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Pavement Evaluation Project – Tire/pavement Interface Noise Results on Massachusetts Pavements Using the On-Board Sound Intensity Method

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16. Abstract

The main focus of the All States Massachusetts study will be to look at the noise levels that result from the different materials All States has designed and produced over the last ten years. Initially, the goal is to simply quantify the noise properties of the pavements in Massachusetts. Then a secondary goal after finding the overall noise levels would be to analyze differences in the sound properties due to differences in mix type, mix design, and aging. This information can then be utilized throughout the pavement selection process to allow for noise concerns to be accounted for while retaining the safety and maintenance capabilities necessary in a given locale. This project will encompass fifteen different pavement surfaces located throughout eastern Massachusetts. The measurements will be recorded between December 13, 2010 and December 17, 2010. The pavement selection was completed by All States Material Group. Each pavement section is roughly two miles long, which will allow the CAIT acoustic technicians to choose appropriate testing locations according to the AASHTO TP 76-09 specifications.

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Scope

This project was completed by The Center for Advanced Infrastructure and Transportation-Pavement Resource Program (CAIT) for All States Material Group in Massachusetts. The following report is a comprehensive review of the noise properties of fifteen different pavement surfaces that were tested in Massachusetts.

Introduction

The main focus of the All States Massachusetts study is to look at the noise levels that result from the different materials All States has designed and produced over the last ten years. Initially, the goal is to simply quantify the noise properties of the pavements in Massachusetts. Then a secondary goal after finding the overall noise levels would be to analyze differences in the sound properties due to differences in mix type, mix design, and aging. This information can then be utilized throughout the pavement selection process to allow for noise concerns to be accounted for while retaining the safety and maintenance capabilities necessary in a given locale.

This project encompassed fifteen different pavement surfaces which were located throughout eastern Massachusetts. The measurements were recorded between October 25, 2010 and October 29, 2010. The pavement selection was completed by All States Material Group. Each material section was roughly two miles long, which allowed the CAIT acoustic technicians to choose appropriate testing locations according to the AASHTO TP 76-09 specifications.

The first set of materials tested on Monday October 25, 2010, was located on I-295 near the Rhode Island-Massachusetts border. Four different materials were located there: an Asphalt Rubber Gap Graded placed in 2008 (ARGG 2008), Asphalt Rubber Gap Graded with Advera warm mix additive placed in 2008 (ARGG w/Advera WM 2008), Novachip placed in 2008, and a Novachip with asphalt Rubber placed in 2008.

The second day of testing, Tuesday October 26, 2010, contained 3 different test sections. On I-95 near Attleboro, MA two different contractors had placed similar Asphalt Rubber Gap Graded mixes in 2009. Both mixes were evaluated to see the variation in the noise characteristics between contractors. The second test section of the day was located on I-495, where two different materials had been placed in 2009 between exits 21-23, which provided an opportunity to look at an Asphalt Rubber Gap Graded and an Open Graded Friction Course. The third test section evaluated that day was on I-290 near Northborough, MA. I-290 provided an OGFC that was placed in 2006.

The third day of testing, Wednesday October 27, 2010 was utilized to export the data recorded the previous days. Rain and wet pavement conditions required that testing would be put on hold and eventually caused a late start on Thursday.

On Thursday October 28, 2010, I-495 and Rt-2 provided two different pavements. On Rt. 2, standard 19mm Superpave dense graded asphalt was tested near Littleton, MA. A two year old OGFC section was provided on the I-495 section. The third test section, tested in the afternoon, was located farther north on I-495, which provided two additional materials: an Asphalt Rubber Gap Graded laid in 2010 and a 9.5mm Superpave + 2% Latex mix which was also laid in 2010.

The last test section was located on I-95 near Amesbury, MA. It was evaluated on Friday October 29, 2010. It provided two pavements that were each paved a year apart, an OGFC placed in 2003 and an OGFC placed in 2002. These were the oldest test sections evaluated in Massachusetts.

Testing Procedure

The testing was conducted in the right lane, at 60 mph ± 1mph. The driver was required to keep the right wheels within the standard wheel path within the lane, verify speed control throughout each test, monitor the equipment in the right side mirror, and assess the roadway for anything that could change the noise quality of each test (i.e. A large truck passing by, a sound wall, an overpass etc.). The equipment utilized to measure the tire/pavement noise on the outside of the vehicle is shown in Figure 1. The technician with the laptop begins each test and watches the test section to make sure the test begins at the same point during each run. The equipment utilized to measure the tire/pavement noise on the inside of the car is shown in Figure 2. The technician running the laptop was required to monitor the coherence and PI spectrum during each test to ensure the validity of each measurement. After the test was complete, the technician with the laptop needs to record all pertinent information for that measurement and prepare for the next. Two people are required for testing for all instances. At a minimum of one location along each different material, the ambient air temperature, pavement temperature, tire temperature, wind speed, barometric pressure and the tire pressure are recorded. Before the start of each day of testing, each microphone is required to undergo standard calibration with a pistophone. The calibration information was recorded no later than one hour before the measurements begun and was repeated after the measurements were completed. If the measurement period length was greater than four hours, microphone calibration was required again at the four hour limit.

Figure 1: Sound Intensity Testing Apparatus

Figure 2: Test Setup from Inside the Vehicle

The frequency analysis of the measured sound intensity was performed using one-third octave band resolution. During measurements, the frequency range of 200 to 10,000 Hz (center frequencies of one-third octave bands) was included. One third octave bands with center frequencies of 500 to 5000 Hz consistently provide accurate results. The one-third octave band filters conform to ANSI S1.11. Directly measured or derived A-weighted values are described in the report. Verification of the microphones was recorded at the beginning and end of each test section, and the data was validated according to AASHTO TP 76-09.

The measurements were recorded as an energy average (linear) over a 5.0 second measurement period. The signals were A-weighted prior to digitization, using an OBSI setup of two intensity probes measuring the leading edge and trailing edge of the tire simultaneously. The sound intensity levels of the two probes were energy averaged for each run. The averages for all runs were then averaged together arithmetically. A minimum of three runs were completed to meet the criteria to meet the coherence, PI index, and run-to-run criteria put forth by AASHTO TP-76-09. The run to run difference in any one-third octave band level with a center frequency between 500 and 5000 Hz shall be no greater than 1 dB, the PI Index for each measurement shall be no less than 5dB in each one-third octave band with a center frequency between 500 and 5000 Hz, and the coherence of sound pressure between the two microphones of the sound intensity probe shall be greater than 0.8 for each one-third octave band with a center frequency between 500 and 5000 Hz. Any runs that did not comply with any of the above listed criteria were disregarded upon analysis.

Site selection was determined on location as a 440 foot test section (5 second measurement at 60mph) for each material for which testing was desired. Each area where testing of a material was desired by All States, was assessed by the sound testing crew by completing a dry run over the material to determine appropriate sites to test. A good site had a contiguous section of pavement with no material changes and no bridge decks. Mile marker signs were utilized for site selection as they remain in the same location and were the easiest to find and distinguish between throughout all of the runs. If testing in the area was completed again in the future, measurements can be taken at the same locations as they were for this study. The minimum number of testing sites along each material selection was four but for most materials more were utilized to provide better statistical analysis.

The analysis of the measurements taken was completed in several separate processes using the following methods. Following the test section selection process and the testing procedure set forth by the OBSI method AASHTO TP 76-09, each test section with three or more viable measurements were averaged together to get a representation for the overall material. Typically, following the OBSI method, one 440 foot test section was required to complete a material analysis. CAIT's acoustic technicians suggest that a better material characterization can be created by testing multiple sites on a particular material and averaging all of the results for that particular material. A table and coinciding bar graph of overall material averages was compiled for each roadway to show the range of differences between all of the materials tested. The benefit of the bar graph is the easy ability to see the variability of all of the materials tested at the tire/pavement interface. Secondly, one-third octave band frequency spectrum graphs are created for each site and then averaged to represent each material. The frequency graphs show the measured sound intensity levels along the one-third octave band spectrum, which is the typical frequency band used to show sound measurements for OBSI. The one-third octave band allows us to easily see unique spectral signatures for different materials while avoiding frequency clutter. We can then compare different materials to determine differences in the way the tire generated noise will be perceived by a receiver. The averaged one-third octave band frequency can be viewed as an averaged snapshot of an equalizer showing a sound generated from a tire interacting with a particular pavement. Typically, the higher frequencies shown on our one-third octave band frequency spectrums are more irritating to the human ear, and the lower frequencies are more readily ignored by the human ear. A-weighted measurements are shown because it is the weighting scheme which resembles the average human perception of sound.

After the overall table, bar graphs, and spectrum graphs were generated, the variance in test runs for each pavement surface was determined using the f-test for two-sample variance analysis. If the variances were statistically similar, t-tests for two-samples assuming equal variance analysis were completed. If the variances for each material were statistically not similar, t-tests for two-samples assuming unequal variances were completed. The resultant data was compiled into a statistical matrix which helped to determine which materials exhibited statistically similar loudness using the A-weighted decibel values. Based on the results, pavement surfaces determined to be statistically similar were then graphed side by side to show where the similarities and differences occurred. Ideally, if two different materials can provide equal loudness while remaining fundamentally different in terms of safety, maintenance, and longevity in a particular region, it would allow pavement engineers to make better pavement selections. Similarly, if certain materials are known to remain quieter for longer in a given region, the information can be utilized during pavement selection and pavement rehabilitation.

Results

Road	Material	dB(A) Overall	Stdev (1s)
I-495 S	9.5mm superpave + 2% Latex	100.0	0.4
I-495 N	ARGG 2009	100.5	0.7
I-95 S	ARGG 2009	100.5	0.2
I-95 N	ARGG 2009	100.5	0.2
I-295 N	ARGG 2008	100.8	1.2
I-495 N	ARGG 2010	100.8	0.2
I-95 S	7 year old OGFC	101.2	0.6
I-95 S	Lynch AR-GG 2009	101.2	0.2
I-95 N	Lynch AR-GG 2009	101.3	0.2
I-495 S	OGFC 2008	101.3	0.7
I-295 N	ARGG w/advera warm mix 2008	101.4	0.3
I-95 N	8 year old OGFC	101.7	0.7
I-495 S	OGFC 2009	101.8	0.4
I-495 N	OGFC 2008	102.0	0.2
I-290 E	OGFC 2006	102.9	1.2
I-290 W	OGFC 2006	102.9	1.2
Rt-2 E	19 mm superpave	103.1	0.6
Rt-2 W	19mm superpave	103.1	0.6
I-295 S	Novachip w/asphalt rubber 2008	104.5	0.2
I-295 S	Novachip 2008	105.1	0.2

Table 1: Overall Noise Levels

The overall values shown in Table 1 indicate the average overall levels recorded on each of the different materials tested by CAIT in Massachusetts for All States Materials Group. The overall values represent the loudness of the noise that would be heard at the tire pavement interface.

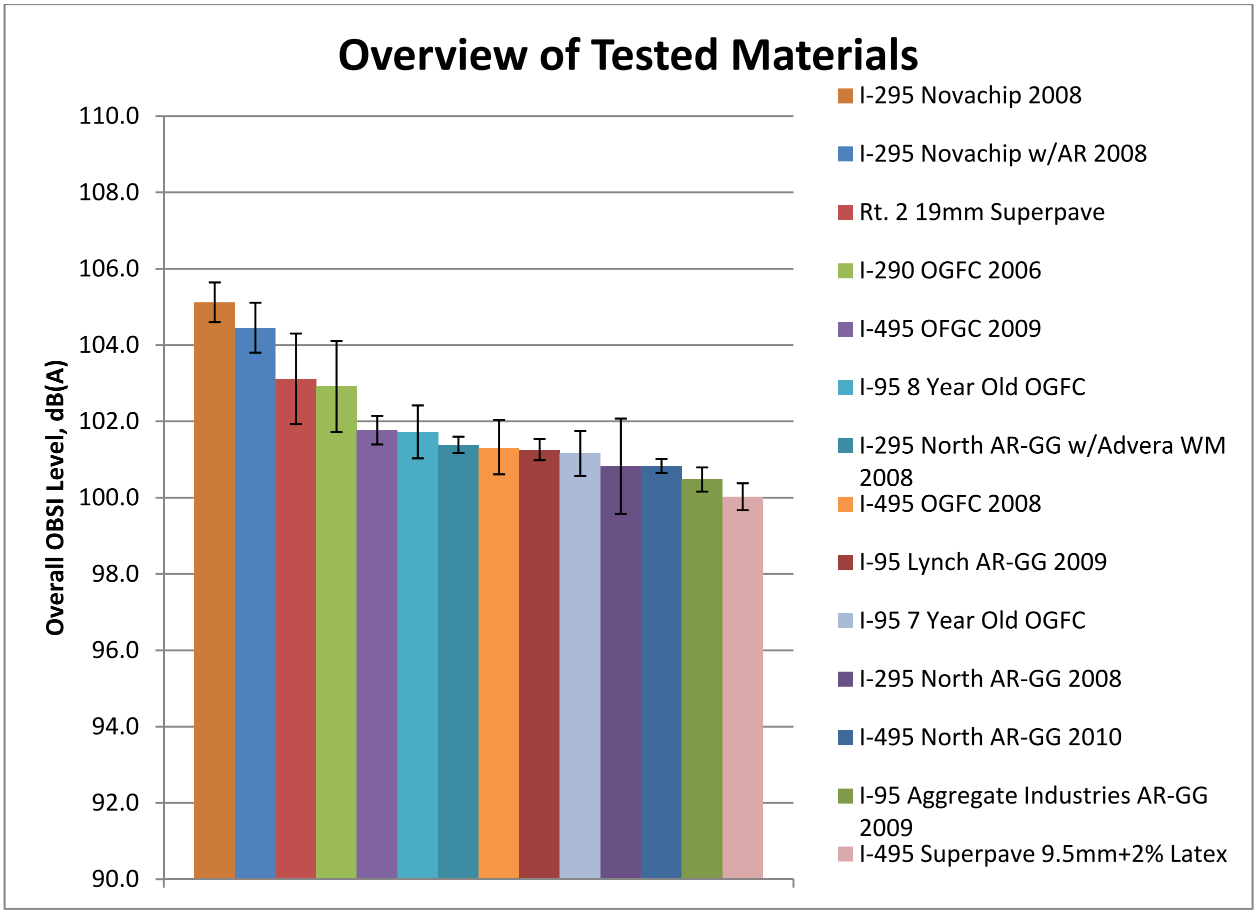

Figure 3: Average overall levels for the materials tested in MA reported in A-weighted decibels (dBA).

The overview of materials shows the average overall noise level recorded for each material. The loudest material, the I-295 Novachip that was placed in 2008 was 5 dB louder than the quietest material, the I-495 9.5mm Superpave mix, which is a noticeable difference. When looking at overall sound levels, it is important to remember that the decibel scale is logarithmic. When the noise levels compared are related to the same type of noise, a one to three decibel change is considered “just perceptible” to the human ear. A five decibel change is considered “noticeable.” A ten decibel change is “twice” as loud.

Measuring overall noise is a useful tool to begin to understand the loudness of noise propagating from the tire/pavement interface, but it does not describe the quality of the noise itself. To begin to understand the quality of the sound, spectrum graphs that range from 400 Hz to 5000 Hz represented along a one-third octave band are used, where higher frequencies relate to higher pitched noise. Since the measurements are A-weighted, the frequencies are already represented along an equal sound power to what an average human would perceive. Higher frequencies are perceived as “more annoying” to the human ear, as opposed to lower frequency noise. Therefore, pavement surfaces that generate noise more towards the higher frequency ranges are less desirable than pavement surfaces that generate noise at the lower frequency range, even when the average A-weighted decibel values are identical.

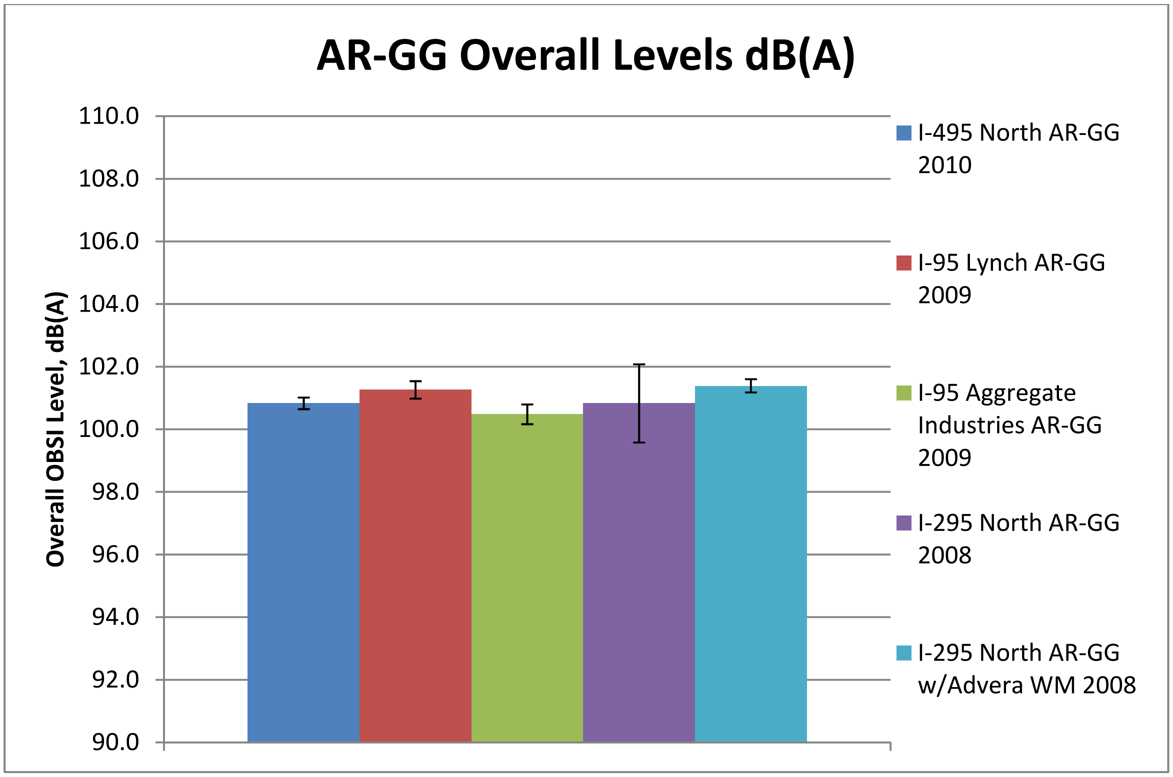

Figure 4: ARGG overall levels, dB(A)

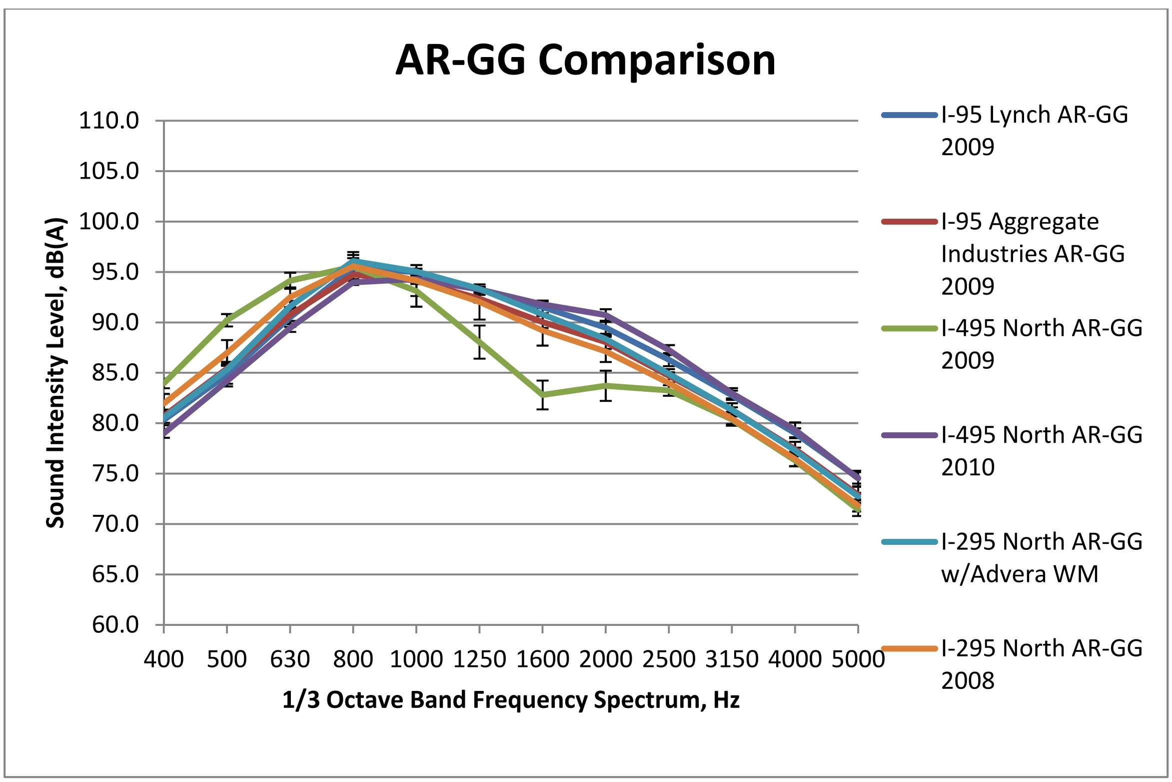

Figure 5: ARGG Spectrum Comparison

The asphalt rubber gap graded mixes, shown in Figure 4, appear to be similar on the overall levels, but when looking at the spectrum graph (Figure 5), it appears that the I-495 North ARGG that was placed in 2009 has perceptible differences in sound quality. Figures 6 through 8 show three examples of the ARGG pavements tested in MA. The more open pavement surface shown in Figure 6 is most likely the cause of the reduced noise level for the I-495 N ARGG pavement between 1000 Hz to 2000 Hz frequency range. The other two ARGG pavements shown below (Figures 7 and 8), have more binder filling the void spaces in between the aggregate.

Figure 6: I-495 N ARGG 2009

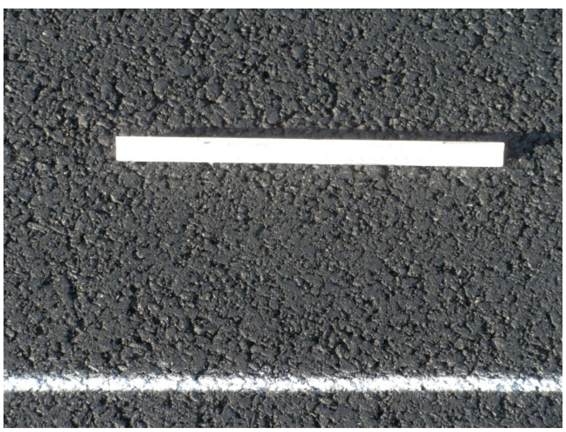

Figure 7: I-495 S ARGG 2010

Figure 8: I-95 N ARGG Lynch 2009

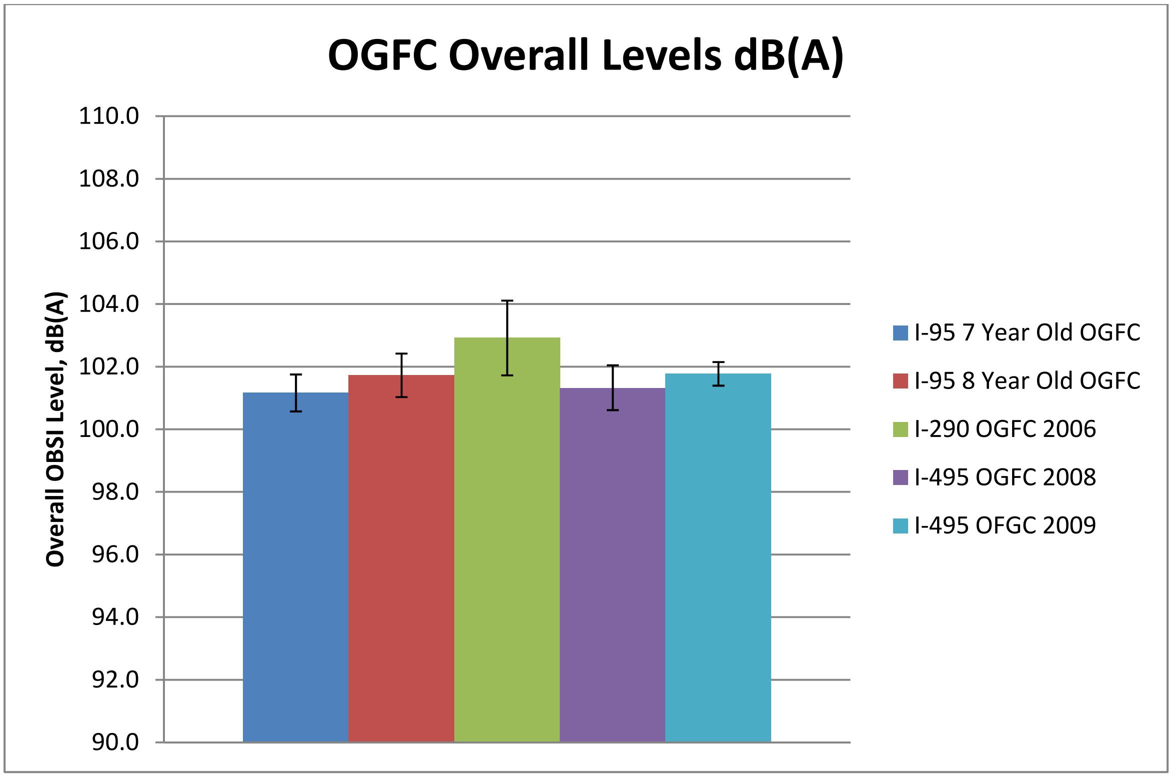

Figure 9: OGFC overall levels, dB(A)

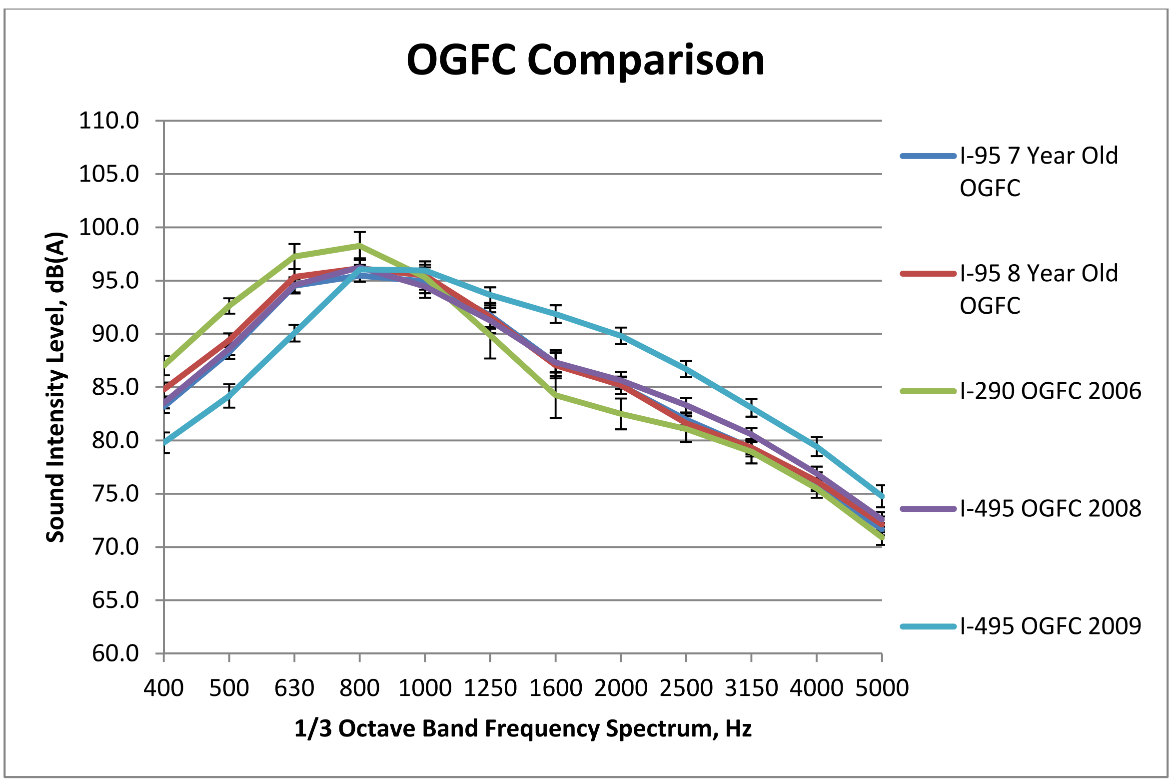

Figure 10: OGFC Spectrum Comparison

The OGFC surfaces, shown in Figures 9 and 10, were surprisingly loud, with overall levels between 101 and 103 dB(A), where we would normally consider OGFC surfaces to be quiet pavements with levels under 100 dB(A). Figure 9 definitively shows that the OGFC materials tested in MA did not show a perceptible change in noise level over time. The eight year old OGFC tested was on I-95 was roughly the same overall loudness as the newest OGFC from 2009. In Figure 10, of the five OGFC materials evaluated, only the I-495 OGFC that was placed in 2009 did not follow the standard trend of open-graded materials. Typically in open-graded materials, the lower density causes the sound intensity level for the frequencies between 1250 hz to 5000 hz to usually be lower, which is evident in all but the 2009 I-495 OGFC. This can be more easily seen in the OGFC vs DGA (Figures 17 and 18) or OGFC vs ARGG (Figures 21 and 22) charts shown later. At this time, it is not evident as to the reasoning for the differences in the frequency spectrum of the I-495 OGFC pavement surface. Figures 11 and 12 show examples of the OGFC pavements surfaces evaluated in MA. The I-95 OGFC pavement from 2002 (Figure 12) shows significantly more wear than the I-495 S OGFC 2009 pavement (Figure 11).

Figure 11: I-495 S OGFC 2009

Figure 12: I-95 N OGFC 2002

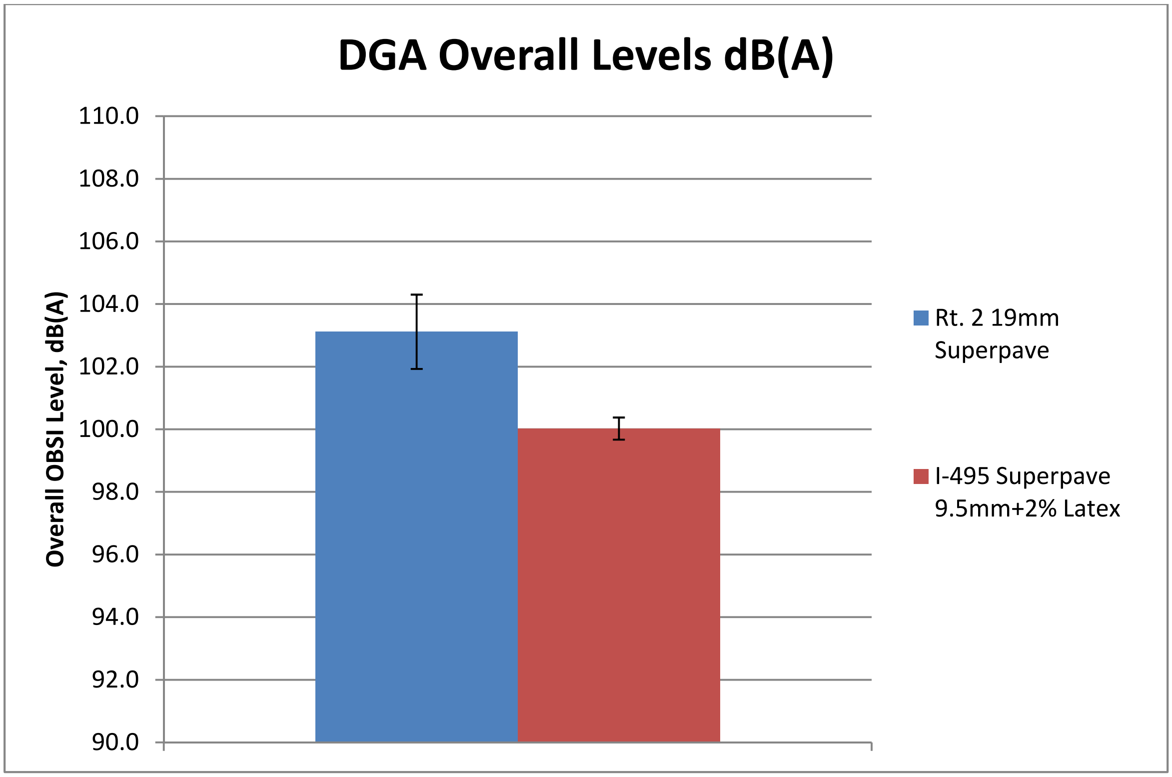

Figure 13: DGA Overall Levels dB(A)

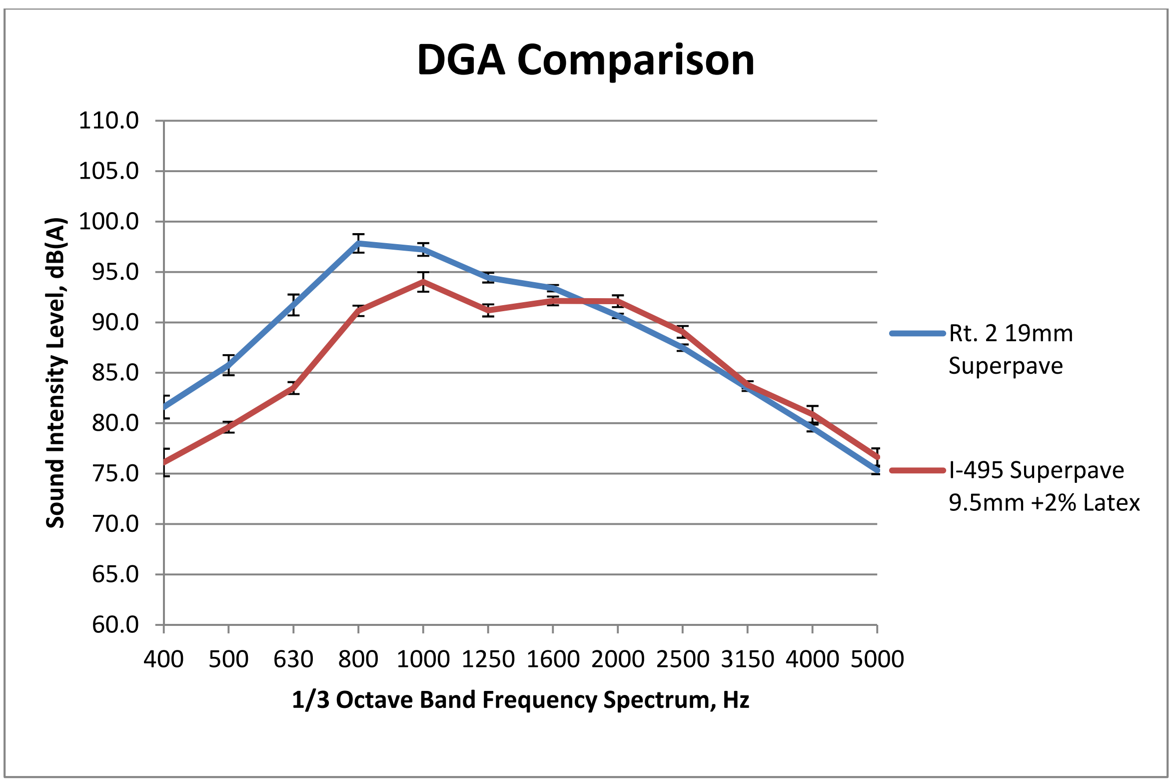

Figure 14: DGA Spectrum Comparison

The dense graded asphalts, as shown in Figure 13, range from 103.1 dB(A) to 100.0 dB(A). The sound profiles shown in Figure 14 are a good example of how aggregate size influences noise levels. The larger the aggregate the louder the surface, especially in the lower frequency range. The same can be said for texture; the rougher the material, especially those with positive texture, the louder the surface, which is typically seen in the low end of the frequency spectrum. This is also easy to see in Figures 15 and 16, which show examples of the two dense graded asphalt materials tested. As expected, the 19mm mix is significantly rougher than the 9.5mm mix, which led to the direct increase in noise seen in Figure 13.

Figure 15: Rt. 2 19mm Superpave

Figure 16: I-495 S 9.5mm Superpave + 2% latex

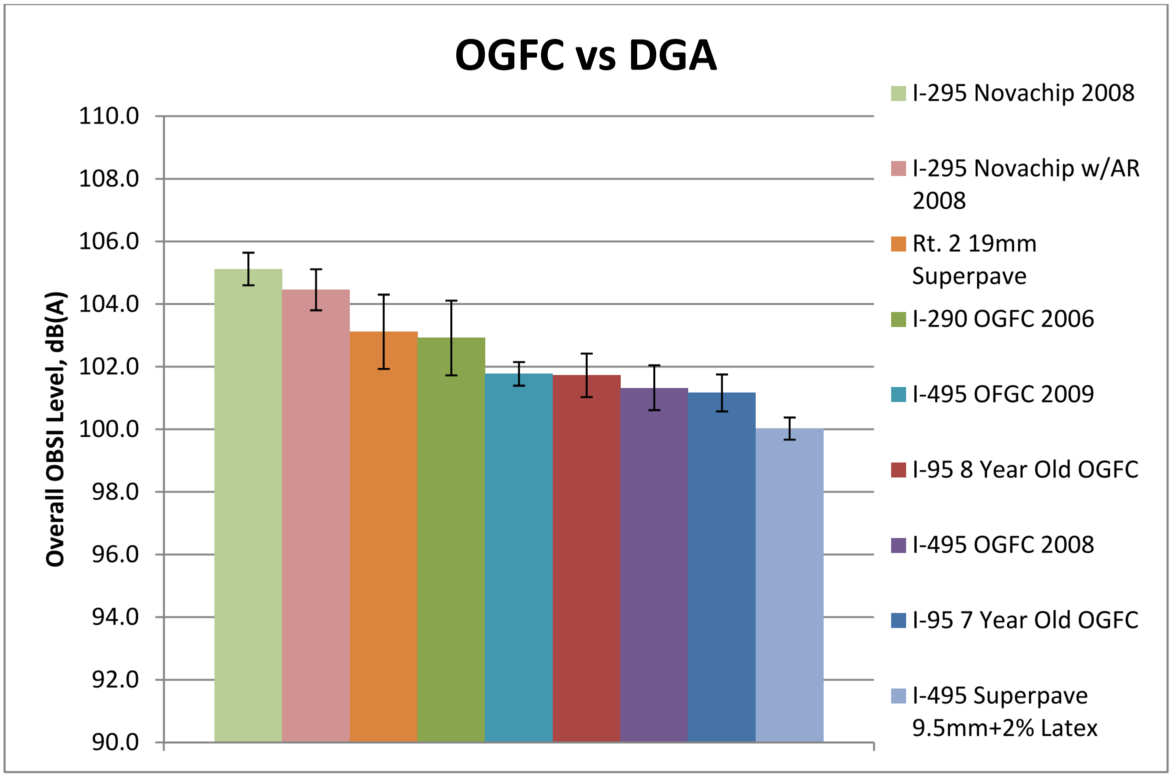

Figure 17: OGFC vs DGA Overall Levels, dB(A)

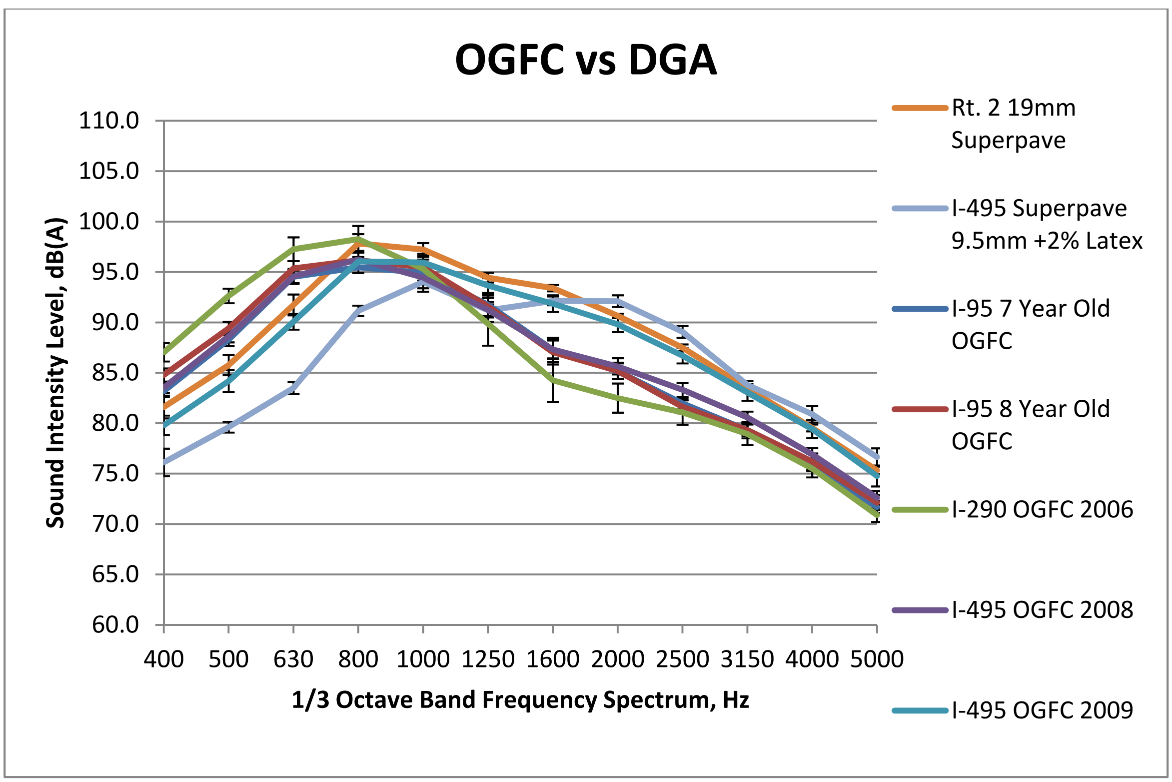

Figure 18: OGFC vs DGA Spectrum Comparison

Since OGFC pavements are typically considered 'quiet pavements' they were compared to the DGA pavements tested in Massachusetts to compared differences between the pavement surfaces. Both the overall bar chart (Figure 17) and the spectrum graph (Figure 18) show that even though the OGFC and DGA pavements in Massachusetts were loud, the OGFC pavements still did a better job in reducing the noise levels in the 1250 hz to 5000 hz range. The higher frequencies relate to higher pitched whines which can be more annoying to the human ear than the lower frequencies. For instance, the I-495 OGFC 2008 is 5 dB(A) quieter at 2000 hz than the 19mm superpave material. The most interesting comparison is the Rt. 2 19mm superpave material was only ½ decibel higher than the I-495 2009 OGFC. Figure 19 shows the I-290 OGFC 2006 pavement, which although paved in 2006, exhibits a more plesant sound quality (shown on Figure 18) than I-495 2009 OGFC pavement. Figure 20 shows the I-495 N 2008 OGFC pavement, which also outperforms the I-495 2009 OGFC. In Figure 19, the larger aggregate exposed on the pavement surfaces most likely accounts for the major difference between the I-290 OGFC 2006 pavement and the I-495 OGFC 2008 pavement.

Figure 19: I-290 OGFC 2006

Figure 20: I-495 N OGFC 2008

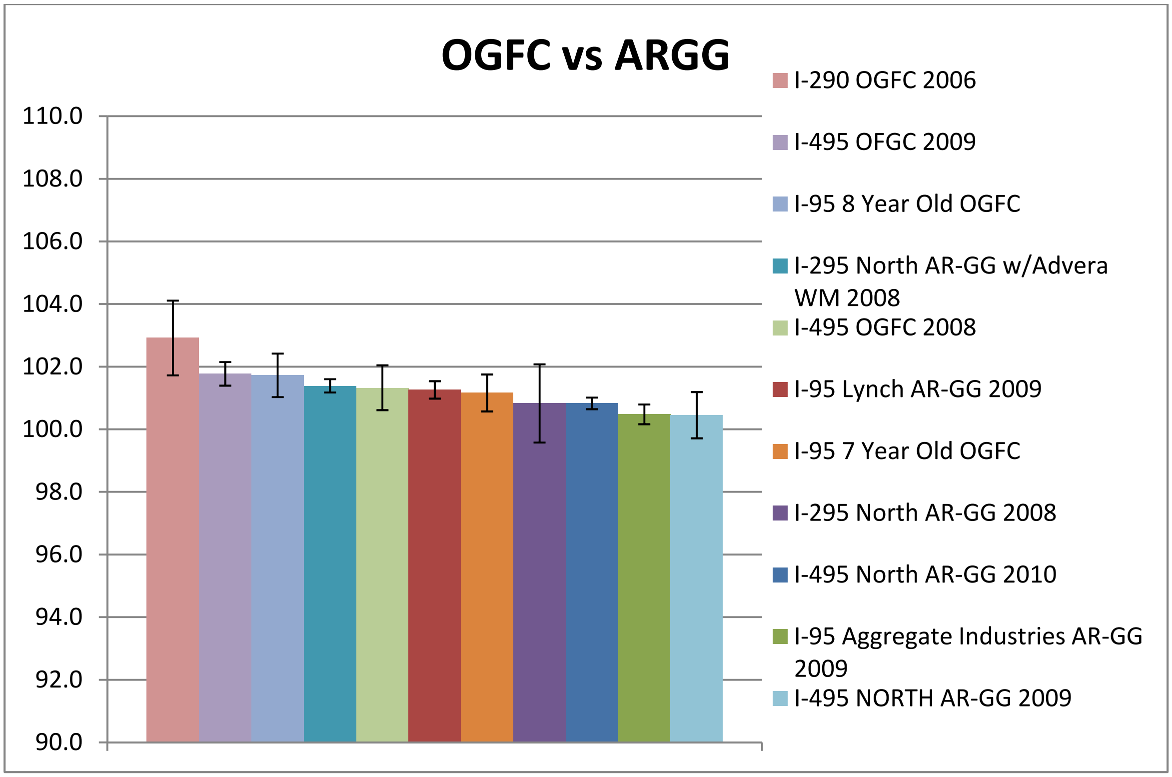

Figure 21: OGFC vs ARGG Overall Levels, dB(A)

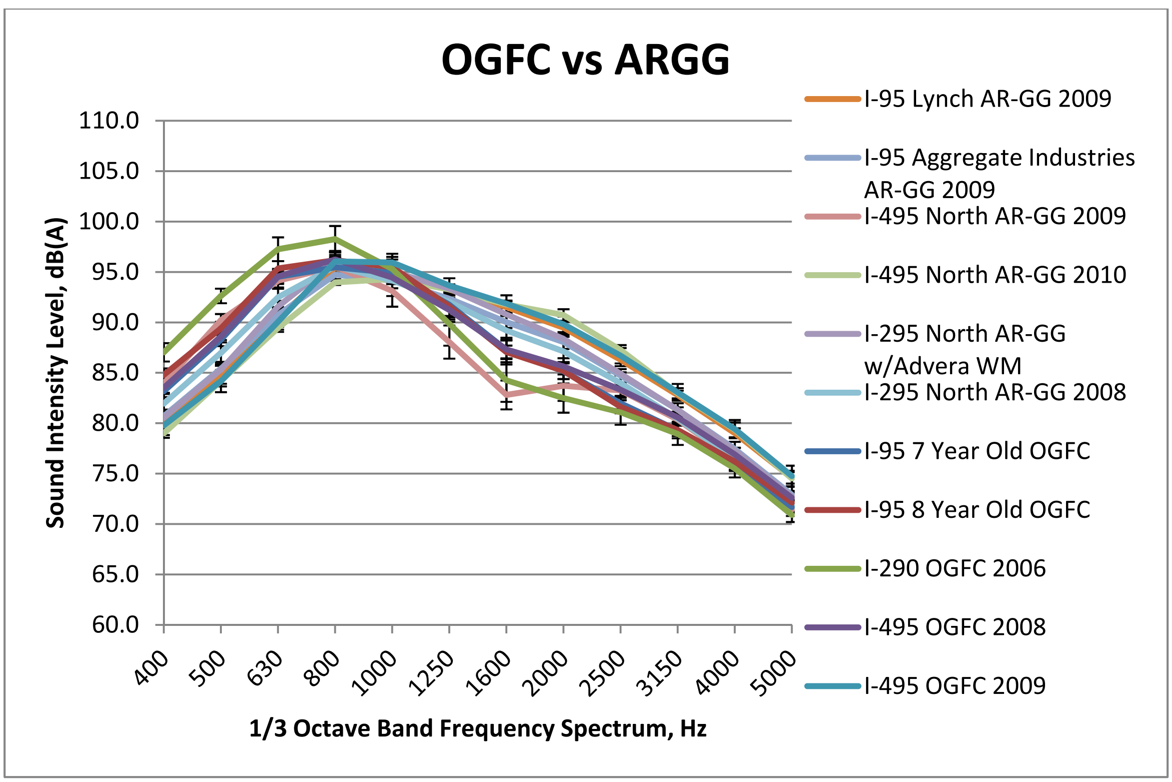

Figure 22: OGFC vs ARGG Spectrum Comparison

Several of the asphalt rubber gap graded mixes had similar overall levels (Figure 21) to the open graded friction course levels found in Massachusetts. The spectrum graph (Figure 22) showing the comparison of ARGG pavements to OGFC pavements shows that with only a few outlying materials, most of the gap graded mixes noise values fell in between the open graded mixes especially between the 1000 Hz to 5000 Hz range. Typically as pavements get older, especially open graded pavements, the noise gets louder. Regarding the pavements tested in Massachusetts, some of the newer OGFC pavements were louder than the older pavement sections. Unfortunately, no ARGG pavements older than two years were evaluated to see the longevity of the noise properties. The differences between ARGG and OGFC pavements will be discussed more when comparing the statistically similar pavement data. Figures 23 shows the I-295 N ARGG from 2008 that was compacted using warm mix technology and Figure 24 shows the same material, an identical mix that was laid opposite the warm mix on I-295 N with the standard compaction procedures. The warm mix pavement was ½ decibel louder than the standard mix pavement. The 7 year old OGFC, I-95 N OGFC 2003 (Figure 25) was similar to the ARGG mixes, which can be seen in both Figure 21 and Figure 22.

Figure 23: I-295 N ARGG w/advera WM 2008

Figure 24: I-295 N ARGG 2008

Figure 25: I-95 N OGFC 2003

Statistical Comparisons

Disclaimer

The process followed to create the following comparisons uses only the calculated A-weighted overall values as the population. This method is useful to determine if any of the materials exhibit the same overall loudness, but does not relate to the quality of sound or how it would be perceived (i.e. – noise levels along the frequency spectrum). The graphical representations of the different pavements related below are representative of particular materials which were determined to be either statistically significant or not significant, based on the average overall average of each material tested. The graphical representations of each pavement's spectral signature is shown as an aid to understand the quality of sound, not to suggest that equal loudness is equal perception.

Overview

The purpose of completing the statistical matrix was in the interest of trying to determine if any materials of the pavement surfaces had the same overall noise levels. If different materials have similar overall noise levels, possibly they could be substituted for other materials to fulfill design criteria. The variance between each overall level for each material was determined using the f-test for two-sample variance analysis. If the variances were statistically similar, t-tests for two-samples assuming equal variance analysis was completed. If the variances for each material were statistically not similar, t-tests for two-samples assuming unequal variances was completed. A 95% confidence interval was used to determine the statistical significance. The resultant data was compiled into a statistical matrix (Figure 26) which helped to determine which materials exhibited statistically similar loudness. The statistical matrix results lead to three relevant discoveries; the two novachip pavements were statistically not similar, not all of the OGFC pavements were similar to each other, and there were several ARGG pavements that were statistically similar to certain OGFC pavements. The results for the statistical analysis are shown in this section.

Statistical Matrix

	OGFC 2003 I-95 S	OGFC 2002 I-95 N	ARGG 2009 I-95 Lynch S	ARGG 2009 I-95 Lynch N	ARGG 2009 I-95 Aggregate Industries S	ARGG 2009 I-95 Aggregate Industries N	Novachip w/AR 2008 I-295 S	ARGG 2008 I-295 N	Novachip 2008 I-295 S	ARGG 2008 I-295 N w/advera WM	OGFC 2006 I-290 W	OGFC 2006 I-290 E	19mm DGA Rt. 2 W	19mm DGA Rt. 2 E	ARGG 2010 I-495 N	9.5mm DGA I-495 S	ARGG-2009 I-495 N	OGFC 2009 I-495 S	OGFC 2008 I-495 N	OGFC 2008 I-495 S
OGFC 2003 I-95 S		N	N	N	Y	Y	N	Y	N	Y	N	N	N	N	N	N	N	N	N	N
OGFC 2002 I-95 N			N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	Y	N
ARGG 2009 I-95 Lynch S				Y	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N
ARGG 2009 I-95 Lynch N					N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N
ARGG 2009 I-95 Aggregate Industries S						Y	N	N	N	N	N	N	N	N	N	N	N	Y	N	Y
ARGG 2009 I-95 Aggregate Industries N							N	N	N	N	N	N	N	N	N	N	N	Y	N	Y
Novachip w/AR 2008 I-295 S								N	N	N	N	N	N	N	N	N	N	N	N	N
ARGG 2008 I-295 N									N	N	N	N	N	N	Y	N	N	N	N	Y
Novachip 2008 I-295 S										N	N	N	N	N	N	N	N	N	N	N
ARGG 2008 I-295 N w/advera WM											N	N	N	N	N	N	N	N	N	N
OGFC 2006 I-290 W												N	N	N	N	N	N	N	N	N
OGFC 2006 I-290 E													N	N	N	N	N	N	Y	N
19mm DGA Rt. 2 W														N	N	N	N	N	N	N
19mm DGA Rt. 2 E															N	N	N	N	N	N
ARGG 2010 I-495 N																N	N	N	N	Y
9.5mm DGA I-495 S																	N	N	N	N
ARGG-2009 I-495 N																		N	Y	N
OGFC 2009 I-495 S																			N	Y
OGFC 2008 I-495 N																				N
OGFC 2008 I-495 S																				

Figure 26: Statistical Matrix

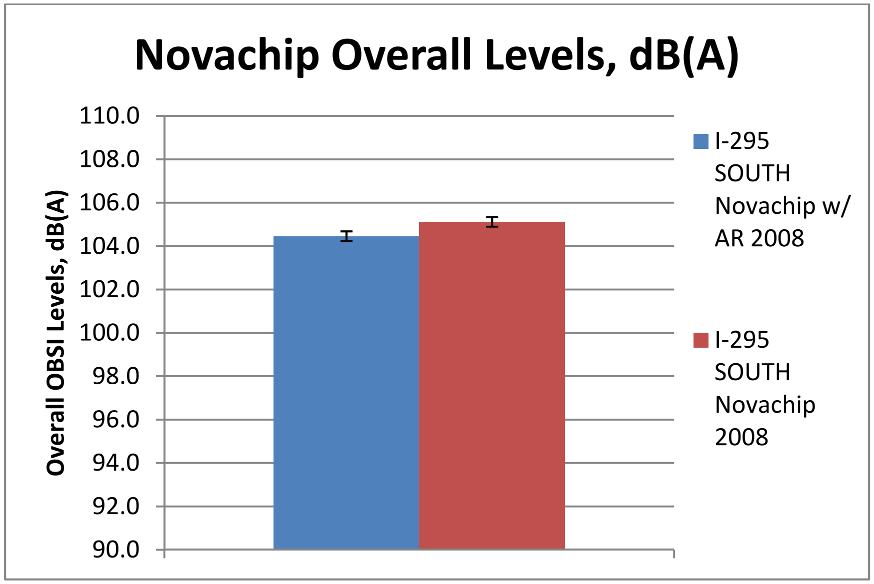

Figure 27: Novachip Overall Levels, dB(A)

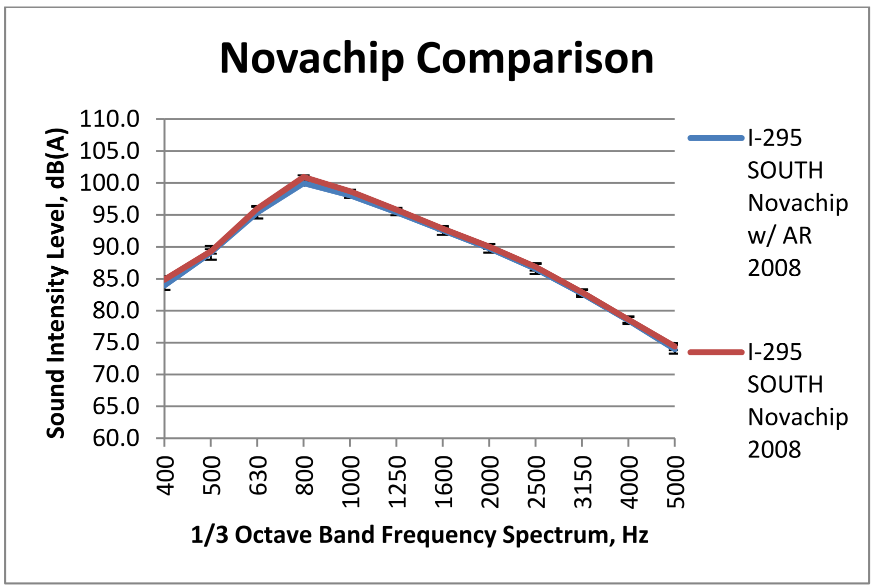

Figure 28: Novachip Comparison

The two different novachip pavements shown in Figures 27 and 28 were interesting to separate out because they were shown to be statistically not similar, although they are only ½ decibel different on the overall level. Using OBSI measurements, it is generally recommended to make conclusions based on measured differences of over one decibel. Although with sound intensity measurements it is possible to measure small pressure differences accurately under one decibel. Since we utilize a sound intensity measurement technique, the pavement temperatures recorded for these two pavements were similar, and the measurements were done on the same day with the same environmental and procedural controls, we determined that the two novachip pavements were not statistically similar with the Novachip AR being quieter. The A-weighted average overall chart shown in Figure 27 shows how close the two materials were in terms of loudness, while the spectrum analysis shown in Figure 28 shows how similar the sound was between the two different materials.

ARGG 2008 I-295 N vs Statistically Similar OGFCs

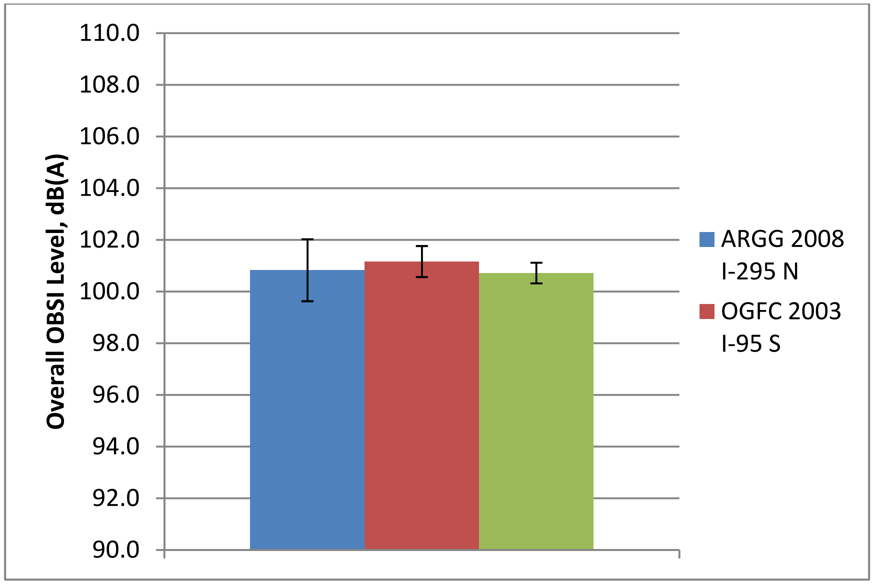

Figure 29: ARGG 2008 I-295 N vs Statistically Similar OGFCs (Overall, dBA)

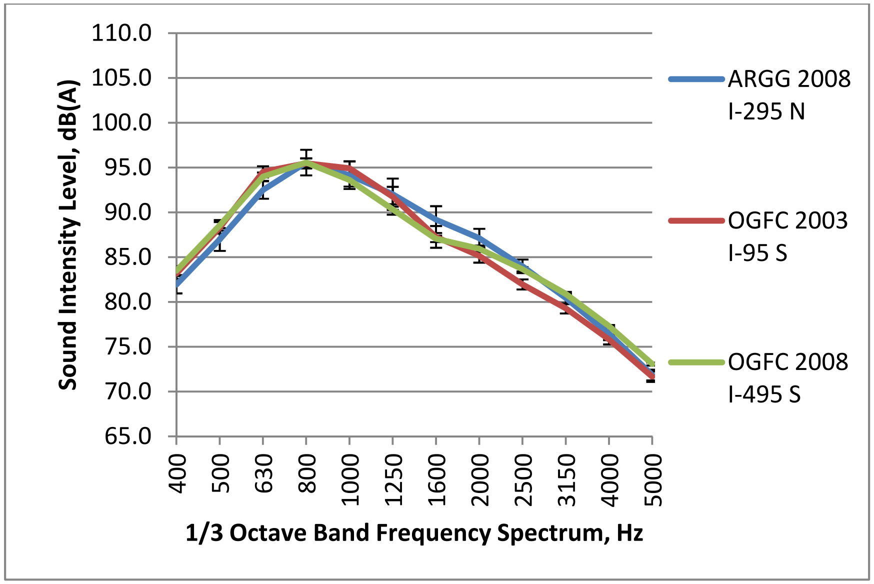

Figure 30: ARGG 2008 I-295 N vs Statistically Similar OGFCs (Spectrum)

The material measured on I-295 N, an asphalt rubber gap graded mix, was shown to be statistically similar to two different open graded friction course materials, the OGFC on I-95 S that was placed in 2003 and the OGFC on I-495 S that was placed in 2008. The overall level chart (Figure 29) shows that the overall noise level for the three pavements are within ½ decibel of each other. The spectrum chart (Figure 30) shows how the pavements are relatively similar along the entire spectrum. It is important to notice on the spectrum graph that the OGFC from 2003 is more than one decibel quieter than the OGFC from 2008 in the 2000 hz to 3150 hz frequencies... Since the pavements are so similar on both the frequency spectrum and the overall level, it is safe to say that this particular ARGG mix could be used as a substitute for an OGFC pavement for noise reduction purposes. It would be adventageous to look further into the noise properties of ARGG materials over their expected lifespan in Massachusetts.

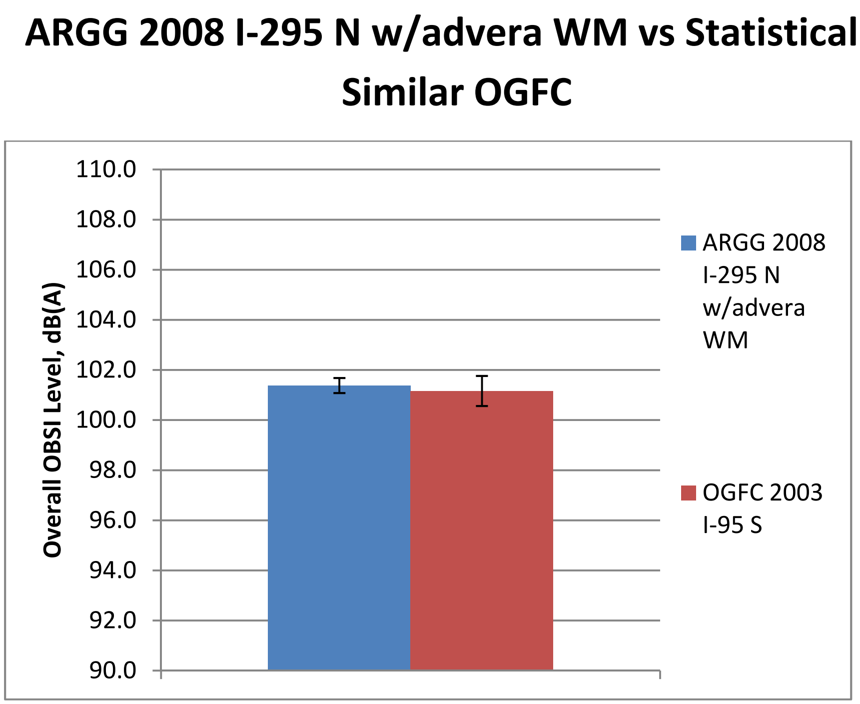

Figure 31: ARGG I-295 N w/Advera WM vs Statistically Similar OGFC (Overall dBA)

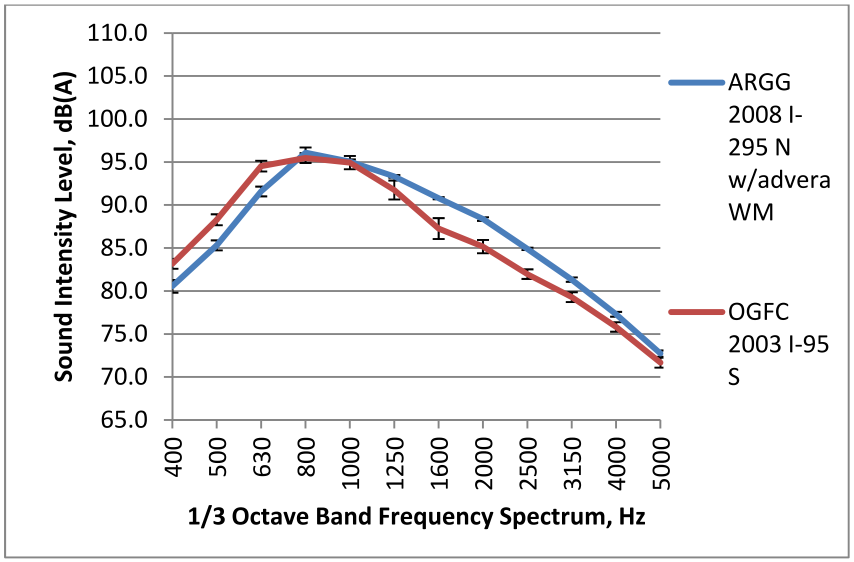

Figure 32: ARGG I-295 N w/advera WM vs Statistically Similar OGFC (Spectrum)

The ARGG from I-295 N w/advera Warm Mix was calculated to be statistically similar to the OGFC on I-95 S that was laid in 2003. The comparisons can be seen on Figures 31 and 32. As seen in Figure 32, the I-95 2003 OGFC has at least a 2 dB quieter profile between the 1250 hz to the 3150 hz range. Since this range is considered to be more annoying to the average person, if it is taken into consideration that the OGFC has lasted for seven years already and still has a reasonably good sound profile, it seems that this OGFC mix would be better to use for sound quality than the ARGG warm mix.

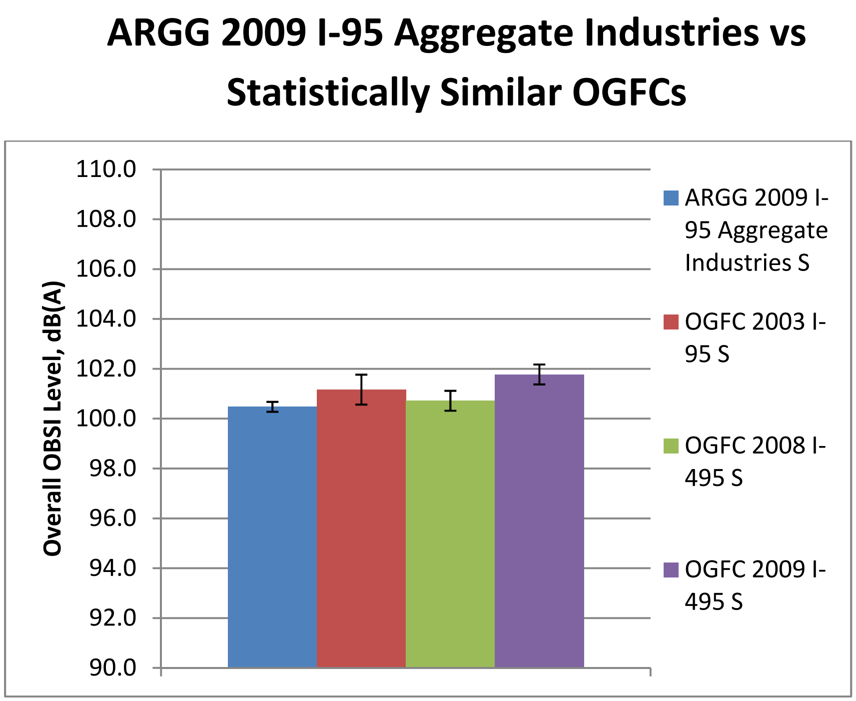

Figure 33: ARGG 2009 I-95 Aggregate Industries vs Statistically Similar OGFCs (Overall, dBA)

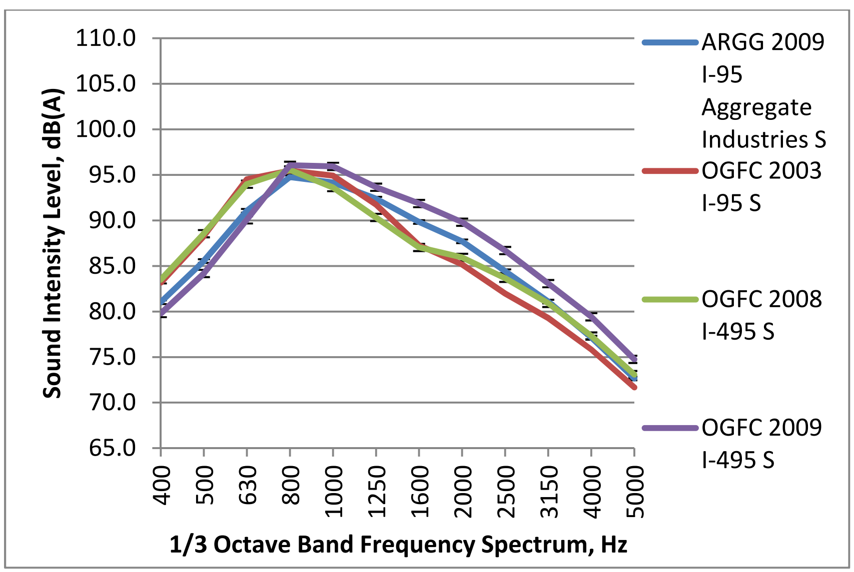

Figure 34: ARGG 2009 I-95 Aggregate Industries vs Statistically Similar OGFCs (Spectrum)

The ARGG 2009 I-95 placed by Aggregate Industries was calculated to be statistically significant to OGFC 2003 I-95 S, OGFC 2008 I-495 S, and OGFC 2009 I-295 S. This can be seen in Figures 33 and 34. The spectrum comparison in Figure 34 graphically explains why each of the pavements were determined to be statistically equal, where the ARGG 2009 I-95 Aggregate Industries material is positioned directly in the middle of the other pavements.

ARGG 2009 I-495 N vs Statistically Significant OGFC

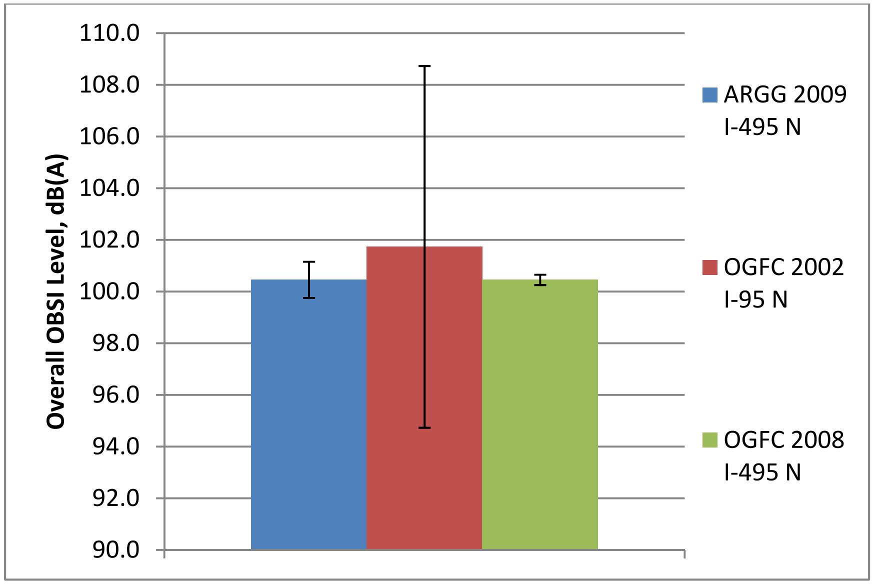

Figure 35: ARGG 2009 I-495 N vs Statistically Significant OGFC (Overall, dBA)

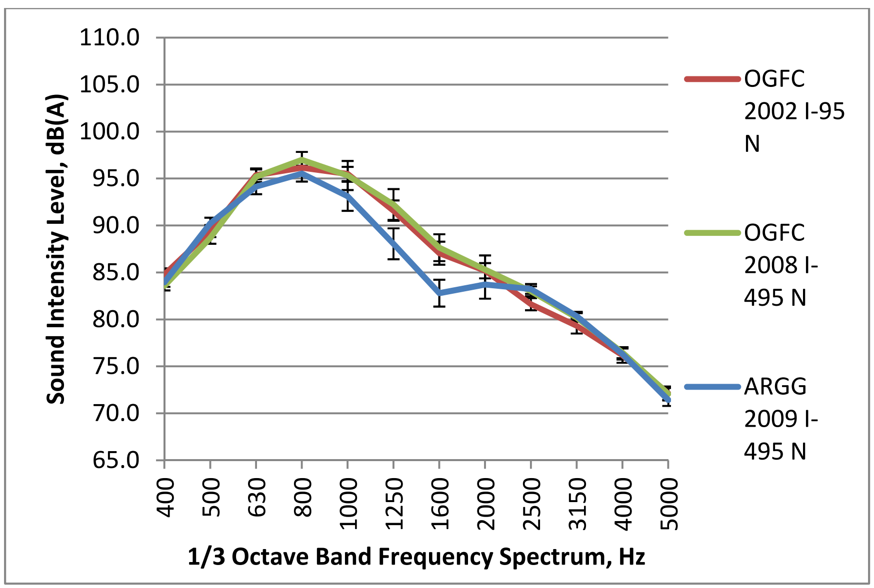

Figure 36: ARGG 2009 I-495 N vs Statistically Significant OGFC (Spectrum)

The ARGG 2009 I-495 N material was calculated to be statistically equal to the OGFC 2002 I-95 N and OGFC 2008 I-495 N materials. This can be seen in Figures 35 and 36. Figure 36 shows that the ARGG 2009 I-495 N material and the OGFC 2008 I-495 N materials were similar in the lower end of the frequency spectrum, diverged from 800 hz to 2000 hz, and was similar in the higher end of the spectrum.

ARGG 2010 I-495 N vs Statistically Significant OGFC

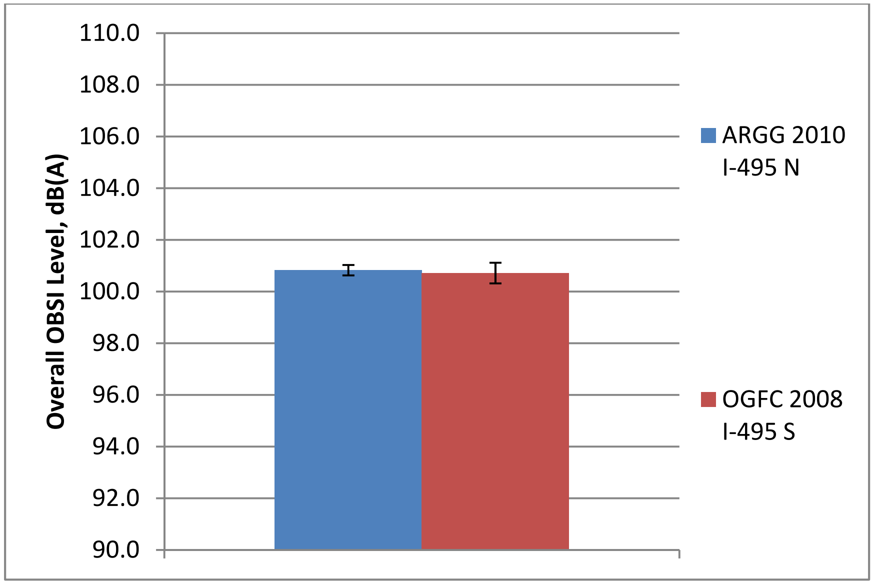

Figure 37: ARGG 2010 I-495 N vs Statistically Significant OGFC (Overall, dBA)

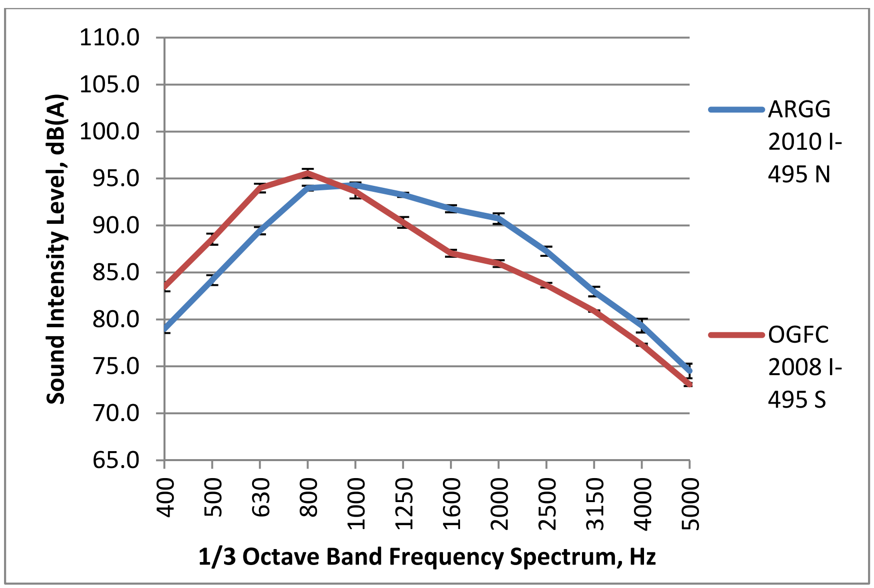

Figure 38: ARGG 2010 I-495 N vs Statistically Significant OGFC

The ARGG 2010 I-495 N was calculated to be statistically similar to the OGFC 2008 I-495 S materials. This is shown in Figures 38 and 39. The overall values compared were very close to each other, at 100.7 dB(A) for the OGFC 2008 I-495 S and 100.8 dB(A) for the ARGG 2010 I-495 N materials, which suggests that the two materials have equal loudness. However, as shown in Figure 39, both materials have severely different spectral signatures. This is the main reason why the statistical approach taken throughout the statistical section of this paper should be observed with caution. Driving on either material would create an entirely different experience, just as standing on the side of the road would create an entirely different experience, even though the loudness of both materials is essentially the same. Based on the assumption that greater decibel levels at higher frequencies are more annoying to the human ear, the I-495 S OGFC mixture would be considered a better option for noise mitigation than the ARGG I-495 N pavement surface.

Conclusions

The main focus of the All States Massachusetts study was to look at the noise levels that resulted from different materials All States has designed and produced over the last ten years. Initially, the goal was to quantify the noise properties of the pavements in Massachusetts, find the differences in the sound properties due to differences in mix type, mix design, and aging, and make recommendations for future pavement selection based on the overall loudness of each different material. This project encompassed fifteen different materials which were all located throughout eastern Massachusetts. The measurements were recorded between October 25, 2010 and October 29, 2010. The material selection was completed by All States Material Group. Each material section was roughly two miles long, which allowed the CAIT acoustic technicians to choose appropriate testing locations according to the AASHTO TP 76-09 specifications.

The materials selected by All States Materials Group provided a wide array of materials that ranged in age from less than one year to eight years old. The overall loudness varied just over 5 decibels, with the lowest pavement noise recorded at 100.0 dB(A) for a 9.5mm Superpave+2% Latex mixture, and the highest pavement noise recorded was 105.1 dB(A) for a Novachip material. After quantifying the overall levels, spectrum graphs were created for each material, and comparisons were initially drawn between each type of material. The ARGG materials tested had overall levels between 100.5 dB(A) and 101.4 dB(A), the OGFC materials tested had overall levels between 101.2 dB(A) and 102.9 dB(A), the DGA materials tested had overall levels between 100.0 dB(A) and 103.1 dB(A), and the Novachip materials tested had between 104.5 dB(A) and 105.1 dB(A).

The effects of age were not as apparent as we expected, some of the pavements, such as the I-495 OGFC that was placed in 2009 were louder than some of the oldest pavements tested, such as the I-95 OGFC that was paved in 2002. The ARGG pavements tested only varied in age by a maximum of two years and no correlation between ages was found. The effect of asphalt rubber in Novachip was not found to be beneficial from a noise perspective, since it only reduced the noise level by ½ decibel.

A statistical analysis was completed comparing each material to each other. The resulting information provided several pavements that could potentially be exchanged during material selection for rehabilitation projects. The comparisons were completed off of the overall levels, so the materials that were determined to be similar would exhibit an equal loudness. In the statistical comparison section, it is discussed that although the statistically similar pavements would exhibit equal loudness the sound generated from each different material would be different. It is advised to be careful when choosing alternative pavements, to consider the noise quality of the different pavements to ensure that the most benefit is received by the producers, users, residents, and the general public.