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MIXING and COMPACTION RECOMMENDATIONS for WARM MIX ASPHALT (WMA) with RECYCLED ASPHALT SHINGLES (RAS)

FINAL REPORT
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In cooperation with

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16. Abstract

The use of recycled asphalt shingles (RAS) is an attractive option for asphalt mixture producers due to the high amount of recycled asphalt binder available in RAS. By weight, RAS contains 10 to 25% asphalt by total weight of the shingle. The asphalt binder in RAS is generally much stiffer than conventional paving asphalts due to the requirements of the roofing shingle industry. This increase in asphalt binder stiffness generally results in a stiffer asphalt mixture that is more difficult to compact in the field. Some asphalt mixture suppliers are looking at utilizing warm mix asphalt (WMA) technologies to help with compaction, but still limited information exists on the use of WMA with RAS and how the mixing and compaction properties are influenced.

With the transportation infrastructure industry moving towards sustainable technologies and recycling when possible, the use of recycled asphalt shingles (RAS) in hot mix asphalt looks appealing. However, the handling and performance of these mixtures is still highly questioned and viewed as potentially problematic by most agencies.

A laboratory study was conducted to evaluate the impact on recycled asphalt shingles (RAS) on the compactability of asphalt mixtures. Two different methodologies were utilized in the study: 1) Asphalt binder based testing; and 2) Asphalt mixture based testing. In addition to the RAS, two different types of WMA technologies were included to evaluate the change in asphalt compactibility. The results of the study showed that performance grading of the RAS required the RAS to be blended with a much softer asphalt binder at varying percentages; the inclusion of recycled asphalt shingles, whether it is Post Manufacturer or Post Consumer, will detrimentally impact the mixing and compaction properties of the asphalt mixtures; and that the addition of WMA technologies to the RAS asphalt mixtures does appear to aid in the compaction properties of the final asphalt mixture.

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MIXING AND COMPACTION RECOMMENDATIONS FOR WARM MIX ASPHALT (WMA) WITH RECYCLED ASPHALT SHINGLES (RAS)

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PROBLEM STATEMENT

The use of recycled asphalt shingles (RAS) is an attractive option for asphalt mixture producers due to the high amount of recycled asphalt binder available in RAS. By weight, RAS contains 10 to 25% asphalt by total weight of the shingle. The asphalt binder in RAS is generally much stiffer than conventional paving asphalts due to the requirements of the roofing shingle industry. This increase in asphalt binder stiffness generally results in a stiffer asphalt mixture that is more difficult to compact in the field. Currently there is no guidance on the mixing and compaction temperatures for asphalt mixtures with RAS. Some asphalt mixture suppliers are looking at utilizing warm mix asphalt (WMA) technologies to help with compaction, but still limited information exists on the use of WMA with RAS and how the mixing and compaction properties are influenced. The mixing and compaction temperature properties of an asphalt mixture is commonly referred to as “workability” and this term will be used throughout the report.

With the transportation infrastructure industry moving towards sustainable technologies and recycling when possible, the use of recycled asphalt shingles (RAS) in hot mix asphalt looks appealing. However, the handling and performance of these mixtures is still highly questioned and viewed as potentially problematic by most agencies. The work encompassed in this study utilizes standard and research-grade laboratory procedures to help evaluate the mixing and compaction properties of asphalt materials with RAS. In addition to RAS, two different WMA technologies were also included in the study to see if the mixing and compaction properties of RAS asphalt mixtures could be improved.

Asphalt Workability

To date, the quantification of workability has primarily been through the asphalt mixture’s resistance to compaction and hand work in the field. Traditionally, the asphalt binder viscosity has been used to determine mixing and compaction temperatures of hot mix asphalt (McLeod, 1967; Roberts et al., 1996). Compaction temperatures recommended using this procedure affect the general workability of the asphalt mixture since equi-viscous binder conditions are used. However, the increasing use of modified asphalt binders have created problems with selecting appropriate compaction temperatures and is currently being studied in further detail under NCHRP Project 9-39, *Procedure for Determining Mixing and Compaction Temperatures of Asphalt Binders in Hot Mix Asphalt*.

Previous studies have attempted to quantify the workability of mixtures (either hot mix asphalt or Portland cement concrete) using paddle-bucket mixer type devices. Marvillet and Bougault (1979) presented one of the first mixture workability devices at the 1978 meeting of the Association of Asphalt Paving Technologists (AAPT). The authors noted that the device was sensitive to asphalt binder stiffness, amount of asphalt binder and aggregate composition. The paddle-mixer measured the mixture’s resistance to mixing via a spring and potentiometer. The electrical signal was eventually expressed in units of torque (i.e. – higher torque equaled poorer workability). A similar version to the Marvillet and Bougault (1979) device was developed by the Federal Highway Administration (FHWA) for evaluating the workability of Portland cement concrete (USAE, 2001).

The National Center for Asphalt Technology (NCAT) took the previous paddle-mixer type designs and enhanced the measurement and analysis to quantify the effect of different asphalt mixture constituents (Gudimettla et al., 2003). The authors concluded that the workability of the asphalt mixtures measured in the device was affected by aggregate type and angularity, nominal aggregate size, gradation type (coarse or fine) and asphalt binder stiffness. The results of the NCAT study indicate that not only is the workability of asphalt mixtures a function of the asphalt binder viscosity/stiffness, but also the aggregate properties as the aggregates move across one another.

Recent work being conducted under NCHRP 9-43, *Mix Design Practices for Warm Mix Asphalt*, had attempted to identify possible test procedures/devices that could be used to help assess the general workability/compactability of asphalt mixtures. The test procedures/devices included; Gyratory Compaction Characteristics (Stress and Air Voids); Torque Measurements from Bucket Mixer Type Device; and Force (Nynas Workability Device). Tentative recommendations under NCHRP Project 9-43 are leaning towards using the gyratory compactor to determine the number of gyrations to 92% of G_{mm}, although recommendation has not been made to date. Further validation under Phase II of the study is currently underway (Bonaquist, 2009).

EXPERIMENTAL TEST METHODS

A number of asphalt binder and mixture workability type tests were conducted in order to access their potential for indexing and ranking the workability of warm mix asphalt and additives. Two asphalt binder and one asphalt mixture test was used to evaluate the workability properties of the RAS asphalt mixtures:

- Asphalt Binder: Rotational Viscosity (AASHTO T316, *Viscosity Determination of Asphalt Binder Using Rotational Viscometer)* for determining mixing and compaction temperatures;
- Asphalt Binder: NCHRP Project 9-39, *Procedure for Determining Mixing and Compaction Temperatures of Asphalt Binders in Hot Mix Asphalt*; and
- Asphalt Mixture: Marshall Compactor (Bennert et al., 2009).

Rotational Viscosity – Mixing and Compaction Temperatures

For years, asphalt mixture design and production has used the concept of "equiviscous" temperature ranges for selecting the proper mixing and compaction temperatures of asphalt binders. The purpose of using the equiviscous mixing and compaction temperatures is to normalize the effect of the asphalt binder stiffness on the mixture volumetric properties. In Superpave, the viscosity of the asphalt binder is measured using the rotational viscometer at two temperatures; 135 and 165°C. The log of the viscosity is plotted against the test temperature with a resultant trendline extended through two viscosity ranges;

- Compaction temperature: 0.28 +/- 0.03 Pa-s
- Mixing temperature: 0.17 +/- 0.02 Pa-s

The temperatures at which the resultant trendline intersects the above viscosity ranges represents the equiviscous mixing and compaction temperatures. A schematic of this approach is shown in Figure 1 for a modified (PG52-40) and unmodified (PG52-28) asphalt binder.

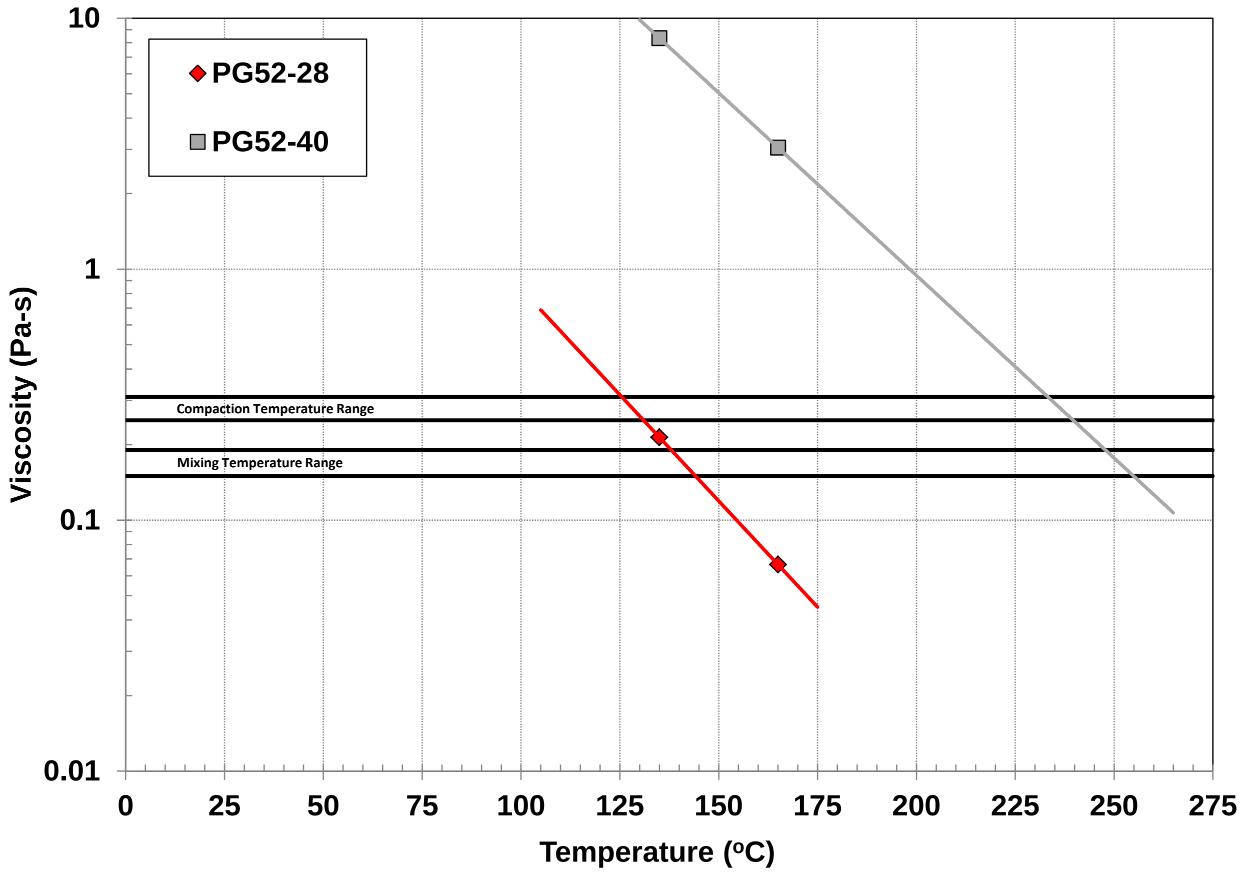

Figure 1 – Mixing and Compaction Temperatures Determined Using "Equiviscous" Approach

Steady Shear Flow

Unlike the Equiviscous procedure, the Steady Shear Flow method uses the Dynamic Shear Rheometer (DSR) to determine the viscosity of the asphalt binder. The approach uses a 500-micron gap and 25-mm diameter plate geometry. The viscosities of the binder are tested over a range of shear stresses at temperatures ranging from 76 to 94°C (169 to 201°F). At high shear stresses, around 500 Pa, the viscosities of modified binders approach a steady state (i.e. – very small change in viscosity with increasing shear stress). Using a log-log temperature-viscosity chart, the viscosities from the 500 Pa shear flow tests are extrapolated out to 180°C (356°F). As with the Equiviscous method, the recommended mixing temperature is based on a viscosity of 0.17 +/- 0.02 Pa-s. The recommended compaction temperature from the steady shear flow technique is 0.35 +/- 0.03 Pa-s, which is higher than the Equiviscous compaction range of 0.28 +/- 0.03 Pa-s.

An example of the Steady Shear Flow testing are shown in Figures 2 and 3 where the viscosity measurements vs shear stress for the binders are reported. The "flattening" of the curves indicates the binders reaching a "steady state" condition. The results from Figures 2 is then used to determine the shear viscosity at 500 Pa vs each temperature tested (Figures 3).

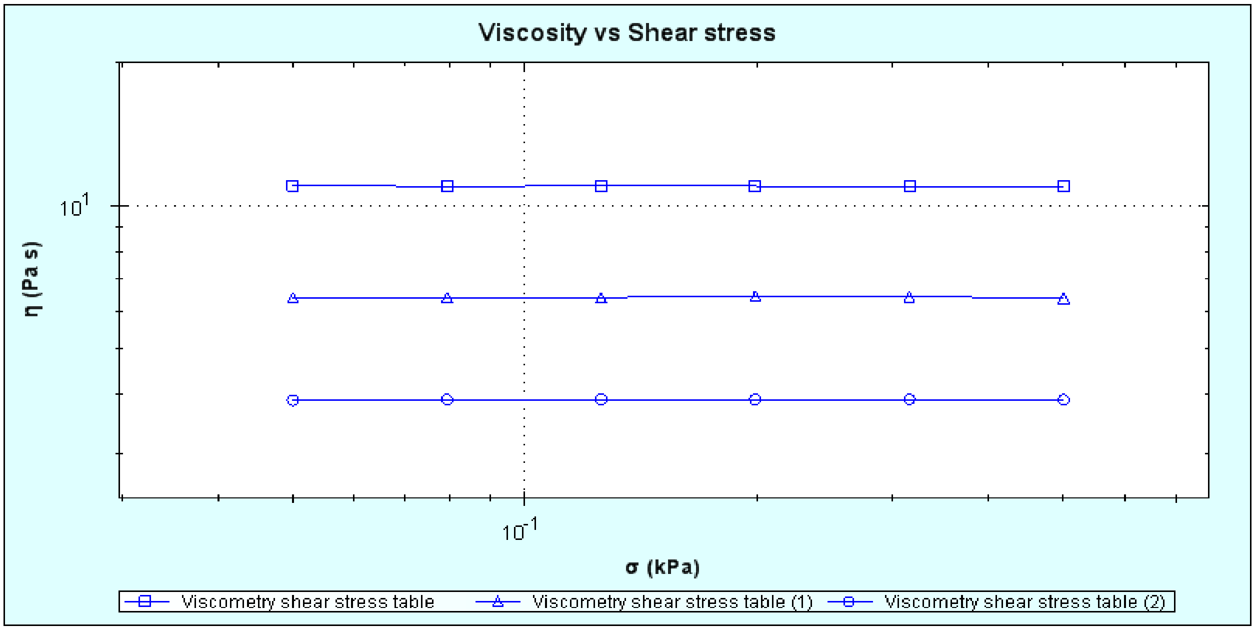

Figure 2 - Viscosity vs Shear Stress for "PG52-28" Asphalt Binder

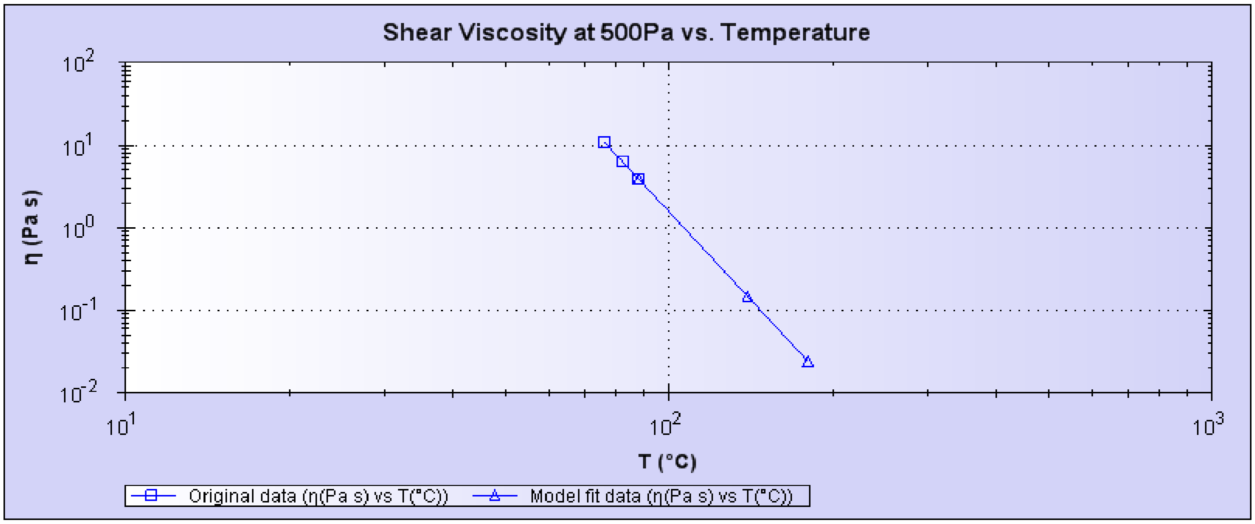

Figure 3 - Shear Viscosity at 500 Pa vs Temperature for "PG52-28"

Marshall Compactor

The Marshall Compactor was also used to evaluate the general workability/compactability of asphalt mixtures. The Marshall Compactor applies a pseudo, constant energy to the asphalt mixtures during compaction through a constant weight, dropped from a constant height at a predetermined number of drops. However, it is well known that the resultant, compacted density of Marshall samples are sensitive to mixture compaction temperature, which in turn, is analogous to workability/compactability. As the mixture cools, the viscosity of the asphalt binder and mixture increases resisting the compactive force of the Marshall Compaction. Therefore, by varying the compaction temperature of different mixtures while applying the identical number of compactive blows, asphalt mixtures with higher levels of workability/compactability should result in higher densities (i.e. – lower air voids).

For the Marshall Compactor work, the asphalt mixtures were mixed at temperatures 15^{o}F higher than the targeted compaction temperature. This was in an effort to simulate typical temperature drops associated with plant production temperatures and laydown temperatures in the field. The temperatures used in the study were as follows:

- Mixing Temperature = 315^{o}F; Compaction Temperature = 300^{o}F
- Mixing Temperature = 270^{o}F; Compaction Temperature = 255^{o}F
- Mixing Temperature = 230^{o}F; Compaction Temperature = 215^{o}F

Prior to compaction, the asphalt mixtures were conditioned for 2 hours at their respective compaction temperature. After the conditioning period, the asphalt mixtures were transferred into the Marshall Compaction molds and compacted to 75 blows per side in accordance with AASHTO T245, *Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus*. Once the samples had cooled, the compacted air voids of the asphalt mixtures were determined. A best fit model in the form of an exponential line was used to fit the data. These models were then utilized to develop a model curve plotted over temperature and compacted air voids. Mixtures exhibiting lower air void values at lower compaction temperatures are considered more workable and compactable. Bennert et al., (2009) had successfully used this procedure to evaluate the WMA technology impact on asphalt mixtures.

MATERIALS

The research study utilized a PG64-22 asphalt binder from Axeon Specialty Products in Paulsboro, NJ as the base asphalt binder. Two different WMA technologies were preblended in the PG64-22 asphalt binder; Evotherm and SonneWarmix. The Evotherm additive is produced by Ingevity and is described as a surfactant. The SonneWarmix is a parafinnic hydrocarbon and produced by Sonneborn. Both technologies allow for the additive to be preblended with the asphalt binder, which allows for easy handling and thorough blending/mixing with the asphalt materials.

Asphalt Mixture – Job Mix Formula

The asphalt mixture design utilized for the study was a 12.5 mm nominal maximum aggregate size Superpave mixture with a Trap Rock aggregate from central New Jersey. The asphalt mixture aggregate blend and volumetrics used in the study is shown in Figure 4.

Binder Content (%)	4.9%
VMA (%)	14.9%
G_{mm} (g/cm³)	2.712
G_{sb} (g/cm³)	2.91
Percent Passing	
19mm	100
12.5mm	95.9
9.5mm	87.3
4.75mm	50.1
2.36mm	32.9
1.18mm	25.5
0.6mm	19.9
0.3mm	13.9
0.15mm	8.7
0.075mm	6.2

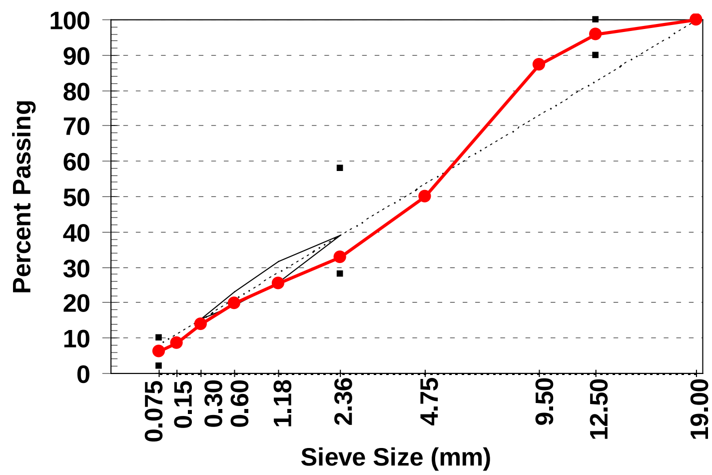

Figure 4 - Mixture Design Properties

The study looked at the impact of two different types of RAS; 1) Post Manufacturer Waste and 2) Post Consumer Waste. The Post Consumer Waste (PCW) is typically the tabs and scraps of asphalt shingles thrown away during the manufacturing process of the shingle. Since this type of RAS is "new", it typically has slightly softer asphalt binder properties than the Post Manufacturer Waste. Post Manufacturer Waste (PMW) is generally the waste shingle material removed from old homes or buildings. Due to the time at which the shingles have been exposed to the environment, asphalt binder from PMW can be extremely stiff and difficult to work with.

Asphalt Binder Grading – Recycled Asphalt Shingles

The asphalt binder from the RAS was extracted and recovered in accordance with AASHTO T164, *Procedure for Asphalt Extraction and Recovery Process* using tri-chlorethylene (TCE) as the solvent medium. The asphalt binder content was determined during the extraction process. The asphalt binder was recovered from the TCE solvent in accordance with ASTM D5404, *Standard Practice for Recovery of Asphalt from Solution Using the Rotary Evaporator* (Figure 5). After recovery, the asphalt binder was tested for its respective PG grade, in accordance with AASHTO M320, *Standard Specification for Performance-Graded Asphalt Binder*.

Figure 5 - Asphalt Binder Recovery Equipment at Rutgers University

Due to the extreme stiffness of the RAS asphalt binder, it is extremely difficult to trim asphalt binder specimens in the Dynamic Shear Rheometer (DSR) and especially the Bending Beam Rheometer (BBR). Therefore, to be able to grade the recovered RAS asphalt binder, it needed to be blended with a much softer binder. The methodology, first reported by Bonquist (2007), utilizes a softer virgin binder and then blends of the virgin binder and harder RAS binder. The final asphalt binder grade (i.e. – 100% RAS; 0% virgin binder) is determined by extrapolating out the blended binder results.

The PG grade results of the RAS asphalt binders is shown in Figures 6 through 9 using the methodology from Bonaquist (2007). This resulted in the following grades:

- Post Manufacturer Waste Asphalt Shingles: PG100 – 10 (Continuous PG105.9 – 10.8)
- Post Consumer Waste Asphalt Shingles: PG136 + 14 (Continuous PG137.7 + 9.9)

As the results indicate, the RAS asphalt binder was extremely stiff, especially for the PCW RAS. The PCW RAS had a low temperature grade above the freezing point, indicating that this asphalt binder by itself would be extremely prone to low temperature thermal cracking.

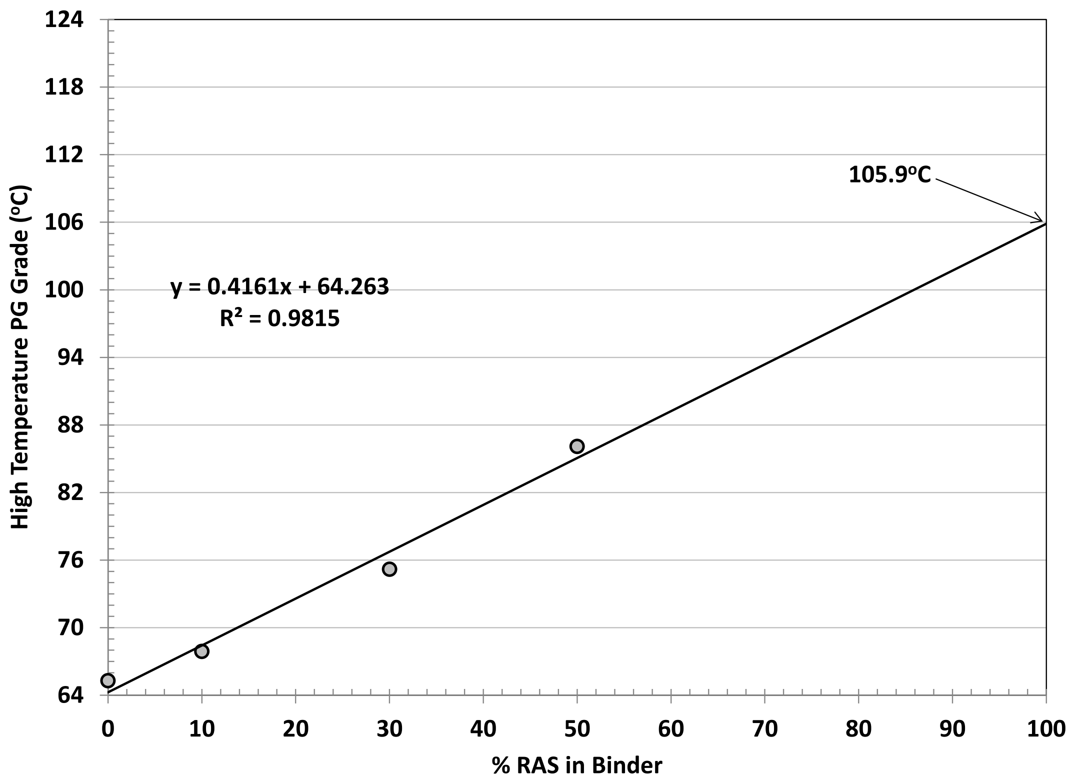

Figure 6 - High Temperature PG Grade: Post Manufacturer Waste Asphalt Shingle

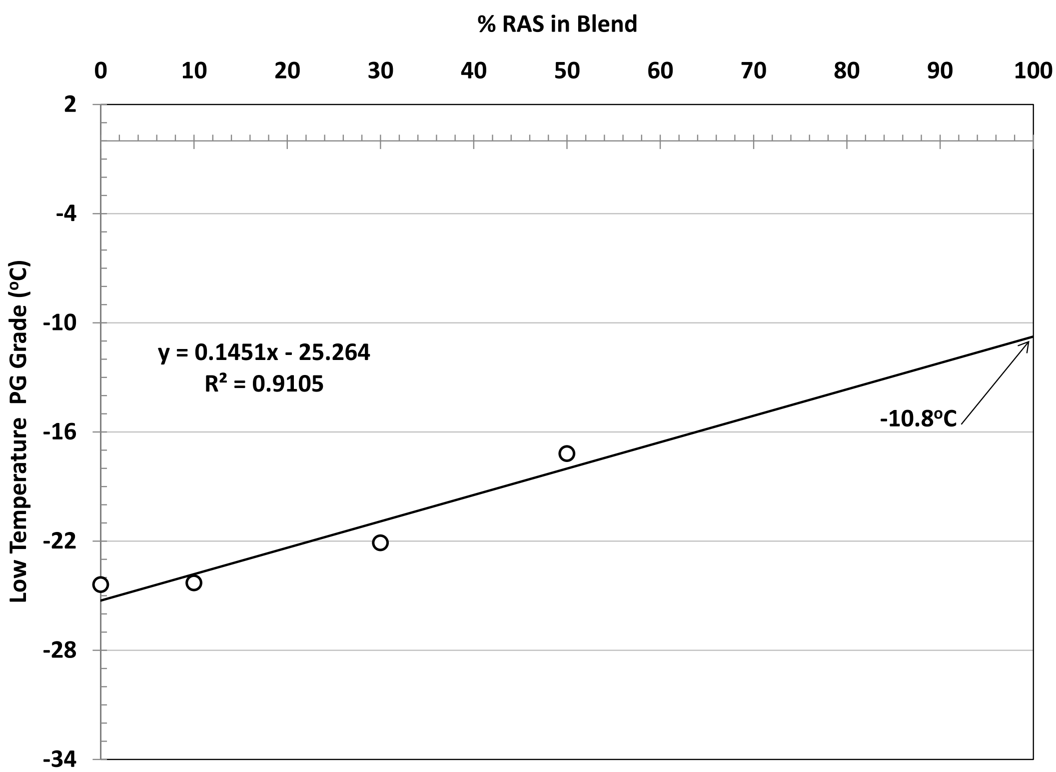

Figure 7 - Low Temperature PG Grade: Post Manufacturer Waste Asphalt Shingle

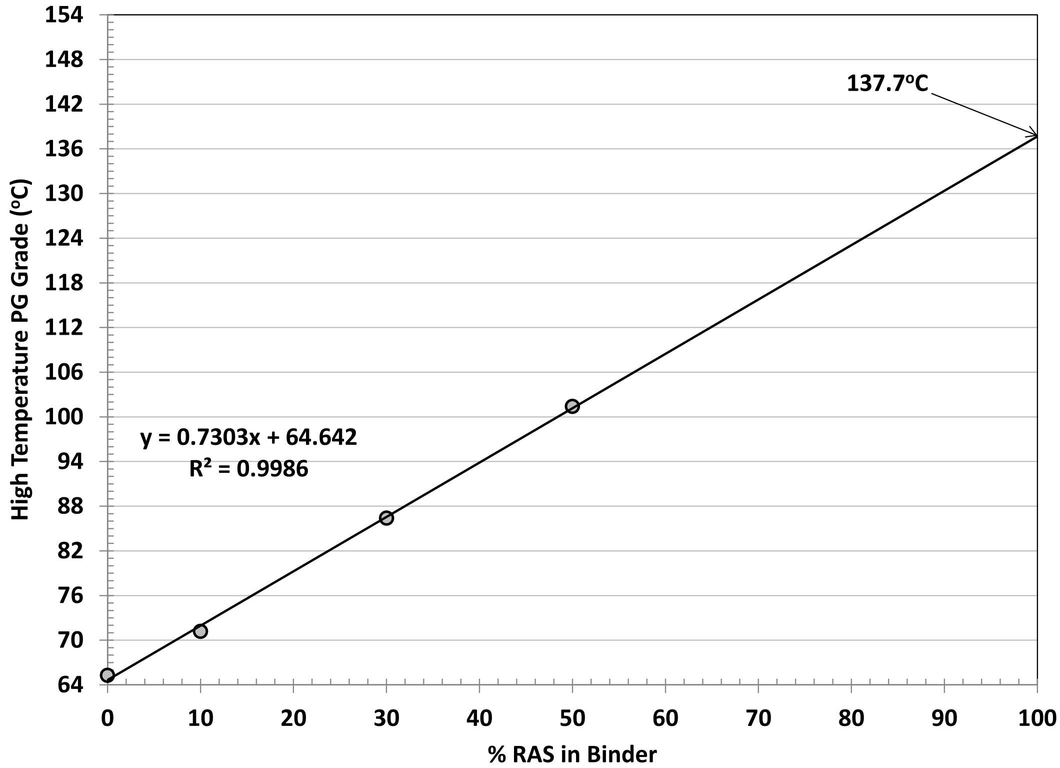

Figure 8 - High Temperature PG Grade: Post Consumer Waste Asphalt Shingle

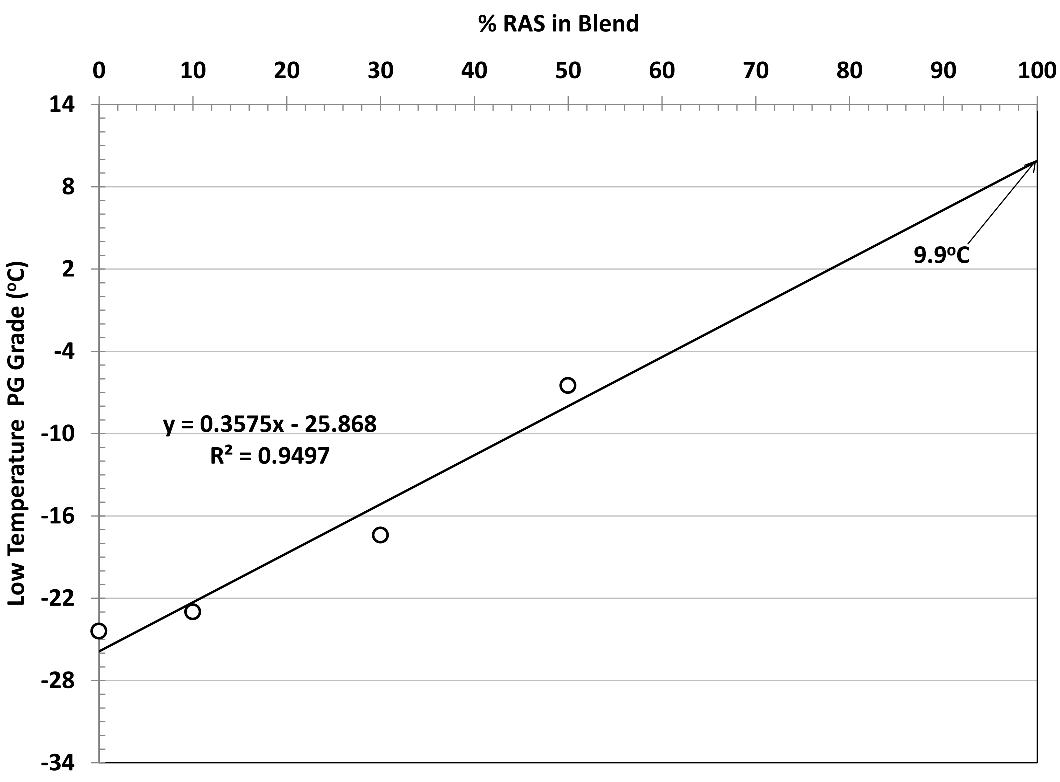

Figure 9 - Low Temperature PG Grade: Post Consumer Waste Shingle

Asphalt Binder Grade – Recycled Asphalt Shingles and Warm Mix Additives

The PG64-22 asphalt binder was blended at two different levels of RAS to simulate potential dosage rates during plant production; 1) 7.5% by total weight of the asphalt binder; and 2) 15% by total weight of the asphalt binder. These percentages, also known as Percent Binder Replacement (PBR), were selected based on currently allowed PBR by state agencies accustomed to using RAS (Gallivan, 2013a; Gallivan, 2013b). At PBR less than 15%, a change in asphalt binder grade (i.e. – using a softer asphalt binder) is not required.

The results for the Post Manufacturer and Post Consumer RAS at different blends are shown in Tables 1 and 2, respectively. Also included in the tables are the asphalt binder properties with the blended WMA technologies described earlier. In general, as the RAS PBR increases, the PG grade of the asphalt binder get warmer. The asphalt binder test results shows that at the 15% PBR, the low temperature grade generally increased from a -22^{o}C to a -16^{o}C PG grade for both the Post Manufacturer and Post Consumer RAS, which would indicate that the general guidelines in the 2014 AASHTO procedures may not necessary take into consideration the actual stiffness of the RAS by simply limiting the amount of RAS by PBR. Future specifications and guidance may need to include the actual RAS binder properties to ensure proper PG grades are obtained.

Table 1 - Asphalt Binder Performance Grading for Post Manufacturer Asphalt Shingles

Shingle Source	WMA Additive	% RAS	High Temperature Binder Performance						Inter. Temp	Low Temperature Performance Grade			PG Grade
			Performance Grade		Multiple Stress Creep Recovery (MSCR)					PAV (20 Hrs)		ΔT_{cr}	
					58°C		64°C						
			Orig	RFTO	J_{nr} (1/kPa)	% Rec	J_{nr} (1/kPa)	% Rec		m-slope	S (MPa)		
Post Manufacturer	N.A.	0%	66.4	65.3	1.41	1.2	3.66	0.0	24.1	-24.9	-24.4	0.5	PG64-22
		7.5%	69.3	69.2	0.88	7.6	2.21	1.6	19.2	-26.8	-28.0	-1.2	PG64-22
		15%	71.9	71.3	0.59	12.7	1.54	3.9	19.3	-20.3	-22.4	-2.1	PG70-16
	0.6% Evotherm	7.5%	69.3	68.5	0.99	6.0	2.46	1.3	18.1	-26.1	-27.6	-1.5	PG64-22
		15%	72.0	71.8	0.56	13.8	1.47	4.8	18.5	-19.5	-22.0	-2.5	PG70-16
	1.0% Sonneborn	7.5%	67.9	67.7	1.09	5.3	2.61	1.9	18.7	-27.0	-27.7	-0.7	PG64-22
		15%	70.5	70.3	0.72	11.1	1.83	3.5	19.3	-20.3	-22.1	-1.8	PG70-16

Table 2 - Asphalt Binder Performance Grading for Post Consumer Asphalt Shingles

Shingle Source	WMA Additive	% RAS	High Temperature Binder Performance						Inter. Temp	Low Temperature Performance Grade			PG Grade
			Performance Grade		Multiple Stress Creep Recovery (MSCR)					PAV (20 Hrs)		ΔT_{cr}	
			Orig	RFTO	58°C		64°C			m-slope	S (MPa)		
					J_{nr} (1/kPa)	% Rec	J_{nr} (1/kPa)	% Rec					
Post Consumer	N.A.	0%	66.4	65.3	1.41	1.2	3.66	0.0	24.1	-24.9	-24.4	0.5	PG64-22
		7.5%	71.7	71.8	0.60	12.1	1.55	4.1	19.4	-20.9	-22.8	-1.9	PG70-16
		15%	76.4	76.3	0.28	24.6	0.77	11.3	20.1	-21.9	-22.7	-0.8	PG76-16
	0.6% Evotherm	7.5%	71.2	71.0	0.64	10.9	1.70	3.5	19.6	-22.6	-23.1	-0.5	PG70-22
		15%	76.0	76.3	0.26	25.4	0.72	12.5	21.4	-21.1	-22.7	-1.6	PG76-16
	1.0% Sonneborn	7.5%	68.9	68.8	0.86	8.4	2.25	2.5	19.5	-22.3	-22.3	0.0	PG64-22
		15%	73.1	74.2	0.37	21.0	1.03	8.8	20.8	-22.7	-22.2	0.5	PG70-22

MIXING AND COMPACTION TEMPERATURES – BINDER TESTING

The mixing and compaction temperatures of the PG64-22 asphalt binder blended with RAS and WMA additives were determined based on the Equiviscous and Steady Shear methods described earlier. Table 3 and Figures 10 through 17. In general, the following trends can be seen in the test data;

1. The mixing and compaction temperature is lower for the Steady Shear Flow method when compared to the Equiviscous method. On average, the Steady Shear Flow method is recommending mixing and compaction temperature 20 to 30oF lower than the Equiviscous method.
2. The addition of RAS requires an increase in the mixing and compaction temperatures when compared to the virgin PG64-22. Based on the binder testing, the following increases were determined below. It was interesting to note that even though the PG grades changed when the source of the RAS changed (i.e. – Post Manufacturer Waste vs Post Consumer Waste), the mixing and compaction temperatures only differed minimally.
    a. When using 7.5% RAS by total weight of asphalt binder
        i. Steady Shear Flow requires an increase of 20^oF for both mixing and compaction temperatures
        ii. Equiviscous requires an increase of 15^oF for both mixing and compaction temperatures
    b. When using 15% RAS by total weight of asphalt binder
        i. Steady Shear Flow requires an increase of 30^oF for both mixing and compaction temperatures
        ii. Equiviscous requires an increase of 30^oF for both mixing and compaction temperatures when incorporating RAS.
3. The addition of the WMA additives had mixed results with respect to improving the workability of the asphalt binders. For the Post Consumer RAS, the WMA technologies had little to no improvement on the mixing and compaction temperatures. This may indicate that the stiffness of the Post Consumer RAS may nullify any beneficial impact from the WMA additives. Meanwhile, the WMA additives were able to reduce the mixing and compaction temperatures of the softer, Post Manufacturer Waste RAS by 5 to 8^oF for the Evotherm and 5 to 15^oF for the SonneWarmix.

Table 3 – Mixing and Compaction Temperatures for Equiviscous and Steady Shear Concepts for a PG64-22 with RAS and WMA

RAS Type and Blend	Steady Shear Flow				Rotational Viscometer			
	Mixing Range, °F		Compaction Range, °F		Mixing Range, °F		Compaction Range, °F	
PG64-22 Base Binder	280.2	287.2	260.1	264.9	306.1	316.8	278.4	285.1
Post Consumer 64-22 7.5%RAS	300.4	308.1	279.1	284.4	319.3	329.4	291.6	298.2
Post Consumer 64-22 15%RAS	310.1	317.7	289.0	294.1	337.5	348.6	306.9	314.1
Post Consumer 64-22 7.5%RAS+ 0.6%Evotherm	296.4	303.8	275.5	280.6	312.1	322.0	284.7	291.2
Post Consumer 64-22 15%RAS+ 0.6%Evotherm	308.1	315.7	287.6	292.5	331.0	340.7	304.0	310.5
Post Consumer 64-22 7.5%RAS+ 1%Sonneborn	299.7	307.2	278.4	283.6	316.8	327.2	288.0	294.8
Post Consumer 64-22 15%RAS+ 1%Sonnerborn	306.7	314.2	285.8	290.8	329.5	339.6	302.0	308.5
PG64-22 Base Binder	280.2	287.2	260.1	264.9	306.1	316.8	278.4	285.1
Post Manufacture 64-22 7.5%RAS	304.9	312.8	282.9	288.3	321.8	332.6	292.3	299.1
Post Manufacture 64-22 15%RAS	302.0	309.7	280.8	285.8	338.5	349.3	308.8	315.9
Post Manufacture 64-22 7.5%RAS+ 0.6%Evotherm	287.2	294.6	266.5	271.6	318.0	328.5	289.2	296.1
Post Manufacture 64-22 15%RAS+ 0.6%Evotherm	298.9	306.5	278.1	283.1	325.4	335.5	297.9	304.5
Post Manufacture 64-22 7.5%RAS+ 1%Sonneborn	292.5	300.0	271.0	276.3	314.6	324.7	286.9	293.4
Post Manufacture 64-22 15%RAS+ 1%Sonnerborn	288.3	295.9	267.8	272.7	322.3	333.1	293.0	300.0

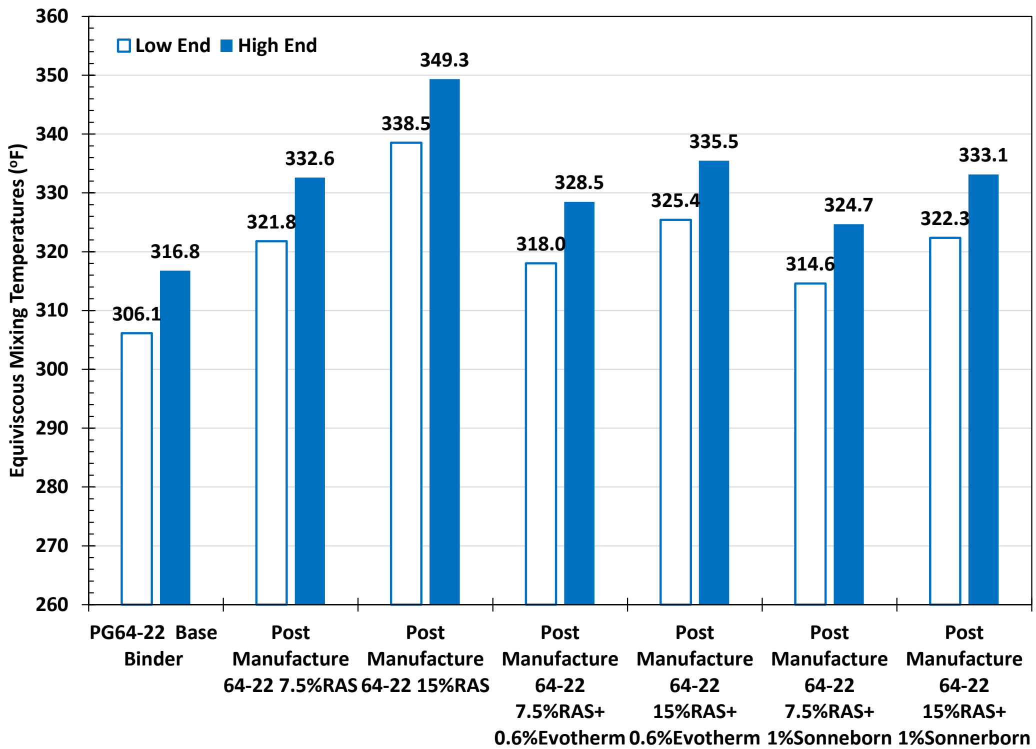

Figure 10 – Equiviscous Mixing Temperature for Manufacturer RAS

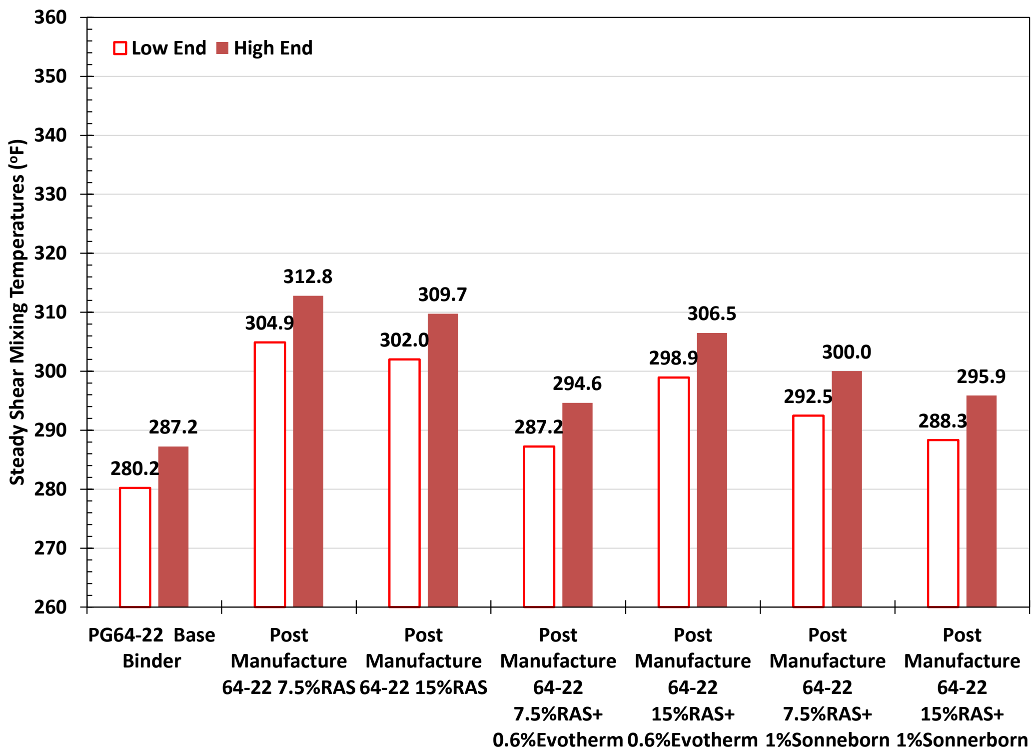

Figure 11 – Steady Shear Mixing Temperature for Manufacturer RAS

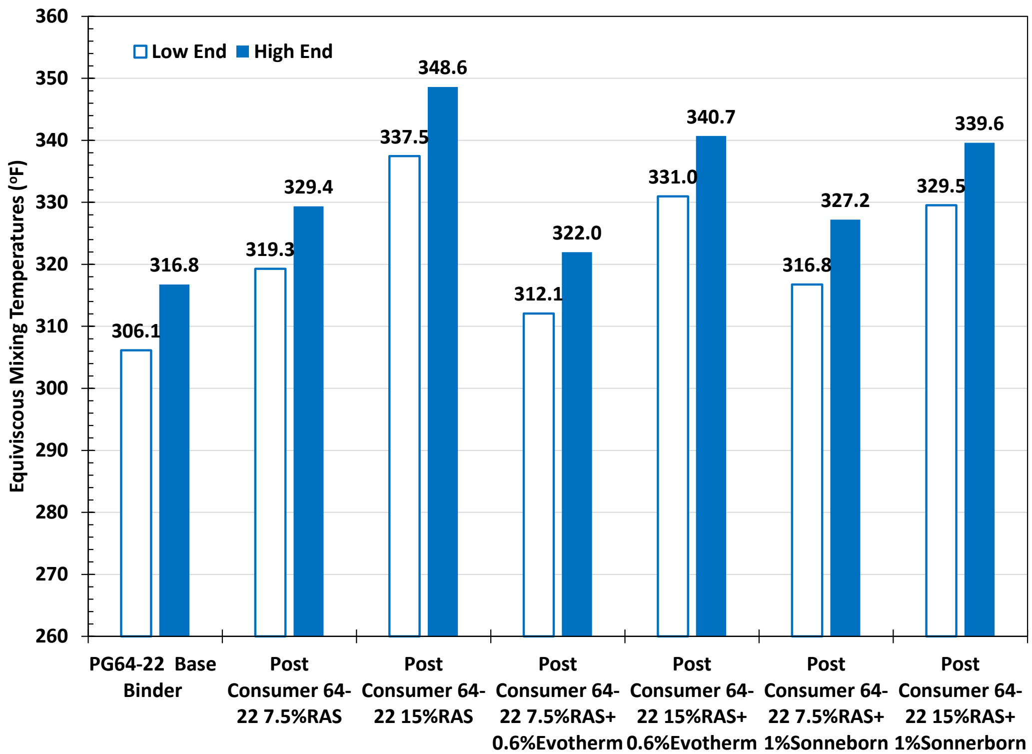

Figure 12 – Equiviscous Mixing Temperature for Post Consumer RAS

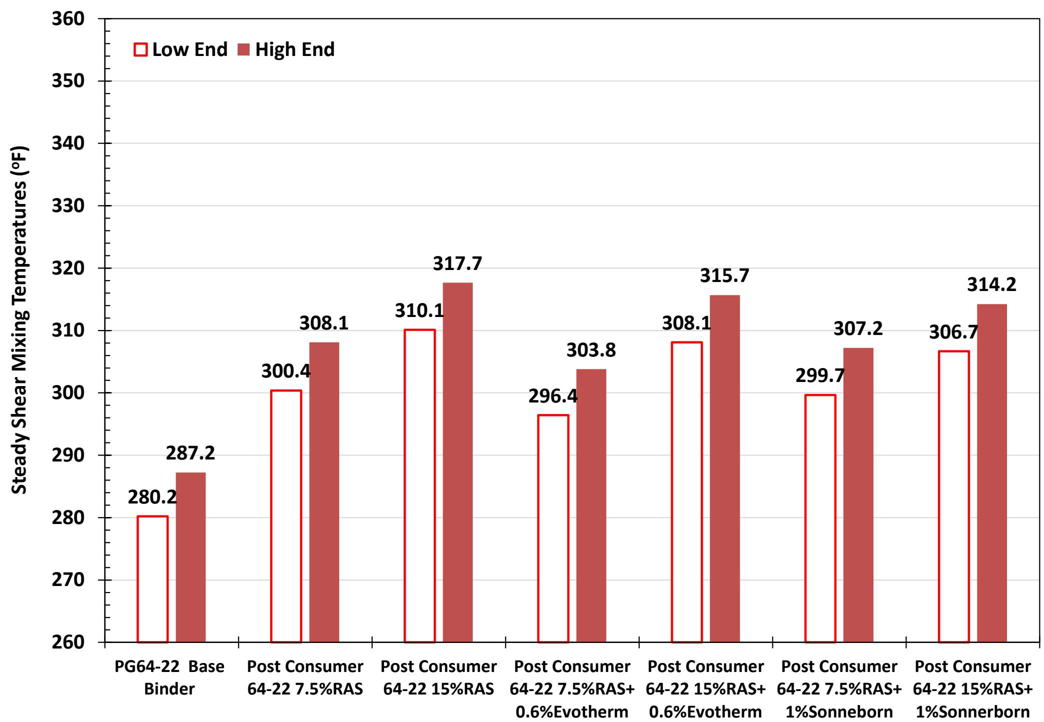

Figure 13 – Steady Shear Mixing Temperature for Post Consumer RAS

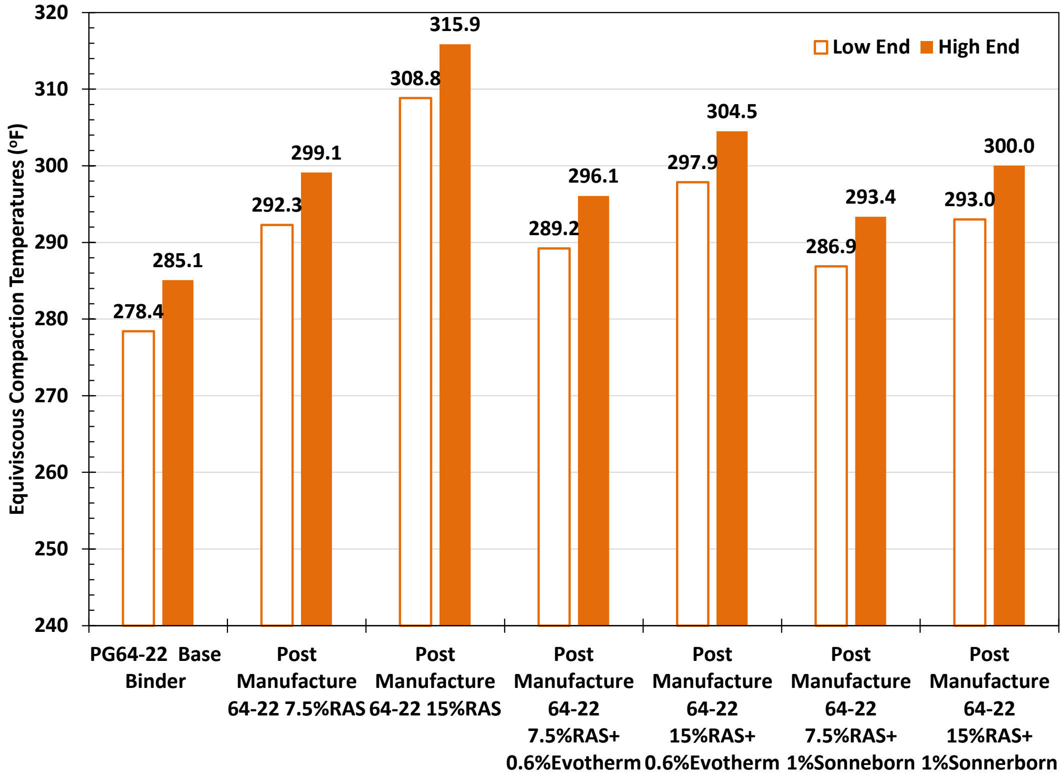

Figure 14 - Equiviscous Compaction Temperature for Post Manufacturer RAS

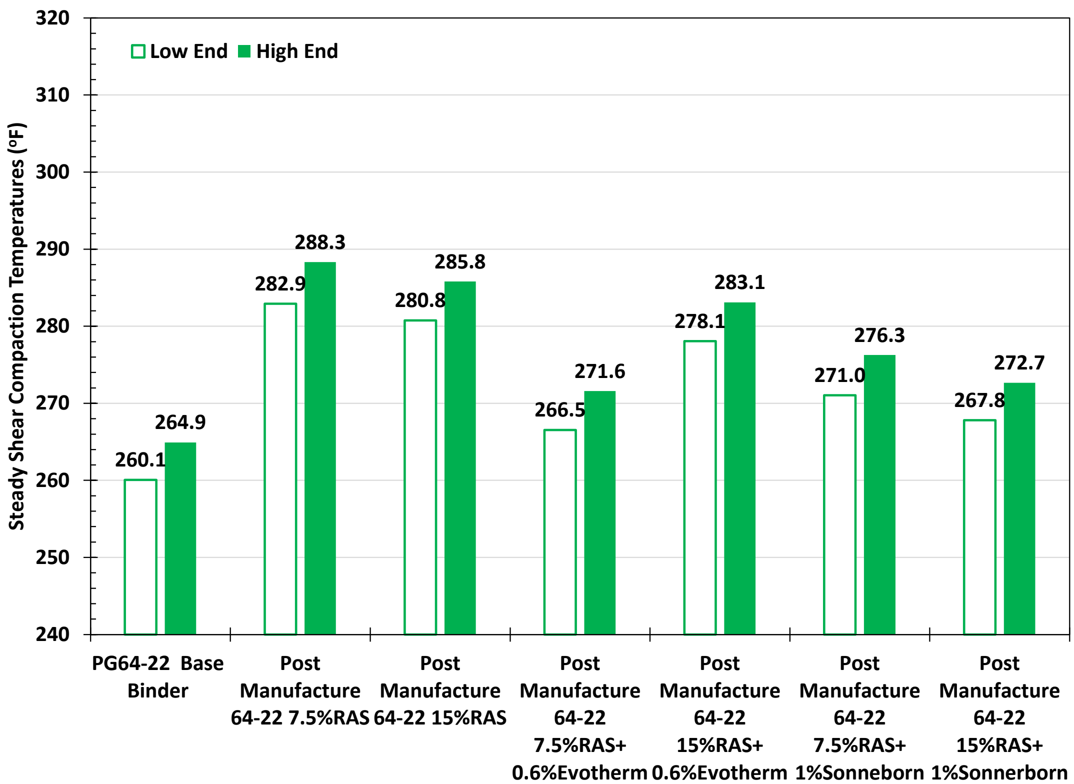

Figure 15 - Steady Shear Compaction Temperature for Post Manufacturer RAS

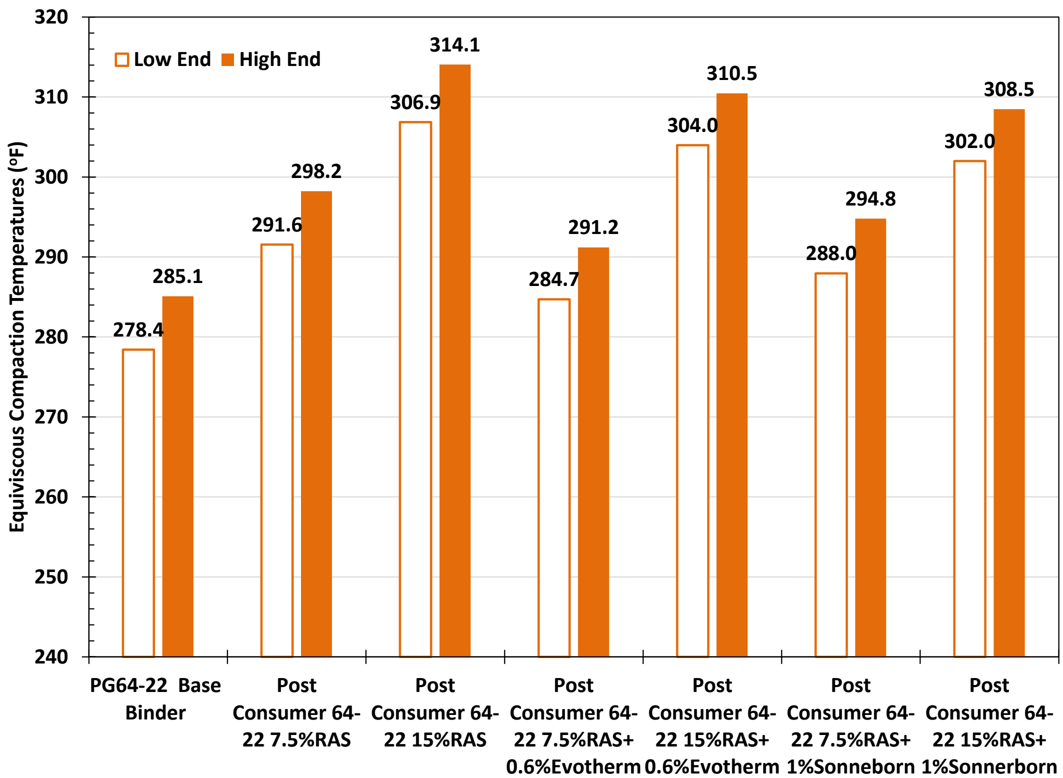

Figure 16 - Equiviscous Compaction Temperature for Post Consumer RAS

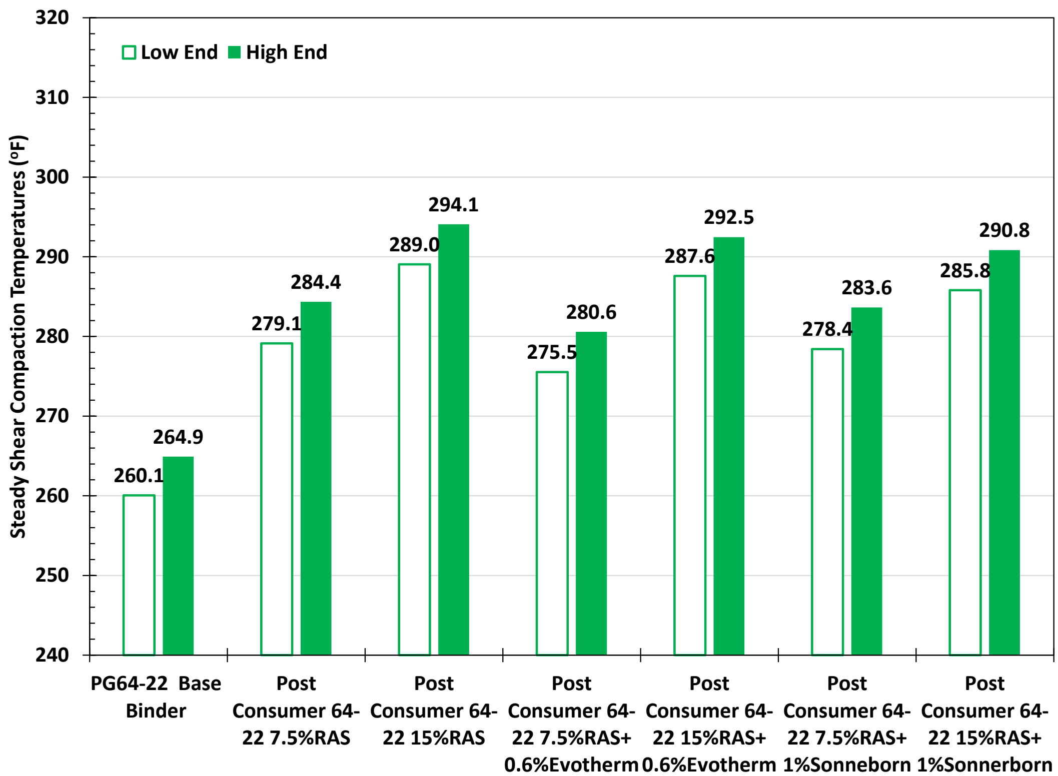

Figure 17 - Steady Shear Compaction Temperature for Post Consumer RAS

WORKABILITY OF ASPHALT MIXTURE

The workability/compactability of the asphalt mixture was evaluated using the Marshall Compactor procedure described earlier. Three specimens were compacted with the specified blend of Post Consumer RAS and a WMA additive and compacted to a different compaction temperature; 300, 355, and 215^{o}F. The compacted air voids for each of the specimens was determined and then averaged for reporting and analysis. Only Post Consumer RAS was used in this portion of the study as there was very limited Post Manufacturer RAS available for testing.

Figures 18 and 19 show the resultant compacted air voids from the study. As the results clearly show, as the compaction temperature increases, the compacted air voids decreases. However, the magnitude and general trend of compacted air voids vs temperature was found to be dependent on the percent of RAS by binder weight, as well as the WMA additive utilized.

Figure 20 shows the Predicted Compacted Air Voids of the virgin PG64-22 asphalt mixture, as well as the mixtures using 7.5% and 15% Post Consumer RAS. As the trendlines indicate, as the percentage of RAS increases, the asphalt mixture becomes more difficult to compact, especially at the lower temperatures.

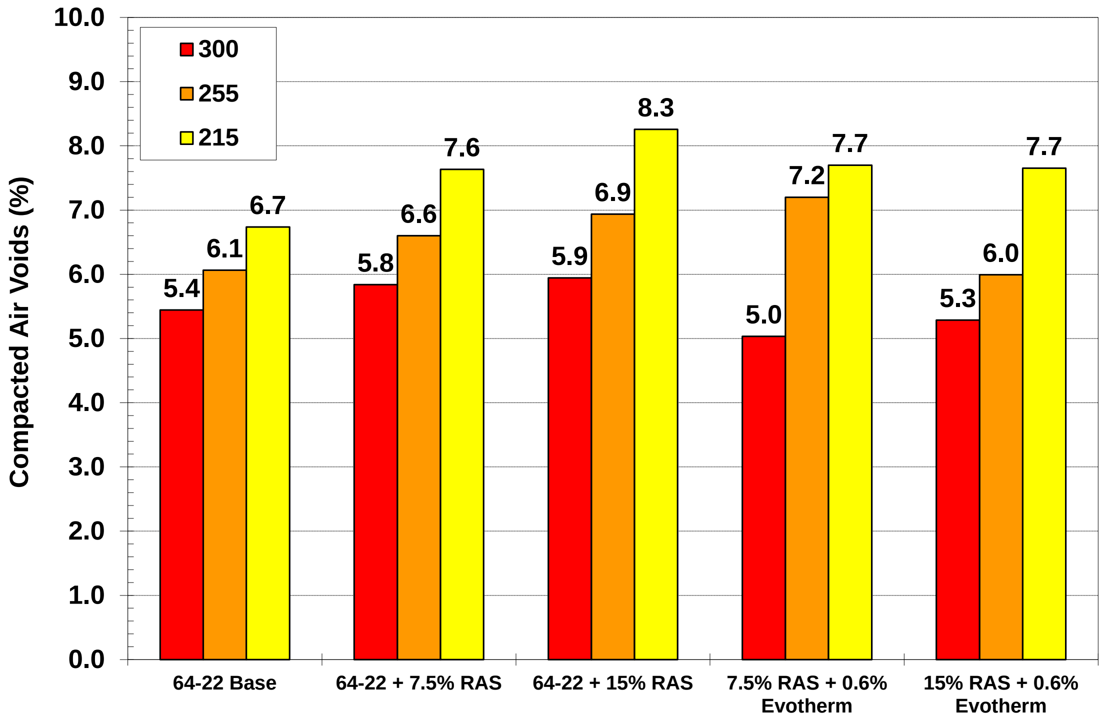

Figure 18 – Marshall Compactor Compacted Air Voids for Post Consumer Recycled Asphalt Shingles – Evotherm WMA Additive

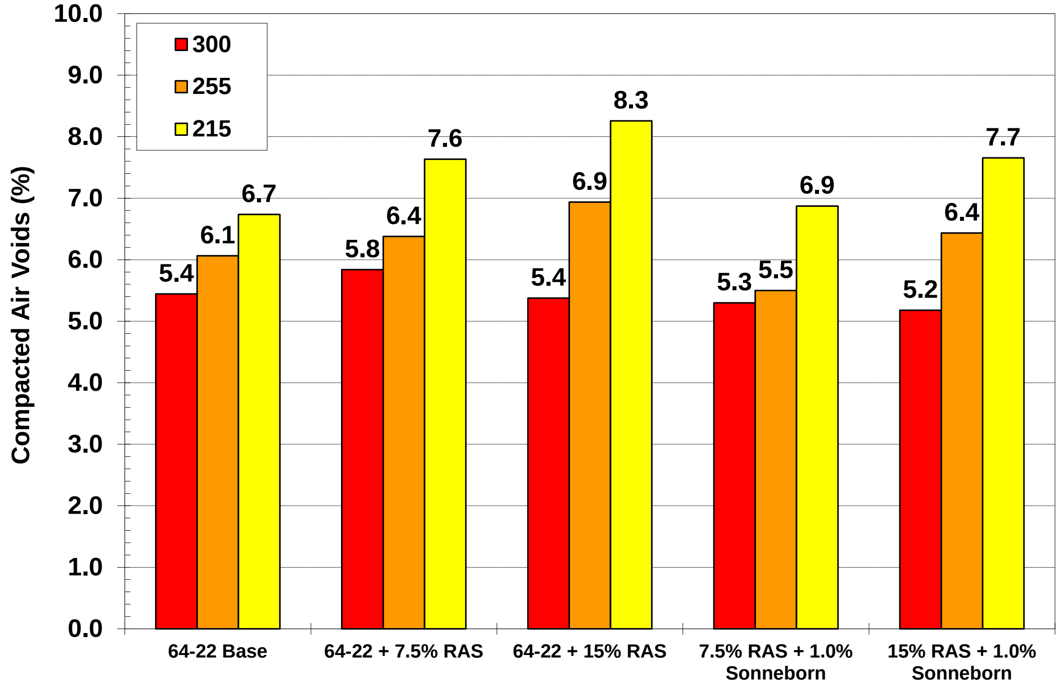

Figure 19 – Marshall Compactor Compacted Air Voids for Post Consumer Recycled Asphalt Shingles – SonneWarmix WMA Additive

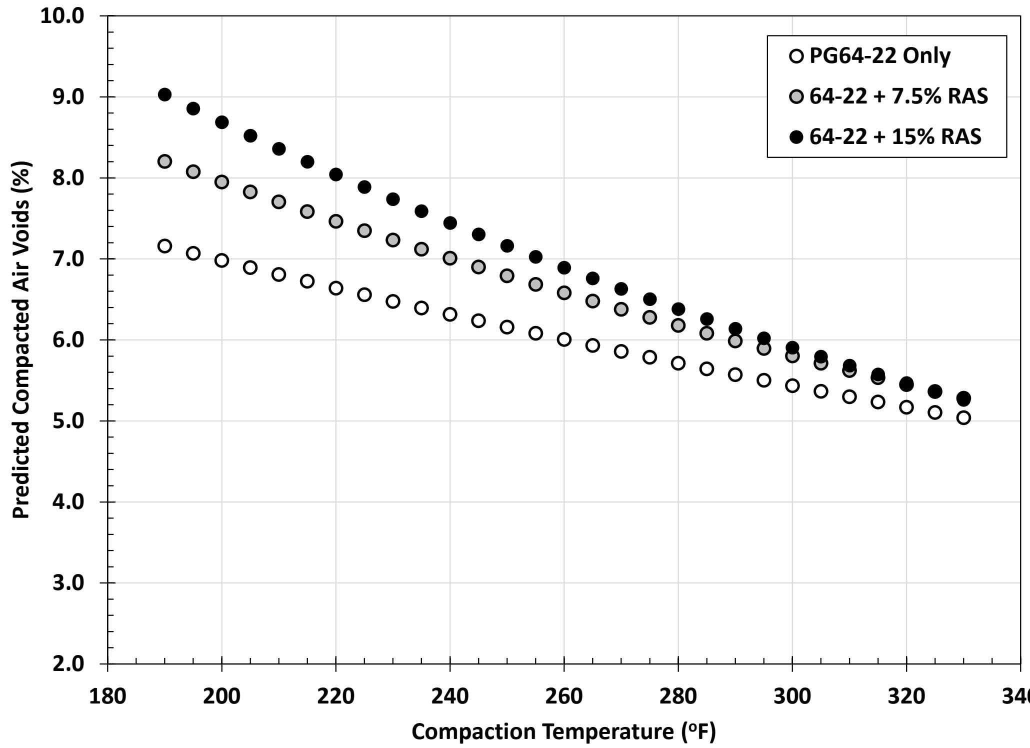

Figure 20 – Predicted Compacted Air Voids of Virgin PG64-22, PG64-22 + 7.5% RAS, and PG64-22 + 15% RAS

WMA has been advertised to help achieve better compaction at lower production temperatures, as well as when asphalt mixture contain higher levels of recycled asphalt binder. Figure 21 shows the comparison of the 7.5% RAS asphalt mixtures with and without the WMA additives. The results show that when using 7.5% RAS, the 1.0% SonneWarmix clearly improved the compaction properties of the RAS asphalt mixture at all compaction temperatures. Meanwhile, the benefit of the 0.6% Evotherm occurred at compaction temperatures above 250^{o}F, with the greatest benefit found at compaction temperatures above 300^{o}F.

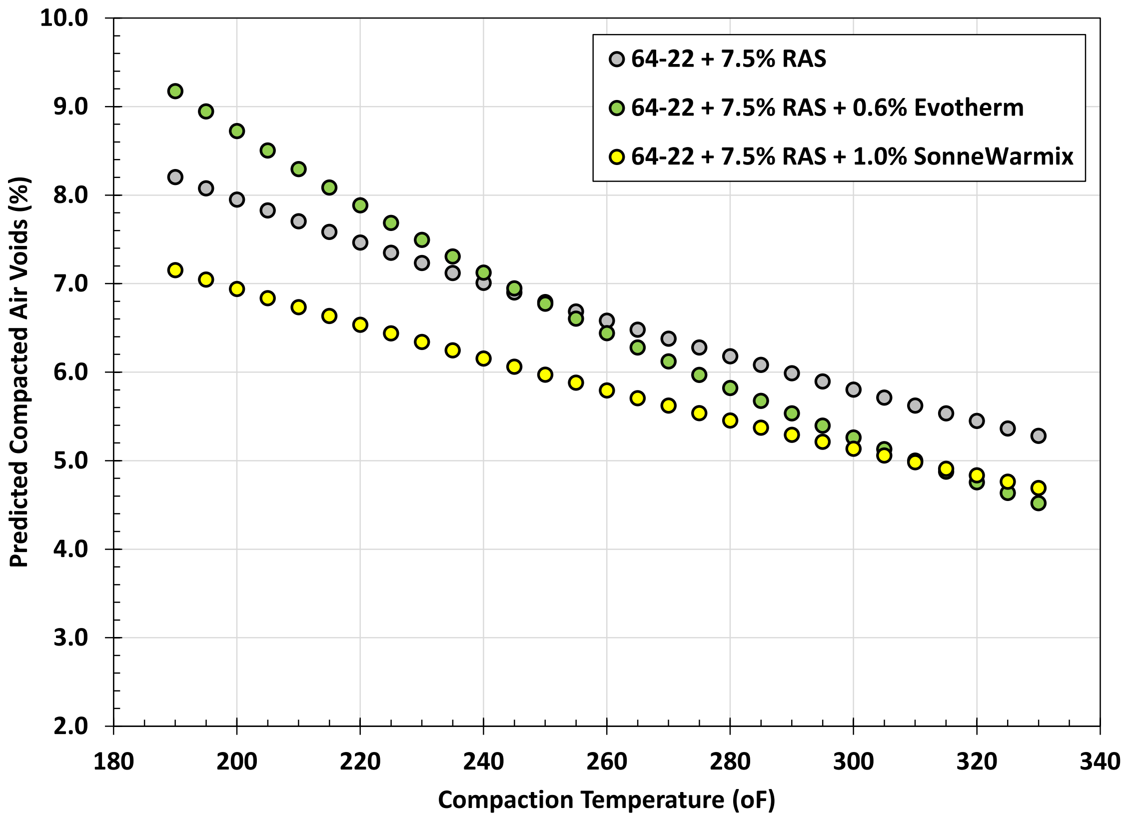

Figure 21 – Predicted Compacted Air Voids for PG64-22 + 7.5% RAS, PG64-22 + 7.5% RAS + 0.6% Evotherm, and PG64-22 + 7.5% RAS + 1.0% SonneWarmix

The compaction results for the 15% RAS asphalt mixtures are shown in Figure 22. Once again, the use of the WMA additives improved the compactibility of the 15% RAS mixture, with both the 0.6% Evotherm and 1.0% SonneWarmix resulting in almost identical compacted air voids and compaction improvement.

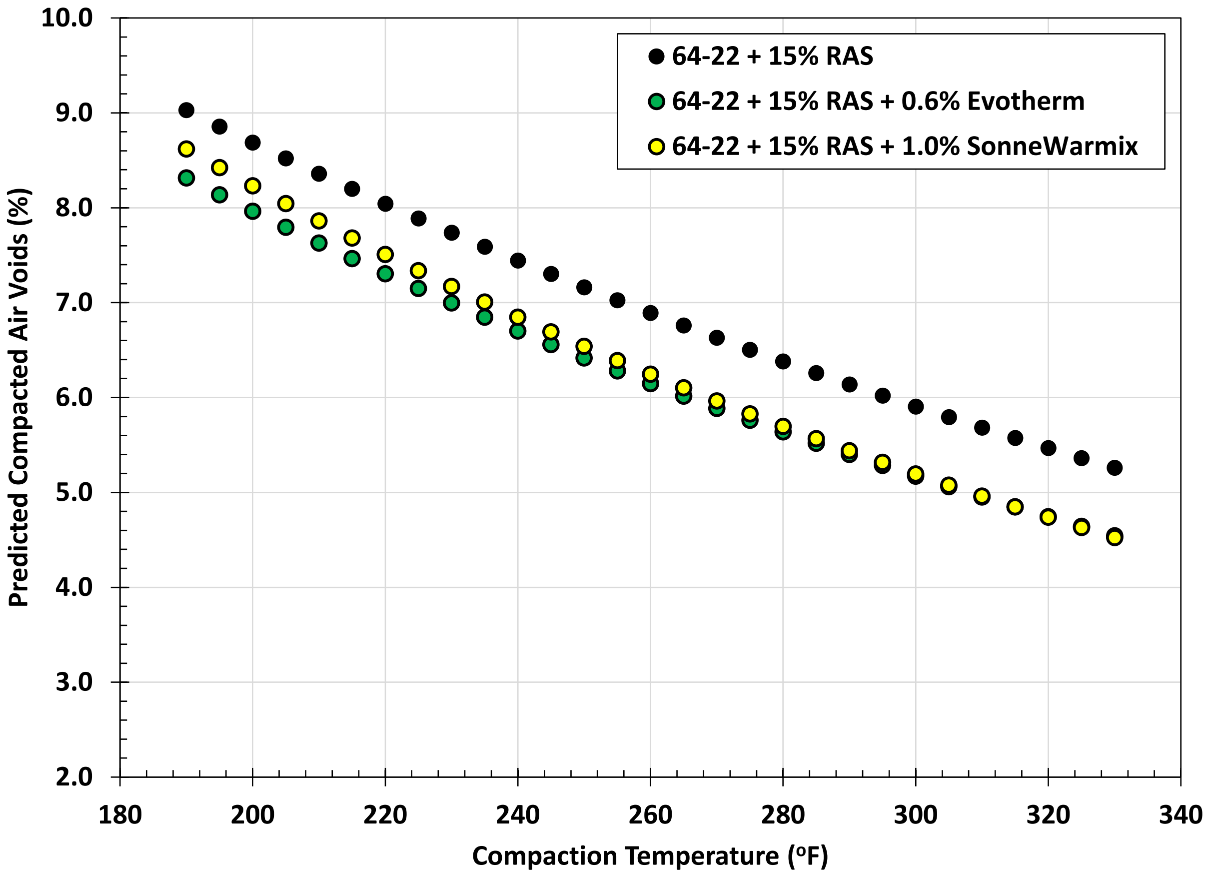

Figure 22 - Predicted Compacted Air Voids for PG64-22 + 15% RAS, PG64-22 + 15% RAS + 0.6% Evotherm, and PG64-22 + 15% RAS + 1.0% SonneWarmix

CONCLUSIONS

A laboratory study was conducted to evaluate the impact on recycled asphalt shingles (RAS) on the compactability of asphalt mixtures. Two different methodologies were utilized in the study; 1) Asphalt binder based testing; and 2) Asphalt mixture based testing. In addition to the RAS, two different types of WMA technologies were utilized to evaluate the change in asphalt compactibility. The results of the study showed:

- Recycled asphalt shingles (RAS) is a very stiff form of asphalt binder. Performance grading of the RAS required the RAS to be blended with a much softer asphalt binder at varying percentages with the resultant test data extrapolated out to 100% RAP: 0% Virgin Binder ratio to determine an approximate PG grade of the RAS. The PG grading also indicated that Post Manufacturer RAS and Post Consumer RAS are much different products. The Post Consumer RAS was much stiffer than the Post Manufacturer RAS asphalt binder.
- The inclusion of recycled asphalt shingles, whether it is Post Manufacturer or Post Consumer, will detrimentally impact the mixing and compaction properties of the asphalt mixtures. Asphalt binder based mixing and compaction temperature analyses indicated that higher mixing and compaction temperatures are required to achieve both Equiviscous and Steady Shear Flow conditions. Unfortunately, elevated mixing and compaction temperatures generally result in stiffening of the virgin asphalt binder/mixture, higher levels of air emission volatiles, and higher energy consumption. Asphalt mixture based analysis showed that utilizing the same applied compactive energy on virgin and RAS asphalt mixtures results in RAS asphalt mixtures having higher compacted air voids in the field. Higher compacted air voids in the field is commonly associated with lesser service life.
- The addition of WMA technologies to the RAS asphalt mixtures does appear to aid in the compaction properties of the final asphalt mixture. Asphalt binder based analyses concluded that anywhere between 5 to 20^{o}F temperature reduction in mixing and compaction temperatures can be achieved when utilizing either the Evotherm or SonneWarmix WMA technologies.

RECOMMENDATIONS

It should be noted that this research only looked at how recycled asphalt shingles impacted the mixing and compaction properties of the asphalt mixture. It was not intended to include mixture performance. The study also assumed that the RAS fully blends with the virgin binder. This may not necessarily be the case, but is extremely difficult to quantify the true amount of blending that does occur.

Future research should look at the impact of RAS with and without WMA on asphalt mixture performance testing. Rutting and fatigue cracking properties should be evaluated in further detail to better understand how RAS fully affects asphalt mixtures.

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