SOUND ABSORPTION AND MATERIAL PROPERTIES OF ASPHALT RUBBER CONCRETE SPECIMENS

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ABSTRACT:
The acoustic and material properties of asphalt crumb rubber (ARC) pavement have been measured and correlated. Laboratory measurements revealed nonlinear relationships between the sound absorption coefficients and material properties of compacted specimens as a function of the percentage of crumb rubber content in conventional and modified binders.
The acoustic performance of conventional asphalt and asphalt rubber concrete specimens are compared to their material properties as a function of crumb rubber content to determine how crumb rubber content influences sound absorption. The normal incidence sound absorption coefficients, porosity, percentage of voids in mineral aggregate and absolute gas permeability are measured for specimens containing 0, 5, 10, 15 and 20% crumb rubber in the asphalt binder. The random incidence sound absorption coefficient and material property data share nonlinear distributions within some frequency ranges, as a function of crumb rubber content in the conventional and modified asphalt binders.

Keywords: asphalt rubber concrete; pavement; sound absorption

1. MATERIALS AND METHODS

1.1 Specimens

The Marshall compacted conventional and ARC specimens were created by the Government of Saskatchewan Ministry of Highways and Infrastructure (2010). The volume of aggregate and modified binder in the mixtures were held constant but the percentage of crumb rubber added to the asphalt binder was varied. The mixtures were composed of aggregate and 7.6% modified binder containing grade 200-300A asphalt and crumb rubber particles passing through a 0.6 mm (600 um) sieve. Five mixtures were created containing 0, 5, 10, 15 and 20% crumb rubber in the modified binders. Specimens were formed in 101.7 mm (4”) diameter, 63.5 mm (2.5”) tall molds and Marshall compacted with 75 blows applied to each side. The specimens were drilled with a 25.4 mm (1”) diameter drill bit and cut to a length of 25.4 mm (1”) to measure the porosity and permeability. Damaged samples were discarded to obtain a balanced set of 55 samples. The porosities and absolute permeabilities of 11 samples from each mixture were measured and averaged. A 63.5 mm (2.5”) diameter drill bit was used to obtain three 63.5 mm (2.5”) tall, compacted samples from each group of specimens to fit the impedance tube.

1.2 Sound Absorption Coefficients

Normal incidence sound absorption coefficients were measured with a Bruel and Kjaer Type 4206-A standard medium impedance tube set with a low pass filter (ISO 10534-2, 1998). Three 63.5 mm (2.5”) diameter cores from each modified binder were drilled from compacted briquettes, wrapped in Teflon and placed in the tube. The sound absorption coefficients of each surface were measured in triplicate between 400 to 3000 Hz and averaged.

The average random incidence sound absorption coefficients of the compacted samples are calculated as a function of the samples’ surface impedances obtained from impedance tube measurements. Assuming the pavement surfaces are locally reacting, the random incidence absorption coefficients can be calculated as a function of their surface impedances (Kuttruff, 1973). This is valid for dense materials forming massive structures such as pavement, “…where the stiffness effect is small enough to be ignored in comparison with the mass effect” (Cox and

D’Antonio, 2009). In this case, the normal component of the particle velocity is purely a function of the sound pressure at the point of impact. Hence, the surface impedance is independent of the particle’s angle of incidence. The random incidence absorption coefficients can be calculated using Paris’ formula (Cox and D’Antonio, 2009).

1.3 Porosity and Voids in Mineral Aggregate

The measured porosities of the 25.4 mm (1”) diameter, 25.4 mm (1”) tall samples were averaged to examine how the presence of air voids affected sound absorption in compacted conventional and ARC pavement. The porosity ϕ of each sample is obtained by comparing its bulk and grain volumes with the following equation:

$$\varphi = \frac{Bulk\,Volume - Grain\,Volume}{Bulk\,Volume} \times 100 \qquad (1.3.1)$$

The length and diameter of each sample were measured three times with a digital caliper and averaged before calculating the bulk volumes using the equation for the volume of a cylinder:

$$Bulk\,Volume = \frac{\pi d^2 l}{4} \qquad (1.3.2)$$

where d is the average core diameter and l is the average core length. The grain volume of each sample was measured with an UltraPoreTM 300 Helium Porosimeter, manufactured by Core Laboratories.

The voids in the mineral aggregate (VMA) will be shown to have a similar percent distribution as a function of crumb rubber content. The VMA are the “…void spaces between the aggregate particles of the compacted mix. This voids space includes the air voids and the effective asphalt content” (Colorado Department of Transportation, 2019).

The porosity and percentage of VMA in compacted specimens are commonly determined using standard procedures such as those provided by Alberta Transportation (2022) using measured parameters from a Marshall mix design.

1.4 Absolute Gas Permeability

Absolute gas permeability measures the ability to transmit a gas through a material when a single fluid is present.

The absolute permeability of each sample was measured to determine if the interconnectivity of the air voids is affected by the crumb rubber content. The samples were placed in an OFITE Model 90 cement gas permeameter connected to a regulated supply of nitrogen gas. The inlet pressure was increased to obtain a pressure difference across the sample as a function of the flow rate. The absolute permeability k for each sample was calculated in millidarcies according to the following equation, based upon Darcy's Law (OFITE Testing Equipment Inc., 2009):

$$k = \frac{2000 P_o Q u l}{A\left(P_i^2 - P_o^2\right)} \tag{1.4.1}$$

where Po is the outlet pressure (assumed to be 1 atm), Pi is the measured inlet pressure, Q is the flow rate in cc/min, u is the viscosity of nitrogen (assumed to be 0.1756 cP) and A and l are the cross-sectional area and length of an individual sample measured with a digital caliper in cm. The average absolute permeability was obtained for each flow rate and reported as a function of the binder content.

2. EXPERIMENTAL RESULTS

2.1 Random Sound Absorption Coefficients

The random incidence sound absorption coefficients for the 5 and 20% crumb rubber specimens remain consistently low throughout the measured frequency range. The 10% specimens exhibit consistently higher sound absorption. The 15% specimens deviate from the general behaviour of their counterparts; smaller sound absorption coefficients are measured up until 1700 Hz, at which point the coefficients rise above the majority of the measured data and increase to their peak values at the upper end of the measured frequency spectrum. It appears more sound absorption may be obtained in situ from asphalt rubber concrete pavement containing 10 to 15% crumb rubber in the modified binder. The conventional samples exhibit the highest levels of absorption between 1300 and 2400 Hz, far surpassing the levels measured from the ARC specimens. However, the conventional specimens absorb the least amount of sound at the lower and upper ends of the measured frequency spectrum.

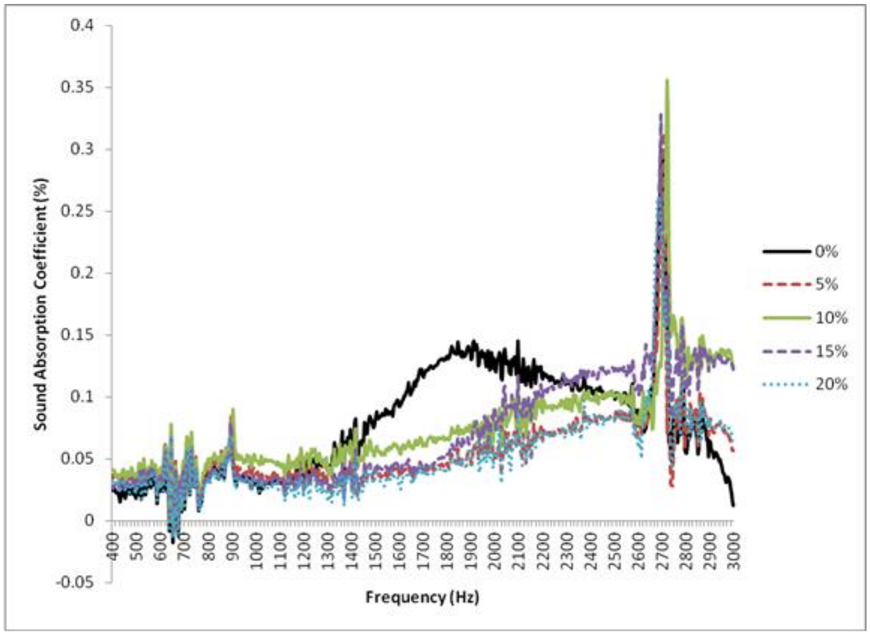

Figure 2.1.1 Random incidence sound absorption coefficients for the conventional and ARC compacted specimens.

The sound absorption coefficient data is tabulated in Appendix B of Drysdale (2012).

2.2 Porosity and Voids in Mineral Aggregate

The average porosity and VMA of the conventional and ARC specimens as a function of crumb rubber modified binder increase in lock-step, peaking at 15%, and then declining at 20%.

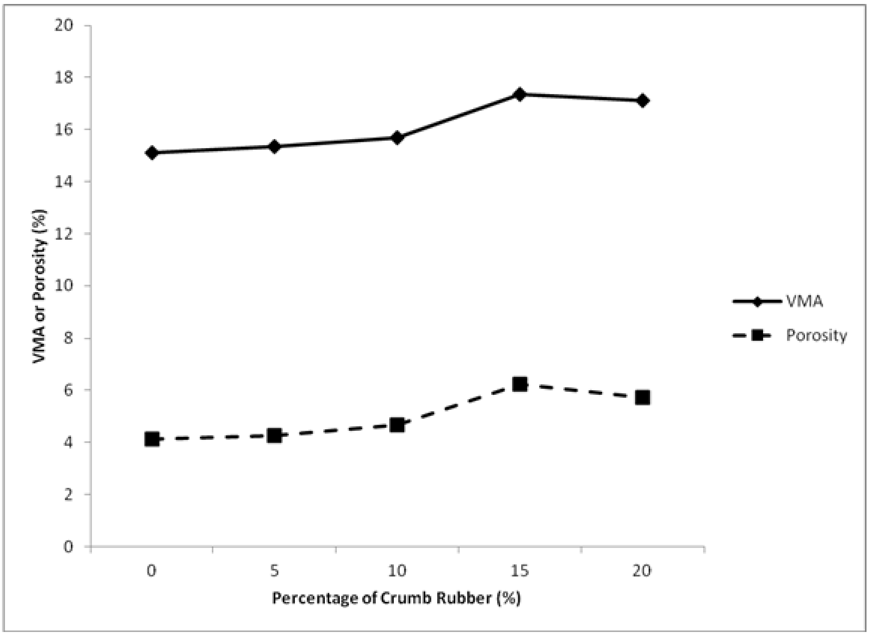

Figure 2.2.1 Average porosity and voids in mineral aggregate of the compacted samples as a function of the percentage of crumb rubber in the modified binders.

Table 2.2.1 Average measured porosities and calculated percentage of voids in the mineral aggregates (VMA) as a function of crumb rubber content.

Treatment (%)	Porosity (%)	VMA (%)
0	4.128	15.1
5	4.252	15.336
10	4.669	15.7
15	6.253	17.364
20	5.722	17.1

2.3 Absolute Gas Permeability

The average absolute permeability of the conventional and ARC samples was measured as a function of crumb rubber content and flow rate. As evident in Figure 2.3.1, the upper limit of the measured flow rates produced an absolute permeability distribution consistent with the distributions observed in the sound absorption coefficients, porosity and VMA. In actual practice, the flow rate and, hence, absolute permeability between a tire and pavement, will depend on the tire and pavement characteristics.

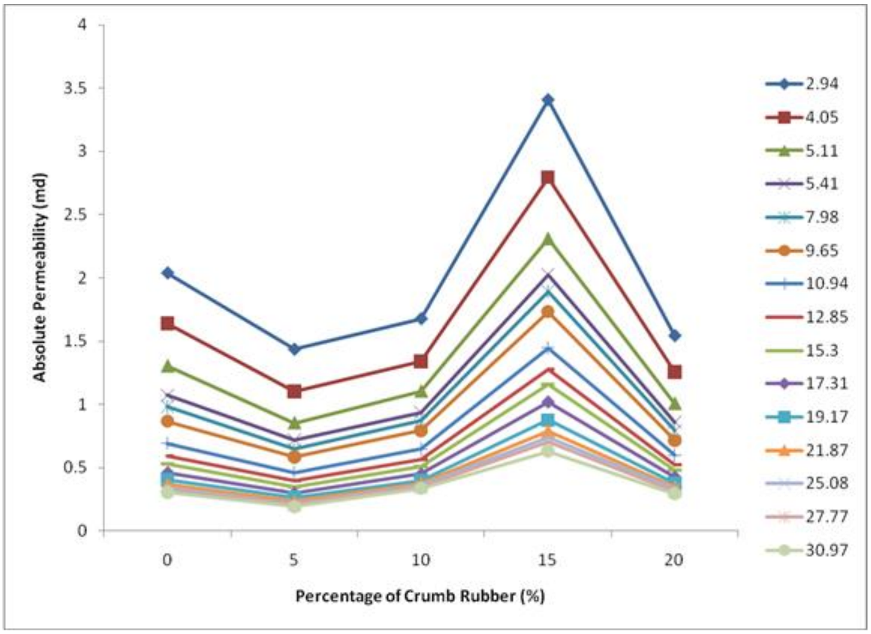

Figure 2.3.1 Average absolute permeability in millidarcies as a function of the percentage of crumb rubber in the modified binders. Each line represents a flow rate in cc/min.

Table 2.3.1 Average absolute permeability as a function of flow rate and crumb rubber content.

Flow Rate (cc/min)	0%	5%	10%	15%	20%
2.94	2.040	1.436	1.678	3.408	1.545
4.05	1.639	1.101	1.342	2.795	1.257
5.11	1.304	0.854	1.104	2.310	1.006
5.41	1.072	0.717	0.938	2.027	0.861
7.98	0.985	0.646	0.872	1.893	0.792
9.65	0.868	0.585	0.793	1.735	0.715
10.94	0.694	0.463	0.648	1.447	0.598
12.85	0.594	0.395	0.565	1.276	0.524
15.3	0.529	0.345	0.511	1.156	0.478
17.31	0.462	0.300	0.450	1.018	0.426
19.17	0.403	0.263	0.400	0.876	0.377
21.87	0.366	0.235	0.377	0.789	0.349
25.08	0.345	0.218	0.364	0.738	0.334
27.77	0.322	0.205	0.350	0.703	0.312
30.97	0.305	0.192	0.338	0.631	0.295

3. DISCUSSION

The measured sound absorption coefficients, porosity, percentage of voids in the mineral aggregate and absolute permeability all increase with increasing crumb rubber in the binder. All the measurement data peak at 15% crumb rubber and decline at 20% crumb rubber by total volume of binder. The consistent data distributions imply sound absorption is correlated with the measured material properties.

Consider the data measured for the 0 to 15% crumb rubber modified binders. Increasing the crumb rubber content creates more voids. The data indicate the increase in voids in the mineral aggregate can be predominantly attributed to air voids as the porosity increases in lock-step with the VMA. More air voids logically permit an increase in air flow; hence, an increase in absolute permeability as evidenced by the measurement data. This is the proposed mechanism for the observed increase in sound absorption with increased crumb rubber content.

The question remains: why does the addition of crumb rubber increase the porosity and percentage of voids in the mineral aggregate? Zanzotto and Svec (1996) studied the use of asphalt crumb rubber modified binders and found, "…phase separation between rubber and asphalt. This can be partially attributed to unreacted vulcanized rubber, and to carbon black created from reacted vulcanized rubber." Hosseinnezhad et al. (2019) state, "Rubber particle size, density differences between rubber and asphalt binder, and swelling of rubber particles are the problems associated with the segregation, which consequently has a negative effect on the application of CRM [Crumb Rubber Modified] in asphalt". Phase separation and segregation of crumb rubber from the asphalt due to the crosslinking structure of vulcanized rubber may be responsible for the increased porosity and voids in mineral aggregate and subsequent permeability. According to a conference abstract by Zimmerman et al. (2016), "air bubbles attach themselves – due to the hydrophobicity of tire rubber – at the surface of rubber particles during the mixing process. Some of them separate from rubber particles and form spherical air voids in the cement paste".

The measured data peak at 15% asphalt crumb rubber and decline at 20%. Sound absorption appears to decline beyond 15% due to a reduction in absolute permeability, caused by a reduction in porosity and air voids.

This research has not experimentally determined why, or if, the air voids become saturated beyond 15% crumb rubber content. The addition of more crumb rubber may initially create surfaces for air bubbles to be created in the mix but as the volume of crumb rubber increases, less surface area is available to form bubbles and the percentage of air voids per volume decline.

The sound absorption is dependent upon air movement through the compacted pavement material as it is for most materials. Some of the measured acoustic frequency ranges exhibit increased sound absorption with increasing porosity and permeability.

4. CONCLUSION AND FUTURE WORK

The porosity, absolute permeability, sound absorption characteristics and surface air void characteristics of Marshall compacted conventional and asphalt rubber concrete specimens have been measured and quantified as a function of crumb rubber content. The measured characteristics share similar data distributions.

Further research is needed to determine the exact nature of the increased air voids in asphalt crumb rubber specimens with increased crumb rubber content and why there is an upper limit to this phenomenon. This work would be well suited for a civil or environmental engineering technology team that could create Marshall mix designs and a technical or engineering team that could assess the specimens' microscopic structures.

5. FUNDING

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