Assessment of Clogging in Open Graded Asphalt Mixes in California

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ABSTRACT: This paper presents results of analysis performed to evaluate the development of clogging of the surface of open graded mixes, and the effects on permeability and noise. The analysis includes data from field measurements over two years in California on open graded, dense graded, and gap graded asphalt mixes, of different ages and in different climate regions. Also included are a few experimental mixes. The analysis considers permeability difference between the wheelpath and between wheelpaths and permeability and noise difference from year to year. Also considered are Computed Tomography (CT) scans of a sample of the cores and analysis of depth of clogging. The results provide an indication regarding which mixes clog and which don't and the depth of clogging for the different kinds of mixes.

1. Introduction

Permeability is the major factor determining the functional performance of open graded asphalt concrete mixes. Open graded pavements let water drain into the mix through their pores rather than keeping it on the surface of the pavement. This results in reduced hydroplaning, water splash, and spray, and hence improved safety. Also, glare from the road surface is reduced and visibility is improved (1). Open graded pavements improve safety by increasing wet weather skid resistance at high speeds. The porous structure of open graded pavements also helps reduce traffic noise (2, 3, 4). However, these mixes can lose their permeability over time.

As open graded mixes have higher air-void content, and hence higher permeability than conventional asphalt mixes, they are susceptible to clogging. Clogging is the blockage of pores with fine particles generated by vehicles and deposited from elsewhere by the wind. When surface pores are clogged with fine materials, permeability decreases, and the benefits of open graded mixes diminish.

According to Sandberg et al. (2), traffic and rainfall are the most important factors affecting in-service permeability of open graded mixes. Fine particles that lodge in the voids of the surface layer can be suctioned out by the hydraulic action of the traffic. This cleaning effect is more pronounced under heavy rainfall and fast traffic. Due to the suction effect of traffic, the wheel tracks were found to remain more permeable compared to shoulders (2, 5). Lower air-void content of open graded mixes in the wheelpaths may also be caused by densification of the mix under traffic loading.

However, according to Bendtsen (6), the most important factors affecting the in-service permeability of open graded mixes are age of the pavement, maximum aggregate size, air-void content and distribution, speed of vehicles, and shape of aggregates. Another study conducted in Denmark (7) evaluated the air-void content of open graded mixes in horizontal planes taken through the thickness using Computed Tomography (CT) Scan, and no significant difference was found between the air-void content of the wheelpath and shoulder. The bottom part of the open graded mix was found to have at least twice the air-void content of the top part, which suggests that fine particles accumulate only in the top part of the surface layer (top 20 to 25 mm). Figure 1 shows the mastic (composed of asphalt binder, sand, and wind deposited fines) distribution of open graded asphalt cores that are six years old from a study in Denmark (8). It can be seen that there is higher mastic and hence a higher sand and fine content in the top 20 mm of the pavement surface.

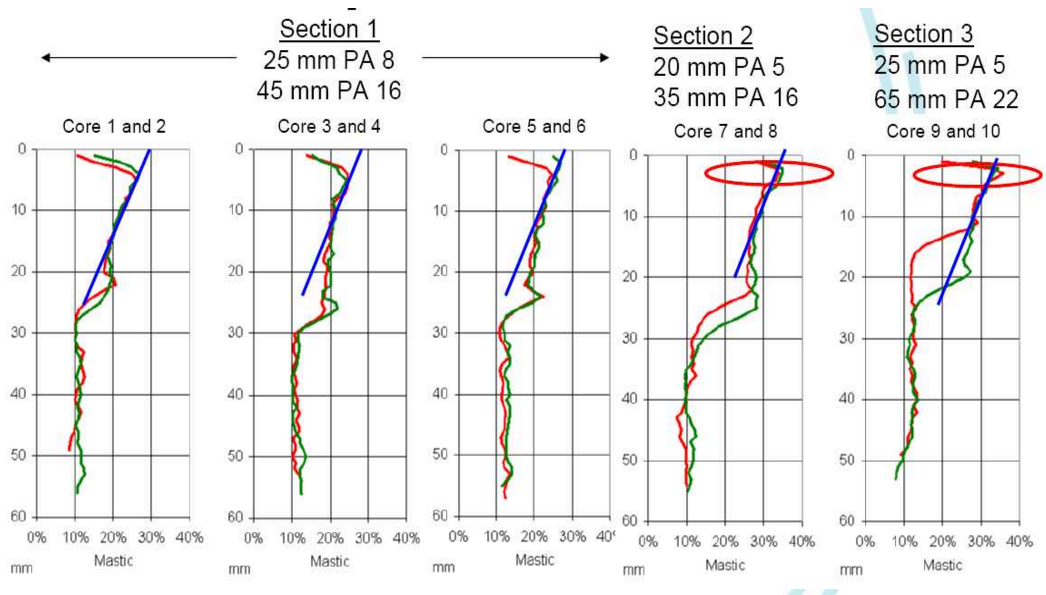

Figure 1: The mastic distribution of the open graded mixes through the thickness (8)

In the United Kingdom, it was found that open graded mixes using larger maximum aggregate size retain their porosity over time compared to mixes with smaller aggregate size (9). Based on this result, the U.K. specifies 20 mm maximum aggregate size for its open graded mixes.

Sandberg et al. (2) suggested that binder type may affect clogging. There is some evidence that sand and fines do not stick to polymer-modified asphalt as much as it sticks to unmodified asphalt binder (2). This may be due to the higher softening point of polymer-modified binder. However, this effect needs further investigation. If the softening point at high temperatures affects the dirt accumulation in the voids, the temperatures experienced by the pavement may also affect clogging.

Open graded pavements offer various advantages due to their higher void content and hence permeability. These mixes should keep their permeability and void content in order to improve safety and reduce noise levels. This study evaluates the development of clogging of open graded mixes and its effects on the permeability and noise levels.

2. Methodology

2.1. Site Selection

This study presents the analysis of data collected over one year from 72 field pavement sections in California. The experimental design is a full factorial including four different asphalt pavement surface types, three different age categories, two traffic types, and two rainfall regions. There are some replicates in the factorial.

The four mix types include open graded asphalt concrete with conventional and polymer-modified binders (OGAC), open graded asphalt concrete with rubberized binder (RAC-O), rubberized gap graded asphalt concrete (RAC-G), and dense graded asphalt concrete with conventional and polymer-modified binders (DGAC).Age categories include less than a year old, one to four years old, and four to eight years old. Traffic type, based on California Department of Transportation (Caltrans) 2004 annual average daily traffic (AADT) data for highways and freeways (10), was categorized as “high” if the AADT (two-way) is greater than 32,000 vehicles per day and was categorized as “low” otherwise. Rainfall is based on annual average rainfall in California from 1960-1990 obtained from CDIM software (11). The rainfall was categorized as “high” if average annual rainfall is greater than 620 mm (24.4 inches) and was categorized as “low” otherwise.

In addition to the mixes selected based on factorial design, a few experimental mixes were also evaluated. These mixes are Bonded Wearing Course (BWC) and European Gap Graded Mix (EU GG). BWC is a gap graded, ultra thin asphalt mix applied over a thick polymer modified asphalt emulsion membrane with nominal maximum aggregate size (NMAS) of 12.5 mm. European Gap Graded Mix (EU GG) has air-void content of 12 % which is close to air-void contents of open graded mixes in California. It has a NMAS of 12.5 mm. Both BWC and EU GG mixes are placed 30 mm thick.

2.2. Data Collection

Clogging was evaluated in two ways: with Computed Tomography (CT) scan and field permeability measurements. In addition, On-Board Sound Intensity (OBSI) was performed to measure Tire/pavement noise.

CT scan is a nondestructive method of testing for morphological studies which uses X-rays to image the object. This technique can also be used to investigate and evaluate the structure of asphalt concrete cores. It allows comparison of the air-void content distribution within a mix and between the different types of asphalt mixes. CT scans were performed using the cores taken from the selected pavement sections. The testing was performed at the Swiss National Roads Laboratory (EMPA). Because CT scanning is a time-consuming process, only 20 cores, two cores from 10 sections, were analyzed by this method. Asphalt concrete specimens of 100 mm diameter were scanned. An image size of 600 mm by 600 mm was used. The resolution of the pictures is 0.2 mm, thus the constituents smaller than 0.4 mm could not be detected. The beam thickness was 0.35 mm and the spacing between adjacent slices was 0.3 mm so that there was a 0.05 mm overlap between adjacent slices.

Field permeability measurements were conducted on each pavement test section for 2 years. Permeability was measured using a falling head permeameter, a device developed at the National Center for Asphalt Technology (NCAT) (12).Measurements were conducted next to twelve core locations evenly distributed at 25-m intervals along each of the 150-m long test sections in the 1st year. In the 2nd year, the measurements were conducted next to six core locations at 50-m intervals on the same section. The measurements were conducted both on the wheelpath and between the wheelpath. Permeability for each section was obtained averaging the 12 measurements in the 1st year and 6 measurements in the 2nd year.

In OBSI measurements two locations of the sound intensity probe are used: one is at the leading edge and the other at the trailing edge of the tire/pavement contact patch. The probe consists of two 25 mm phase-matched microphones spaced 16 mm apart and preamplifiers in a side-by-side configuration. A foam windscreen is placed over the microphones to reduce the wind noise. Signals from the two microphones are input to a two-channel real time analyzer. OBSI measurements are taken at 97 km/h. When that is not possible, an alternative speed of 58 km/h is used. Three replicate measurements are collected at each probe location, which are the results of consecutive passes with the instrumented vehicle on the 150-m sections selected for this study. Air and pavement temperatures are also recorded during OBSI measurements. Measurements were conducted using a Goodyear Aquatread III tire and a Dodge Stratus car. The OBSI results are expressed in terms of A-weighted sound intensity levels, dB (A). OBSI measurements were taken on the pavement test sections annually for 2 years.

3. Results

3.1. CT Scan

Table 1 shows the mix type, age, NMAS, and air-void contents of the surface layer for the sections which were tested by CT Scan. For each section two cores were tested: center (C) and right wheelpath (RW). It should be noted that the air-void contents shown below belong to the voids greater than 0.4 mm in diameter. The very low void content of dense graded mixes may be because they have smaller voids compared to open graded mixes which can't be detected with CT scan.

Figure 2 shows the air-void content distribution (for voids with diameters larger than 0.4 mm) throughout the surface layer of OGAC and RAC-O mixes, and the European Gap Graded mix (EU GG), while Figure 3 shows the DGAC and BWC mixes. According to the figures, there is greater variation in the air-void content of open graded mixes throughout the thickness than the dense graded mixes. There is no clear trend in these plots showing that clogging occurs in the upper 25 mm of the top layer.

Figure 4 shows the air-void content distribution trend for the open graded and EU-GG mix through the thickness of the surface layer. All the sections except es-1 and es-3 have higher air-void contents at the bottom of the layer than at the top. The lower air-void content at the top part of the surface layer that is seen for the rest of the mixes suggest that there is accumulation of sand and fines at the top part of the surface layer which supports the earlier findings. The higher air-void content seen at the top section of the cores of es-1 and es-3 sections may be due to the thickness effect since these mixes have similar gradation properties to other open graded mixes. Thicker mixes may be less clogged or fine particles accumulate deeper in the mix. However, a larger sample size is needed in order to fully evaluate the thickness effects on the clogging.

It should be noted that air-void content of open graded and gap graded asphalt cores may have been affected by drilling. Dirt from drilling may have got into the pores reducing the air-void content. However, water used for coring may also have washed off the dirt and flushed it away. Therefore, the effect of drilling on the air-void content of the asphalt cores is unknown.

Table 1: Air-Void Contents by CT Scan

Core ID	Mix Type	Age (years)	NMAS (mm)	Air-Void Content (%)
01-N114C	DGAC	5	12.5	1.26
01-N114RW	DGAC	5	12.5	1.11
06-N434C	DGAC	6	12.5	2.45
06-N434RW	DGAC	6	12.5	1.46
ES-7C	BWC	3.5	12.5	0.54
ES-7RW	BWC	3.5	12.5	3.56
01-N104C	OGAC	5	9.5	11.19
01-N104RW	OGAC	5	9.5	13.63
01-N105C	OGAC	5	12.5	23.65
01-N105RW	OGAC	5	12.5	24.27
06-N467C	RAC-O	3	9.5	14.28
06-N468RW	RAC-O	3	9.5	14.95
ES-1C	OGAC	3.5	12.5	11.01
ES-1RW	OGAC	3.5	12.5	9.52
ES-3C	OGAC	3.5	12.5	9.79
ES-3RW	OGAC	3.5	12.5	9.88
ES-5C	RAC-O	3.5	12.5	9.62
ES-5RW	RAC-O	3.5	12.5	8.15
ES-10C	EU GG	0.5	12.5	17.99
ES-10RW	EU GG	0.5	12.5	15.93

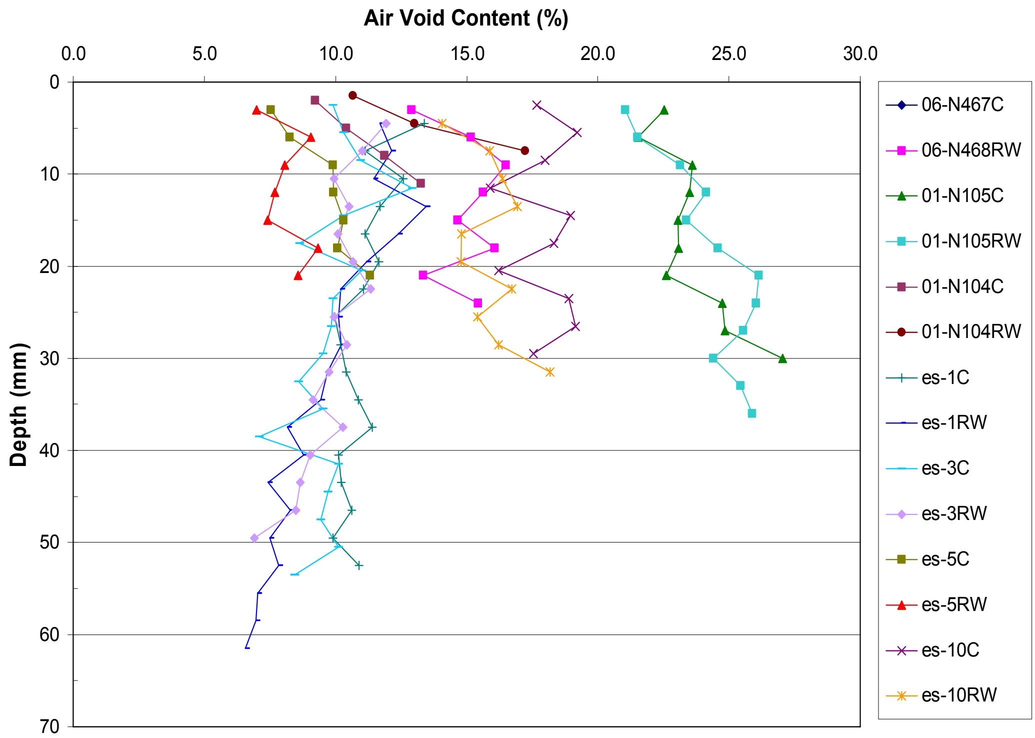

Figure 2: Air-void (%) distribution of open graded mixes and EU Gap Graded mix through the thickness of the core

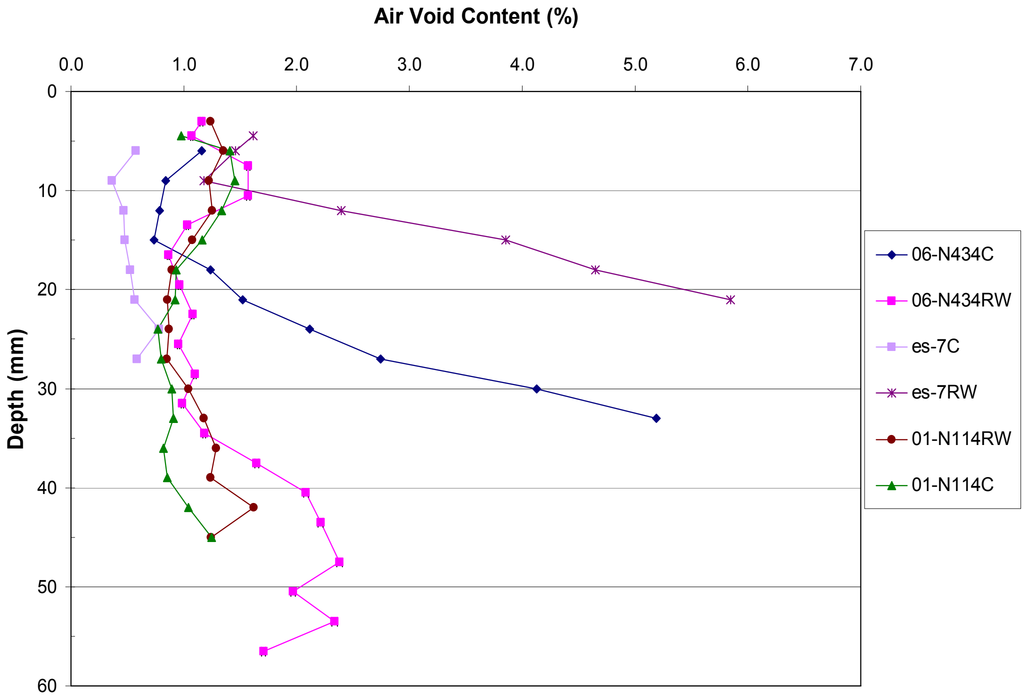

Figure 3: Air-void (%) distribution of dense graded mixes and BWC mix through the thickness of the core

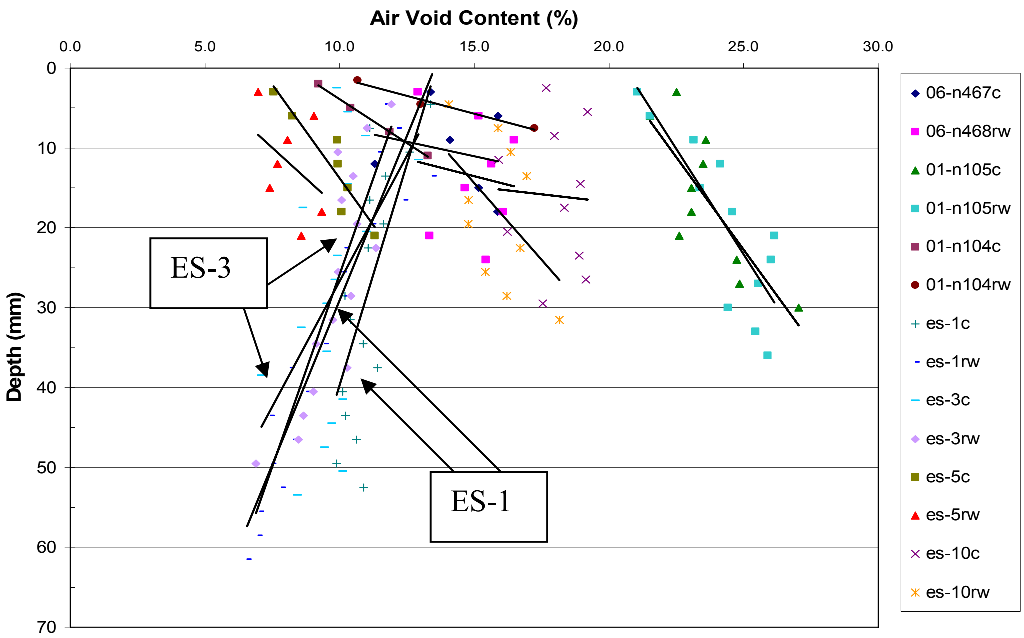

Figure 4: Air-void content (%) trend for open graded mixes and EU Gap Graded mix through the thickness of the core

3.2. Field Permeability Measurements

Clogging was evaluated from field measurements as the difference in permeability between the center and right wheelpath values. If the center permeability is higher than the wheelpath permeability, the mix is clogged with sand and fines carried by vehicles. The reduction in permeability in the wheelpath may also be due to compaction of wheelpath under traffic. Figure 5 shows the clogging variation of different surface types. It can be seen that the difference between the center and right wheelpath values for RAC-G and DGAC mixes are very close to zero. Therefore, clogging analysis was conducted only on the OGAC and RAC-O mixes.

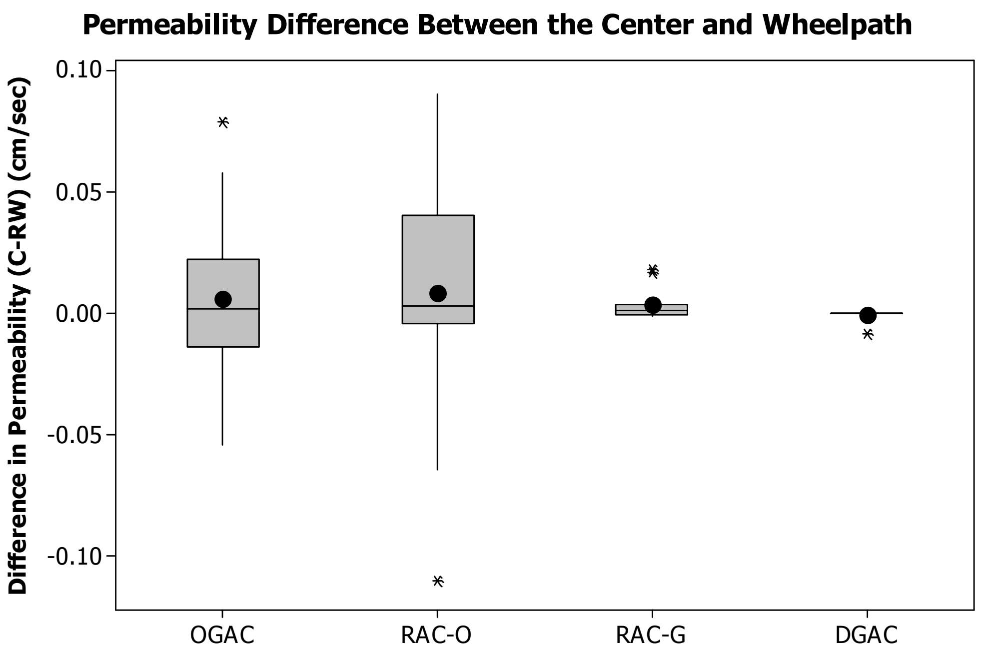

Figure 5: Permeability difference between the center and wheelpath for different mix types

The effects of air-void content, difference in air-void content between center and wheelpath, age, rubber inclusion in the mix, fineness modulus (the higher the fineness modulus, the coarser the asphalt mix), coefficient of uniformity (C_u), NMAS, rainfall, traffic (AADT and average annual daily truck traffic, AADTT), surface layer thickness, and temperature on the clogging were evaluated. Due to the small dataset, one variable was evaluated at a time. Significance level of 0.05 was used in the analysis. A log transformation was applied to cumulative rainfall variables since the variance of error terms was not constant. Table 2 shows the ordinary least squares (OLS) regression models only for the significant variables. The coefficients of the explanatory variable and the constant term, and their *p-values* along with the coefficient of determination (R^2) for each model are given in the table. The dependent variable is the permeability difference between center and wheelpath.

Table 2: Regression Analysis of Clogging Parameters

Model Number	Explanatory Variable			Constant Term		R^2
	Name	Coefficient	P-value	Coefficient	P-value	
1	Air-void Content	0.0034	0.04	-0.047	0.08	10.3
2	Air-void Difference between C and RW	0.0055	0.04	0.00099	0.87	10.1
3	Log (Age*Average Annual Rainfall)	-0.038	0.01	0.129	0.00	15.4
4	log (Age* Average Annual Wet Days)	-0.039	0.01	0.098	0.00	15.0
5	log (Age * Number of Days with Precipitation> 20mm)	-0.028	0.02	0.046	0.01	12.4
6	AADTT (Average Annual Daily Truck Traffic)	0.030	0.03	0.00049	0.93	11.5

Regression analysis revealed that air-void content, the air-void content difference between the wheelpath and center, the cumulative rainfall (age*average annual rainfall), cumulative number of days with rainfall (age*average annual wet days), cumulative number of days with rainfall above 20 mm, and average annual daily truck traffic (AADTT) were found to be significant variables affecting the clogging of open graded mixes. The higher the void content the greater the clogging since there are more voids to be filled. As the air-void content difference between center and right wheelpath increases, the clogging increases. However, this may be due to the densification in the wheelpath under traffic rather than clogging of pores. Densification in the wheelpath would result in lower air-void contents, hence lower permeability values. The cumulative rainfall (since the construction) of the pavement reduces the clogging. Rainfall may keep the pores open and prevent clogging. Since distribution of AADTT was highly skewed, it was categorized as high and low. In the analysis, high AADTT is coded as 1 for sections with truck volumes above 1,750 and low AADTTCL is coded as 0 for sections with truck volumes less than the 1,750. Higher truck volumes (above 1,750) were found to increase clogging. This may be due to the densification of the wheelpath under heavy truck traffic, resulting in less air-void content and permeability rather than clogging of pores with sand and fines. Although the CT scan analysis suggested that thickness may affect clogging, thickness was not found a significant variable affecting the permeability difference between center and wheelpath in the regression analysis.

3.3. Permeability and Noise Levels

Figure 6 shows the variation of permeability values for 1st year and 2nd year measurements for different mixes at different ages. It can be seen that there is usually reduction in the permeability values in one year. The reduction in permeability in one year is lower for older mixes. This is because the mixes are already compacted under traffic or clogged with fines and sand in the first few years. RAC-G mixes lose their permeabilities and have permeability values close to dense graded mixes after a few years under service. Figure 7 shows the variation of sound intensity levels for different mixes at different age. The phase ID indicates the first year and second year measurements. It can be seen that the noise levels usually increase in one year following a trend opposite to that of permeability.

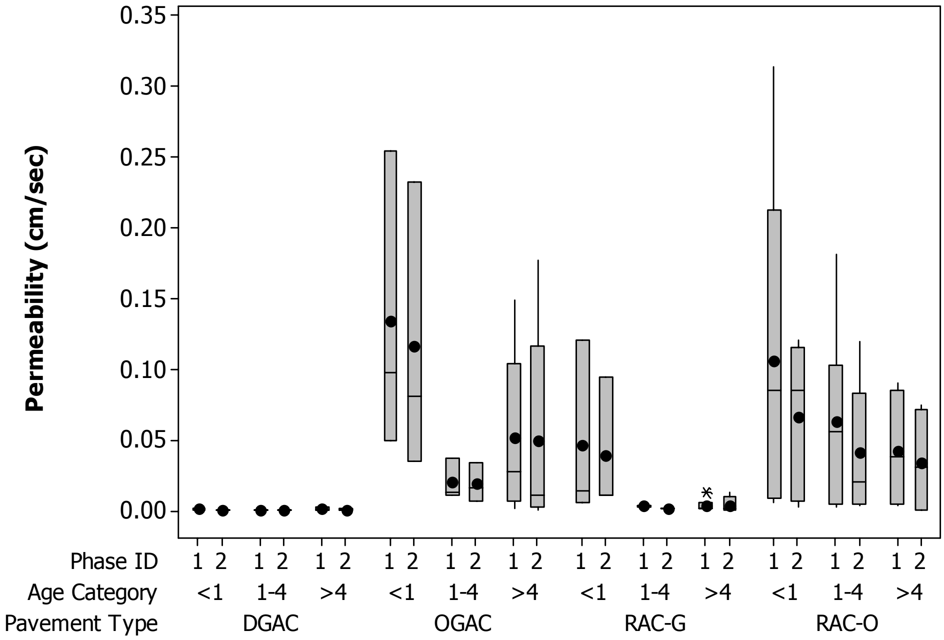

Figure 6: Comparison of permeability values for different surface types at different ages for 1st and 2nd year

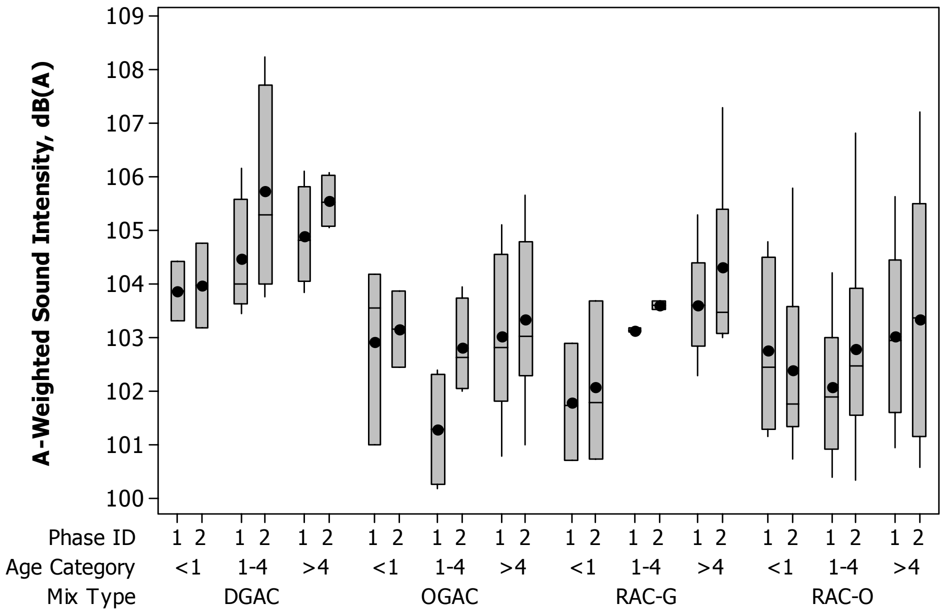

Figure 7: Comparison of A-Weighted sound intensity levels for different surface types at different ages for 1st year and 2nd year

Table 3 shows the regression models for sound intensity levels. Air-void content and permeability are the explanatory variables. A logarithmic transformation was applied to permeability. It can be seen that both air-void content and permeability affect the noise levels when a significance level of 0.05 is used. The higher the air-void content and permeability, the lower the noise levels. It can be seen that coefficient of determination for air-void content is 12.9 while it is 21.5 for permeability. It can be concluded that permeability is a better predictor for noise levels than the air-void content. This may be because clogging takes place in the upper part of the surface layer reducing the permeability while the air-void content stays relatively constant.

Table 3: Regression Analysis of Sound Intensity Levels

Model Number	Explanatory Variable			Constant Term		R^2
	Name	Coefficient	P-value	Coefficient	P-value	
1	Air-void Content	-0.11	0.00	104.37	0.00	12.9
2	log (Permeability)	-0.27	0.00	101.61	0.00	21.5

4. Results and Conclusions

In this paper, clogging potential of open graded mixes and the effects of clogging on the noise levels were evaluated. Clogging was assessed by CT scan and field permeability measurements while the tire/pavement noise was measured by On-Board Sound Intensity (OBSI) Method. Regression analyses were conducted in order to find out the significant variables affecting clogging of open graded mixes and air-void content and permeability effects on the noise levels.

1. The air-void content at the top of the surface layer is usually higher than at the bottom. This indicates that clogging takes places at the top zone of the surface of open graded mixes.
2. Thicker open graded mixes have higher void content in the upper of the top layer. This may be because sand and fine particles accumulate deeper in the mix or there is less clogging with increasing thickness. Thickness effect on clogging is inconclusive at this point. A bigger sample size is needed in order to fully evaluate the thickness effects.
3. Increasing rainfall, number of days with rainfall, and number of days with rainfall above 20 mm reduces clogging. Rainfall helps cleaning up the fine particles and sand in the wheelpath. Mixes with higher air-void content are also more likely to clog. Increasing air-void content difference between center and wheelpath and AADTT increases the difference in permeability of center and wheelpath. However, this difference is due to compaction of wheelpath under traffic rather than clogging with fines and sand.
4. Permeability decreases with time while the noise levels increase with time. The rate of reduction in permeability also decreases with time.
5. RAC-G mixes have permeabilities close to open graded mixes within first year of construction. However, they lose their permeabilities after a few years under service.
3. Permeability is a better explanatory variable for noise levels than the air-void content. This is because clogging affects the permeability rather than air-void content.

These results indicate that open graded mixes including EU GG may be preferred over RAC-G mixes for noise reduction since RAC-G mixes lose their permeability and noise reduction properties after a few years under traffic. Open graded mixes retain their permeability and, and therefore noise and safety properties longer in areas with high rainfall and less truck traffic. This confirms for California mixes earlier findings in other countries.

5. References

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