparatus which can maintain three different constant heads using its valves. This apparatus was made by a steel pipe which is having an inner diameter of 150mm. It also consists of three outlet valves at the heights of 125mm, 130mm and 135mm from the bottom of the steel pipe. The function of the bottom part of the steel pipe is to insert the asphalt sample. This component was clinched to a steel stand. Under the steel pipe, a plastic bucket was stationed to collect the water flowing through the steel pipe. An outlet valve was present in the bucket to maintain a constant water level and another plastic bucket was stationed to collect the water that overflowed through the outlet valve.

Fig. 2. Permeability apparatus developed for this study

Before inserting the sample into the apparatus, perimeter of the samples was covered with a rubber tube to be tight and sealed as shown in Figure 3a. The covered sample was inserted into the apparatus as shown in Figure 3b. Then the top and bottom of the sample were sealed with plastic clay to avoid any gap between steel pipe and the sample as shown in Figure 4.

a b

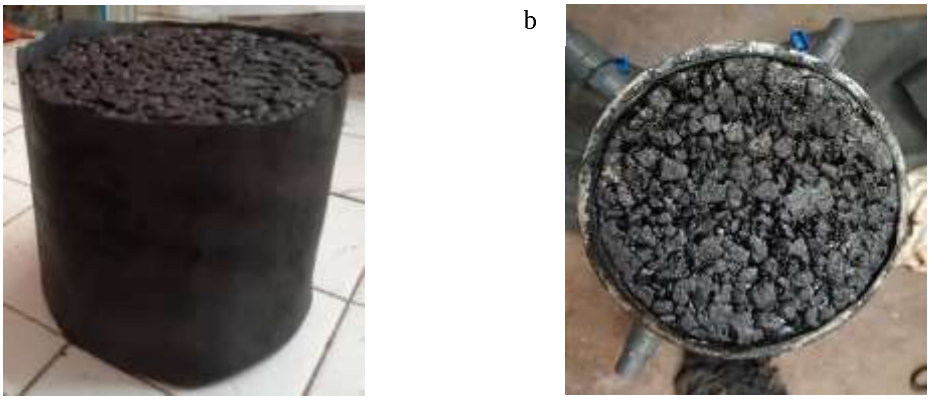

Fig. 3. (a)The samples covered with a rubber tube; (b) After inserting the sample into the apparatus

Fig. 4. Sealing the sample with plastic clay

Using this apparatus, constant head was maintained for a selected head and the permeability test was carried out. The volume of collected water through the bottom valve for a selected time period was measured. Also the head difference was measured. This procedure was carried out for each sample under three pressure heads. This permeability test was repeated for 3 samples from each gradation for the selected gradations.

4.3. Cantabro test

This test method determines the abrasion loss of compacted asphalt specimens. The percentage of weight loss (Cantabro loss) is an indication of durability and relates to the quantity and quality of the asphalt binder.

First OGFC samples from each gradation were prepared in accordance with Tex-241-F (reference). The initial weight of the sample was recorded. Then, the test sample was placed in the Los Angeles abrasion machine (Fig. 5). However, steel balls are not put into the drum as Los Angeles abrasion value test. After placing the sample in the drum, drum was rotated at a speed of 30-33 rpm for 300 revolutions. After 300 revolutions, all the loose materials broken off the test sample were discarded. Final weight of the test sample was recorded (without including any of the discarded material). This procedure was carried out for three sets of test samples from each gradation.

Fig. 5. Los Angeles abrasion machine

4.4. Test to investigate clogging potential

When the accuracy of the laboratory tests for clogging potential is concerned, it is more equitable to use clogging material which is available in the field. Therefore clogging material was collected from the A2 road, from Katubedda to Moratuwa.

The sample was inserted into the permeability apparatus and sealed as described in the permeability test procedure. Then 35g of clogging material was placed uniformly on the top face of the sample. 2 liters of water at room temperature (25°C) were poured on to the sample from the top of the apparatus. This step was repeated for another 9 times. Each time water is allowed to drain off completely before another 2 liters of water is added. The leftover residual soil on the top surface was removed carefully. Then the permeability test was carried out as described previously.

All the above steps after inserting the sample into the apparatus were repeated a number of times, until the change in the measured permeability is negligible. After that, the sample was de-clogged (clean) by back water process. And again the permeability test was carried out.

This procedure was repeated for the 3 gradations.

5. Results

5.1. Results of permeability test

After carrying out the permeability test for all the samples under three different heads, the permeability coefficient of the each sample was calculated using the following equation.

$$k = \frac{Q \times L}{A \times \Delta H} \qquad (1)$$

The parameters of this equation can be identified by the Fig. 6.

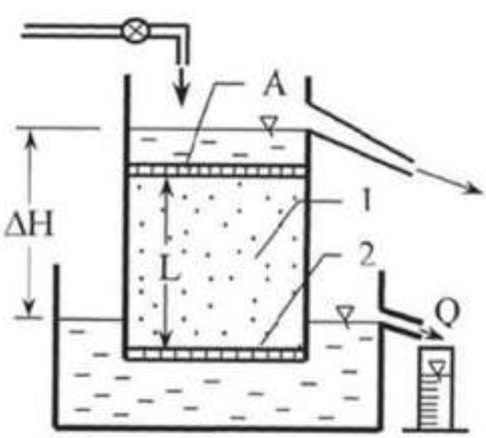

Fig. 6. Simple sketch of permeability test

The average value of the three test samples from one gradation was taken as the permeability coefficient of the particular gradation. Table 2 shows the permeability coefficient values obtained from the test for different gradations.

Table 2. Permeability values of three gradations

Gradation	k1 (mm/s)	k2 (mm/s)	k3 (mm/s)	k (mm/s)	Stnd. Dev.
A	1.177	0.870	0.751	0.933	0.220
B	1.838	0.850	0.971	1.220	0.539
C	1.924	2.191	1.525	1.880	0.335

5.2. Results of Cantabro test

The aim of the test was to find the percentage of weight loss (Cantabro loss) of each OGFC sample. The Cantabro loss was calculated using following equation. Figure 7 shows the sample before and after Cantabro test.

Fig. 7. The samples before and after the testing

$$Cantabro\ loss = \frac{m_o - m_f}{m_o} \times 100 \tag{2}$$

Where,
m_o = Initial mass of test specimen
m_f = Final mass of test specimen

The average value of the three test samples from one gradation was taken as the Cantabro loss of the particular gradation. Table 3 shows the Cantabro loss values obtained from the test for different gradations (A, B, and C).

Table 3. Cantabro loss values of three gradations

Gradation	Sample 1 (%)	Sample 2 (%)	Sample 3 (%)	Avg. Cant. Loss (%)	Std. Dev.
A	9.089	6.829	6.081	7.333	1.566
B	11.220	7.684	9.516	9.473	1.768
C	11.599	13.440	12.014	12.351	0.966

5.3. Results of clogging potential test

The calculated values for permeability coefficient at the initial stage, after adding 35g, 70g, 105g and 140g of clogging material respectively and after cleaning the sample by back washing were obtained. Test results are shown in Table 4 Results shows that permeability reduced significantly with the adding of clogging material and initial permeability of A, B, and C mixtures were reduced by 89%, 93% and 92% respectively and further reduced with addition of clogging material . Back water pressure to clean clogging material is an extensive maintenance activity which cannot be practiced in road projects. However, it was found that only 15-30 % of initial permeability can be recovered. The highest recovery (30.7%) was observed in mixture C and lowest recovery (16.4 %) observed in mixture A.

Table 4. Permeability coefficient values and percentage of permeability reduction during clogging tests

Mass of clogging matrial (g)	**Gradation A**		**Gradation B**		**Gradation C**	
	k (mm/s)	**Permeability Reduction**	**k (mm/s)**	**Permeability Reduction**	**k (mm/s)**	**Permeability Reduction**
0*	0.751	-	0.971	-	1.525	-
35	0.082	89.1%	0.070	92.8%	0.128	91.6%
70	0.019	97.5%	0.021	97.8%	0.080	94.7%
105	0.016	97.9%	0.019	98.1%	0.065	95.7%
140	0.016	97.9%	0.018	98.1%	0.061	96.0%
After cleaning	0.205	72.7%	0.258	73.4%	0.596	60.9%
Recovery after cleaning		**16.4%**		**19.4%**		**30.7%**

Note: * before adding clogging material

The graphical presentation of permeability is shown in Fig. 8.

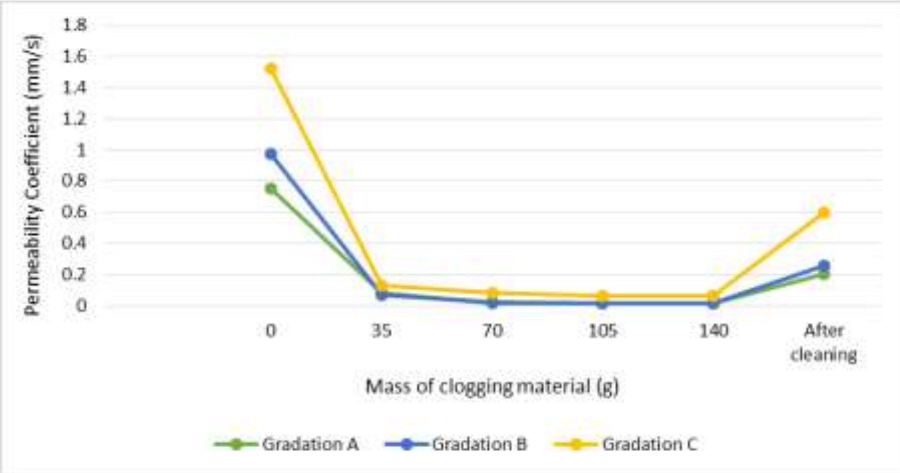

Fig. 8. Variation of permeability coefficient values during clogging tests

Cantabro loss test results and permeability test results of the selected gradations are shown in Figure 9.

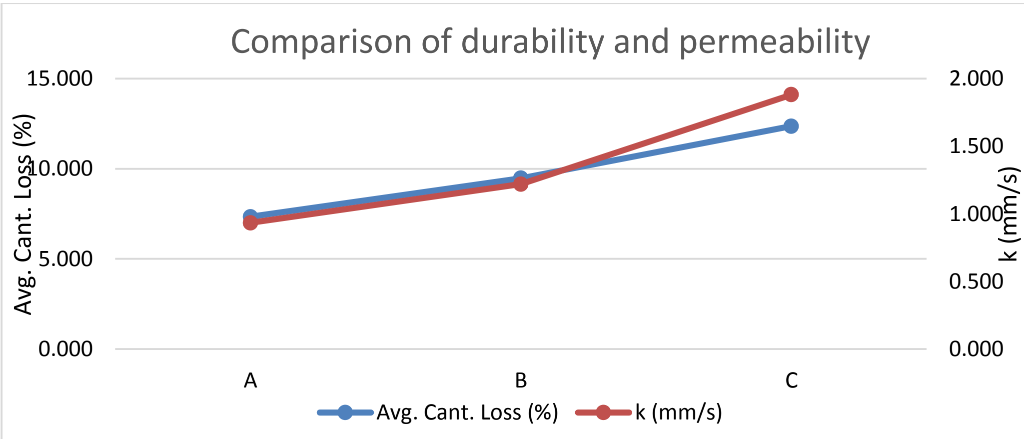

Fig. 9. Comparison of durability and permeability of selected gradations A, B, and C

6. Conclusion

Three different OGFC gradations used in US were selected in this study. Fine aggregate percentages (passing through 4.75mm sieve) of A, B and C gradations are 20%, 23% and 15% respectively. Fines (passing 75 micron sieve) of A, B, C mixtures are 3.4%, 2.5% and 2.3% respectively. Design optimum bitumen content used for the three mixtures (A, B, and C) were 5.5%, 5.3% and 5.3% respectively.

Cantabro test was used for estimation of the durability of OGFC mixtures and gradation A, B and C has high moderate and low durability respectively.

The main reason for the highest durability in gradation A is that Gradation A has more fine particles than the other two gradations. Also the bitumen content (5.5%) is higher than that in Sample B and C. Test results show that high Fines and high bitumen content help to strengthen the bonds between aggregates.

Sample prepared from Gradation C has the highest permeability. Permeability of gradation B and A is in the decreasing order with the lowest permeability is in A. The high fines and high bitumen content in sample prepared from gradation A have minimized the voids and vertical drainage paths in gradation A which leads to lower permeability.

The permeability of sample prepared using gradation C has the highest permeability and lowest durability. It is clear that lesser fine particles (15 % of fine and 2.3 % fines) and lesser bitumen content increases the voids and bond between particles.

It was observed that durability and permeability of the tested samples have shown an inversely proportionate relationship as permeability increases the durability decreases and vice versa.

All the tested OGFC mixes have shown a high potential of clogging whatever the design mixture of OGFC is used. When clogging take place in OGFC pavement, the permeability significantly reduces and the vertical drainage is no longer exist. With the addition of 35g of clogging material, the permeability has been significantly reduced. Permeability reduction of the A, B and C mixtures with addition of clogging material were 89%, 93% and 92% initially and it was further reduced with addition of the clogging material. Finally, permeability of the samples was in the range of 4-2% of the initial permeability. After cleaning using back water pressure, only 15% to 30% permeability recovered. Gradation C shows a higher permeability value than the other two gradations with back water pressure cleaning. It clearly shows the voids in OGFC mixtures close with clogging of particles irrespective of the mixture gradation.

In tropical countries, the dust level is high and clogging will take place rapidly compared to other developed countries. This study reveals that the performance level of the OGFC mixtures in tropical climates with high dust content will have a lower performance level in the same mixtures used in other climate conditions.

Recommendations

Although the test results of clogging potential show that OGFC have a high potential of clogging. However, it does not mean that OGFC is not suitable for use in tropical climate with high dust content. In this study vertical water infiltration of the OGFC samples were evaluated. However, in field conditions, there is not only the vertical water flow but lateral water flow through the mixtures in cross fall of the road should be considered.

Therefore, the test method for measuring clogging potential which only the vertical infiltration was taken into account, cannot be considered as a more accurate method. It is recommended to use a method which can measure the water film thickness of the OGFC pavement model with respect to lateral drainage, for testing the clogging potential of OGFC. A more durable OGFC mixture with better lateral drainage characteristics should be used for the expressway construction in tropical countries because the horizontal drainage may play a major role in reducing the water film thickness on road surface in tropical countries.

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