Analysis of Warm Mix Asphalt Additives

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Abstract

The strength, durability and workability of asphalt paving mixtures has changed significantly due to the use of additives. Warm Mix Asphalt (WMA) is an example of such additives which lowers the temperature of the asphalt mix between 30 to 120°F as compared to conventional HMA. A research study was conducted to evaluate additives Evotherm M1, Kaoamin 14, Sasobit and Rediset in WMA. The results showed that additives reduced the asphalt binder viscosity of 380 cP to an average of 295 cP at a temperature of 135 °C and Sasobit also modified the Performance Grade from a PG 64-22 to PG 70-22. Mixtures with the modified binders were evaluated for compaction, susceptibility to moisture and susceptibility to permanent deformation. Compactability results indicated that the specimens were not susceptible to temperature after been produced and compacted at a temperature of 285 °F and 240 °F, respectively. Susceptibility to moisture results showed that Evotherm M1 with a TSR of 96.1% has less probability to stripping. The Flow Number test showed that compacted mixtures subjected to a traffic level between 10 and 30 MESAL are not susceptible to permanent deformation therefore, not affecting the performance of WMA as compared to HMA.

Keywords: Additives, Hot Mix Ashpalt, Warm Mix Asphalt

1. Introduction

The use of additives in the asphalt industry plays a significant role in paving mixtures for new and reconstructed pavements. Warm Mix Asphalt (WMA) was developed primarily for reducing production and compaction temperatures between 30 to 120°F resulting in a reduction of fuel consumption of approximately 11% (EAPA, 2013). WMA with the right additive is an emerging alternative that has the potential to satisfy energy needs generated by the manufacturing and production of asphalt mixtures, which currently represent more than 90 % of the 5.2 million km and 92 % of the more than 4 million km of paved roads and highways, in Europe and North America respectively (Prowell et al., 2011).

More than 20 commercial additives are used worldwide to produce WMA (AASHTO (2011). The Material Testing Office (MTO) of the Puerto Rico Highway and Transportation Authority (PRHTA) evaluated chemical and organic additives for consideration in the development of mix design and construction specifications suitable for Calcium Carbonate ($CaCO_3$) aggregates, tropical weather and humid conditions prevailing in the island. Three chemical additives and one organic additive, Kaoamin 14, were evaluated in this research study initially marketed as an antistripping agent, was included as part of the testing protocol with three other commercially available additives, namely Rediset, Sasobit and Evotherm M1. The additive developed by Quimikao was also evaluated since it brings two recognized benefits to asphalt producers, namely a reduction of the production and compaction temperature and as a antistripping agent to prevent the loss of the asphalt film on the aggregate surface (Quimikao, 2010).

2. Research Objectives

The objectives of this research study were to:

1. Evaluate the strength and durability characteristics of a controlled asphalt mixture modified by the introduction of four WMA additives, namely Evotherm M1 by MeadWeastvaco, Kaoamin 14 developed by Quimikao, Sasobit produced by Sasol Wax North America Corporation, and Rediset WMX from AkzoNobel.
2. Apply the Superpave mix design method on all four additives with emphasis on:
    a. The effect of compactability/temperature susceptible (240 °F),
    b. Susceptibility to permanent deformation (rutting) and
    c. Susceptibility to moisture (stripping).

3. Literature Review

WMA was one of the Every Day Counts (EDC) initiatives included as part of the Federal Highway Administration (FHWA) national effort as an accelerating technology that will assist state Department of Transportation (DOT's) in reducing overall production and laydown temperatures without sacrificing strength and durability of conventional HMA (FHWA, 2011).

One of the primary benefits obtained in WMA mixes in Puerto Rico is the reduction of viscosity of the asphalt binder, which will be beneficial during the mixing and compaction of the material due to the lack of friction between the aggregates (Prowell et al., 2011). Furthermore, WMA is efficient in the paving process, such as ease of compaction and significant reduction in roller compactive effort, increased haul distances of the asphalt mixture and a potential for a greater percentage of RAP. Other environmental and health related benefits are fuel and emissions reduction while improving the working conditions of the paving crew at the job site (Prowell et al., 2011).

Additional production costs associated with the additive and asphalt plant modifications costs are the two drawbacks associated with WMA. Furthermore, as the mixing temperatures are reduced, the rutting and moisture susceptibility of the mixture tends to increase because the aggregates in the mixture do not dry completely.

According to AASHTO R35 report, four methods are used to produce WMA (AASHTO, 2011). The first method consists of pouring the additive directly to the asphalt binder prior to mixing it with the aggregates. The second method is when the mixture is initially prepared and the additive is then added at the end. The third method uses a portion of wet aggregate in the mixture and the last method is a foaming process in which cold water is injected into the hot asphalt binder.

The asphalt binder has to be heated at a temperature of approximately 300 °F until it is in a complete Newtonian liquid state. The asphalt binder is then weighed to determine the amount of additive that is needed; this amount is typically referred as a percent by weight of binder. Then the additive is poured directly into the hot asphalt binder in the liquid state. The binder should be continuously stirred with a mechanical stirrer to guarantee homogeneity of the modified asphalt binder. At last, the modified asphalt binder is stored at room temperature in a sealed container for future use for a period no longer than two weeks. When the mixture is ready to be prepared, the asphalt binder should be heated at approximately 300 °F and then is added to the aggregates blend until w_t (Equation 1) is reached to allow full coating of the aggregate (AASHTO, 2011).

$$w_t = \frac{w_i}{\left(1 - \frac{P_{b_{new}}}{100}\right)} \tag{1}$$

where:

w_t = target total weight
w_i = oven dry weight of aggregate
P_{bnew} = percent by weight of total mix of asphalt binder in the mixture

4. Additives Evaluated

The four additives evaluated in this study were Rediset, Sasobit, Kaoamin 14 and Evotherm M1. The Rediset additive is a chemical additive produced by the company Akzonobel that enables the production of hot mix at lower temperatures. As result of the addition of Rediset it will reduce the mixing and compaction temperatures by more than 54°F, which will also reduce fuel consumption by at least 20%. It will assist significantly to lower CO_2 emissions at the paving site and at the hot-mix plant. The additive comes in a pellet form and it is added to the binder or to the mixer with a required dosage of 1-2% of the bitumen, which will provide an anti-oxidant feature that will improve the adhesion and cohesion properties between the aggregate and the bitumen. The addition of the chemical additive in the mix design does not require any modification from the hot mix plant nor the mix design.

The Sasobit additive is made by Sasol Wax North America Corporation. It is an organic additive produced to lower plant mixing temperatures, from 300°F to 250°F. The reduction in temperatures will represent a reduction of emissions and thermal cracking and cost savings of up to 19% (Prowell et al., 2011). Due to the chemical structure, Sasobit will dissolves easily when it is mixed with the asphalt binder at temperatures above 248° F. The additive can be easily blended into the binder and can be added to both the binder and the mix with a required dosage of 1.5% by weight of the binder. Sasobit allows the usage of RAP, which can be increased to 35% or more (Prowell et al., 2011).

Kaoamin 14 additive is produced by Quimikao S.A. It brings benefits such as the reduction of the temperature of the production of the mix between 40 to 50 °F, depending upon the amount of additive used. The chemical additive will produce a mix with more adhesion and cohesion between the aggregate and the binder. Also, the mix is more resistant to the damage caused by humidity in the environment. Since Kaoamin14 is added directly to the binder with a recommended dosage between 0.3 to 1.0 %, the mix will show more fluidity and handling and the percentage of voids will be less than the conventional HMA mix. The chemical properties of the additive Kaoamin 14 brings an additional property to the WMA, which is the reduction of the oxidation of the asphalt to prevent the loss of flexibility and the formation of cracks that will allow the penetration of water and other incompressible components that are harmful to the asphalt (Quimikao, 2010).

Evotherm M1 additive is produced by Asphalt Innovation. It has the flexibility that can either be added to the binder or the mixture. The use of this additive allows temperature reduction of 63 to 90° F in comparison with the conventional HMA. This reduction in temperature will reduce the fuel consumption; lower emissions and it will reduce fumes exposure to workers at plants and job sites. The Evotherm M1 requires a recommended dosage of 0.25-0.75% by weight asphalt binder in order to guarantee the results that the asphalt producers are trying to achieve (Prowell et al., 2011).

5. Methodology Description

The research methodology is shown in Figure 1. Once the literature review regarding WMA and additives was completed, the initial dosage of each additive for the base scenario was established.

The laboratory phase was then conducted following AASHTO test method shown in the flow chart in order to verify the aggregates properties of the mix design, the rheological properties of the asphalt binder and the mixture performance. The laboratory results were analyzed in an integrated manner to come with recommendations of the suitable additives for the particular criteria, namely compactability, susceptibility to moisture induced damage and susceptibility to permanent deformation.

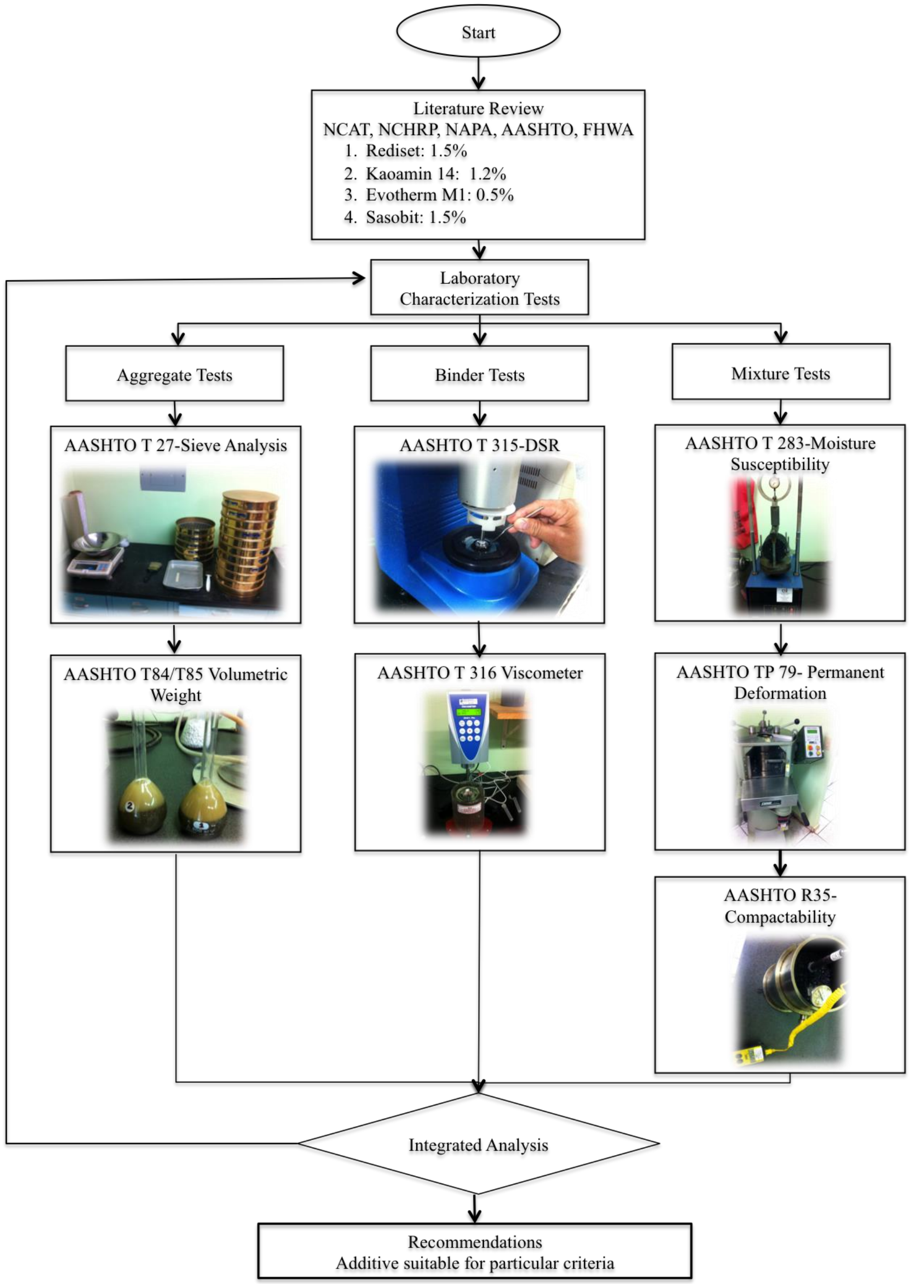

Figure 1: Research methodology

6. Laboratory Analysis

The viscous and elastic behaviors were determined at different temperatures near its PG using the DSR. Each asphalt binder showed a viscous and elastic properties such as complex shear modulus (G*) and phase angle (δ) that were determined for the control and modified asphalt binders with the corresponding additive. In terms of acceptance parameter, the minimum value for the G* for each asphalt binder is 1kPa, therefore, every sample met the requirement at a temperature of 64 °C. Although the samples passed the test at that temperature, the only modified asphalt binder that reached the temperature of 70 °C was Sasobit, which failed at 76 °C as presented in Figure 2. This result was expected because Sasobit has the property of modifying the PG of the asphalt binder, which assists in the reduction to permanent deformation due to its high value of G*. The values obtained with the Evotherm M1 and Kaoamin 14 additives shows that it does not contribute in reducing the susceptibility to rutting; on the other hand, it will increase it comparing to the control asphalt binder. The higher the value of G*, the stronger the compacted mixture will be to rutting susceptibility.

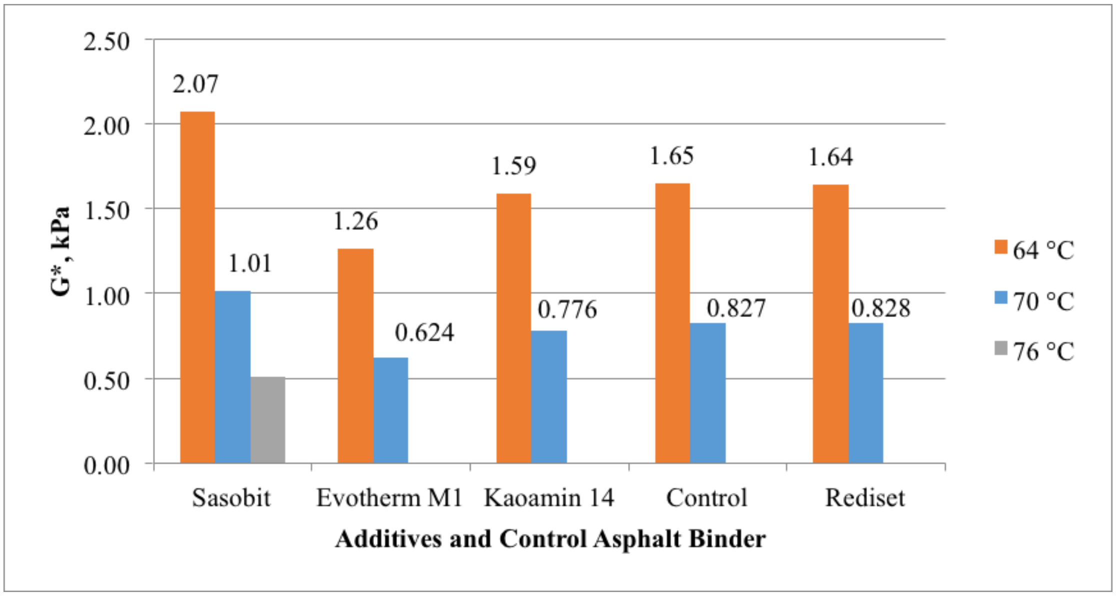

Figure 2: Complex shear modulus as a function of temperature for each asphalt binder

Using the Brookfield viscometer at a temperature of 135 °C and 165 °C, each sample of modified asphalt binder was heated to bring it to its liquid state prior to starting the viscosity test. Every sample of modified asphalt binder was weighed to obtain a sample of approximately 10.8 g to introduce it into a cylindrical tube. Figure 3 shows the reduction in viscosity at a temperature of 135 °C and 165 °C, that each modified asphalt binder achieved when comparing it to the unmodified asphalt binder.

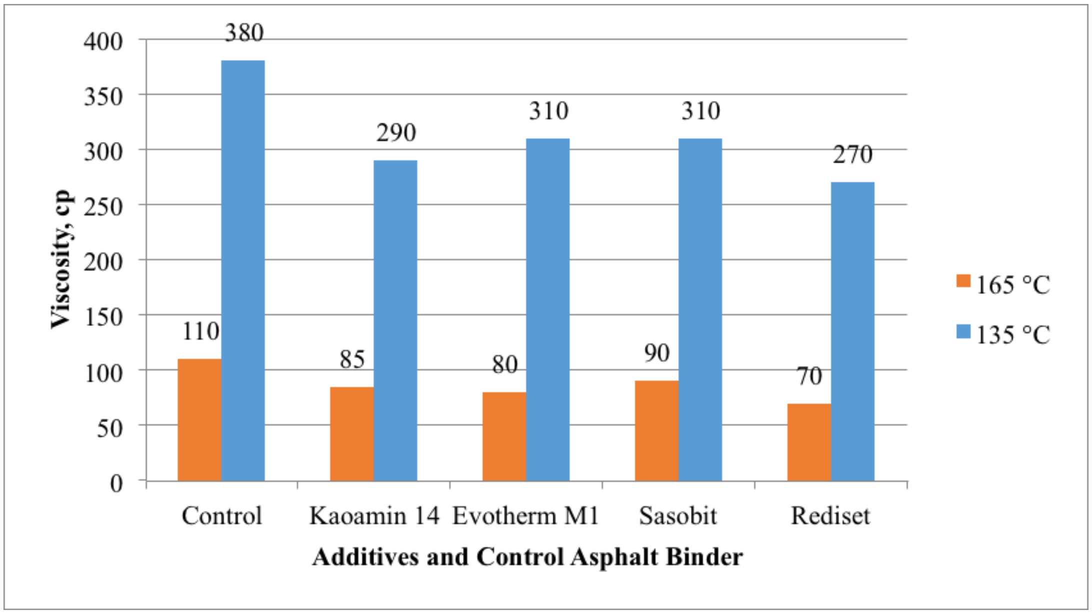

Figure 3: Viscosity of the asphalt binder at 135 °C and 165 °C

The methodology presented in AASHTO T 283 was used to predict the long-term stripping susceptibility of the WMA and for the evaluation of the additives added to the asphalt binder to prevent stripping of the aggregates (AASHTO, 2011). The preparation of six specimens per additive were done laboratory-mixed/laboratory compacted. The mixture with the asphalt binder modified with the additive Kaoamin 14 was compacted at a diameter of approximately 6” and was divided into two groups. Prior to testing each specimen from the conditioned subgroup, they were compacted at approximately 7% air voids and saturated with water until it reached 70 to 80% saturation.

After determining the indirect tensile strength of the dry and conditioned specimens, the interior of the specimens were inspected and it was found that they did not present any visual evidence of moisture damage. The specimens obtained a TSR of 87.8% proving that the mixture has a low probability of moisture susceptibility.

For the additive Sasobit, the compacted specimens of the subgroup that were conditioned obtained a percentage of voids near 7 % reflecting an increase in the diameter. Once the average of each subgroup was calculated the value of the conditioned subgroup was divided by the unconditioned to obtain a TSR of 88.3%, which proves that the compacted specimens with the additive Sasobit has low susceptibility to moisture and stripping.

The results for the mixture modified with the chemical additive Rediset, obtained a TSR of 86.9 % proving the mixtures with the additives Kaoamin 14 and Sasobit have a better susceptibility to humidity as compared to the specimens with the asphalt binder modified with the additive Rediset and there was no visual evidence of moisture damage.

The mixture with the asphalt binder modified with the additive Evotherm M1 obtained a percentage of voids lower than the other mixture with the additives; however they still allow the saturation of the specimens at the time they were conditioned. When the mixture with the additive Evotherm M1 was mixed and compacted, it revealed that of all additives this was the most difficult in terms of workability. Furthermore, the TSR of 96.1 % was the highest value obtained in the test proving that the additive is less susceptible to moisture damage (Figure 4).

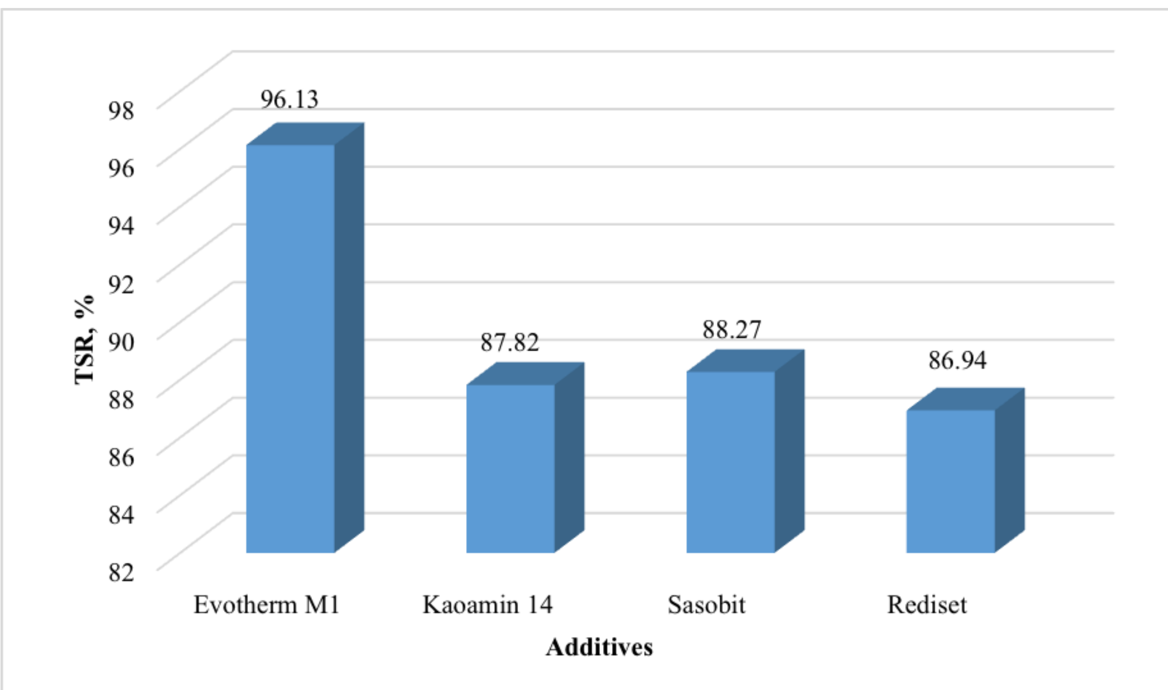

Figure 4: TSR for each mixture with additives

In order to evaluate the susceptibility to permanent deformation of the asphalt mixture, the methodology was followed in accordance t*o AASHTO TP 79* (AASHTO, 2011). Each specimen was coded as follows: for Evotherm M1, EM1-1A, 2A and 3A, for Kaoamin 14, K14-1B, 2B and 3C, for Rediset, R-1C, 2C and 3C and for Sasobit S-1D, 2D and 3D. Each specimen was tested using the required height for the cutting process and the temperature at which the susceptibility to permanent deformation is tested.

The modified asphalt binder flow number test results for the additive evaluated presented in Table 1, shows that the standard deviation results are high, which mean that FN values obtained are far from real and that there was no consistency in the results. However, the Evotherm M1, Kaoamin 14 and Sasobit additives with standard deviation in the FN test greater than 20 have consistency in the specimens tested with the exception of only one of them within each additive (EM1-3A, K14-2B and S-3D) which explains the significant dispersion encountered.

According to the minimum FN cycles required in NCHRP 9-43 report (NCHRP, 2011), for a traffic level between 10 to 30 MESAL the FN should be greater or equal to 105, therefore, almost all additives showed a low susceptibility to permanent deformation of the pavement with the exception of Evotherm M1 with an average FN of 104 (Figure 5). Although the FN was lower than the minimum required, two of the three specimens tested obtained values above the minimum concluding that is not susceptibility to rutting.

Another dispersion parameter calculated was the coefficient of variation (COV) of the FN. The COV shows the percentage of variability in relation to the mean value of the three specimens of each additive. The COV of the additives Evotherm M1, Kaoamin 14 and Sasobit were above 20, showing the significant variability of the FN in the additives.

Table 1: Modified Asphalt Binder Flow Number test results

ID	Air Voids (%) As Compacted	Air Voids (%) As Tested	Flow Number (cycles)	Avg. FN	Std. Dev. FN	COV FN (%)
EM1-1A	7.0	2.9	123	104	22	21
EM1-2A	7.2	3.5	109			
EM1-3A	7.0	4.3	80			
K14-1B	6.8	2.3	179	133	52	39
K14-2B	7.2	3.6	77			
K14-3B	6.2	2.9	144			
R-1C	7.0	3.4	156	155	10	6
R-2C	6.6	3.2	145			
R-3C	7.0	2.6	164			
S-1D	6.9	2.6	228	188	75	40
S-2D	6.9	2.1	235			
S-3D	7.0	3.4	102			

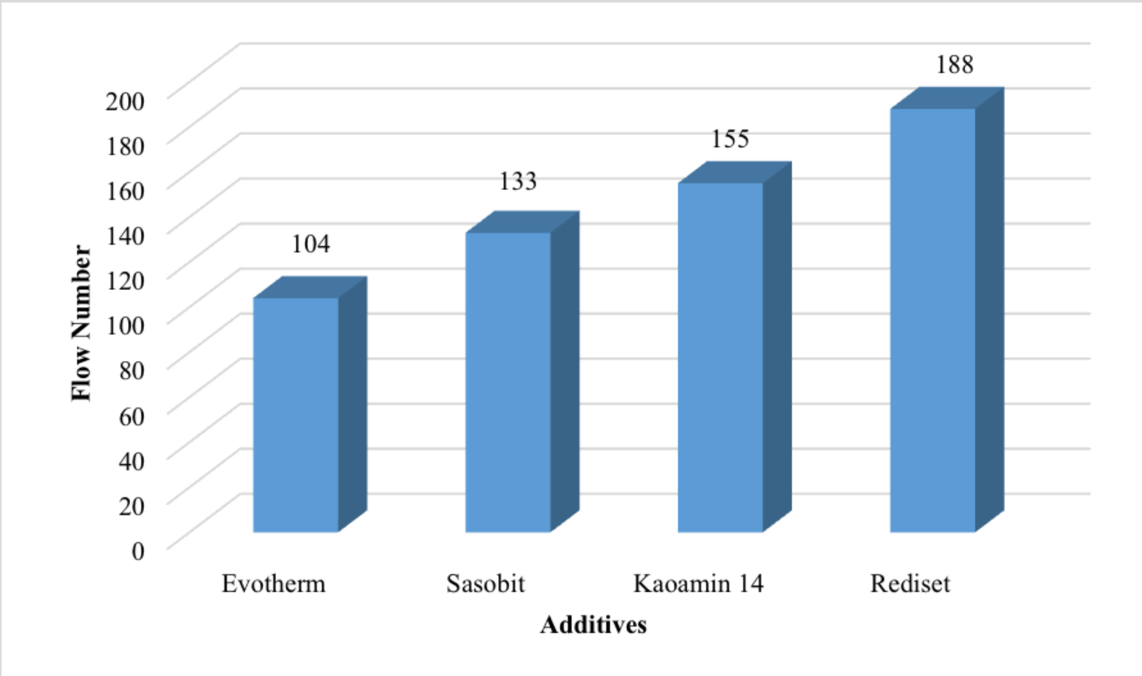

Figure 5: Flow Number for the Modified Asphalt Mixture

For the compactability test, the criterion can be determined to estimate the sensitivity of the mixture at temperatures of 240 °F and 154 °F when being compacted by following the procedure presented in AASHTO R35 (AASHTO, 2011).

The VMA and VFA values were within the required range and the percentage of voids is also within the range of 4 ± 1.25 %, however by analyzing the percentage of voids in the compacted mixture with the additive Evotherm M1, it can be observed that the percentages of voids at 240 °F are 4.7 % and 4.8 % which are higher than the values obtained at 154 °F. Due to the low temperature of the mixture, it requires more pressure to be compacted at N_{design} gyrations, therefore, the lower the temperature, the higher the percentage of voids.

Once the number of gyrations needed to achieve 92% density of the compacted mixture at 240 °F and at 154 °F, the equation 2 shown below was used to compute the gyration ratio of the compactability criterion presented in Figure 6. The computed gyration ratio of all compacted specimens was less than 1.25. The compactability criterion limits the temperature sensitivity of WMA to that for a typical HMA mixture (AASHTO, 2011) meaning that asphalt mixtures with the additives tested, can be compacted at this temperature without affecting its performance.

$$Ratio = \frac{(N_{92})_{T-30}}{(N_{92})_{T}} \tag{2}$$

where:
$(N_{92})_{T-30}$: Gyrations to achieve 92% of relative density at 86 °F below compaction temperature
$(N_{92})_{T}$: Gyrations to achieve 92% of relative density at compaction temperature

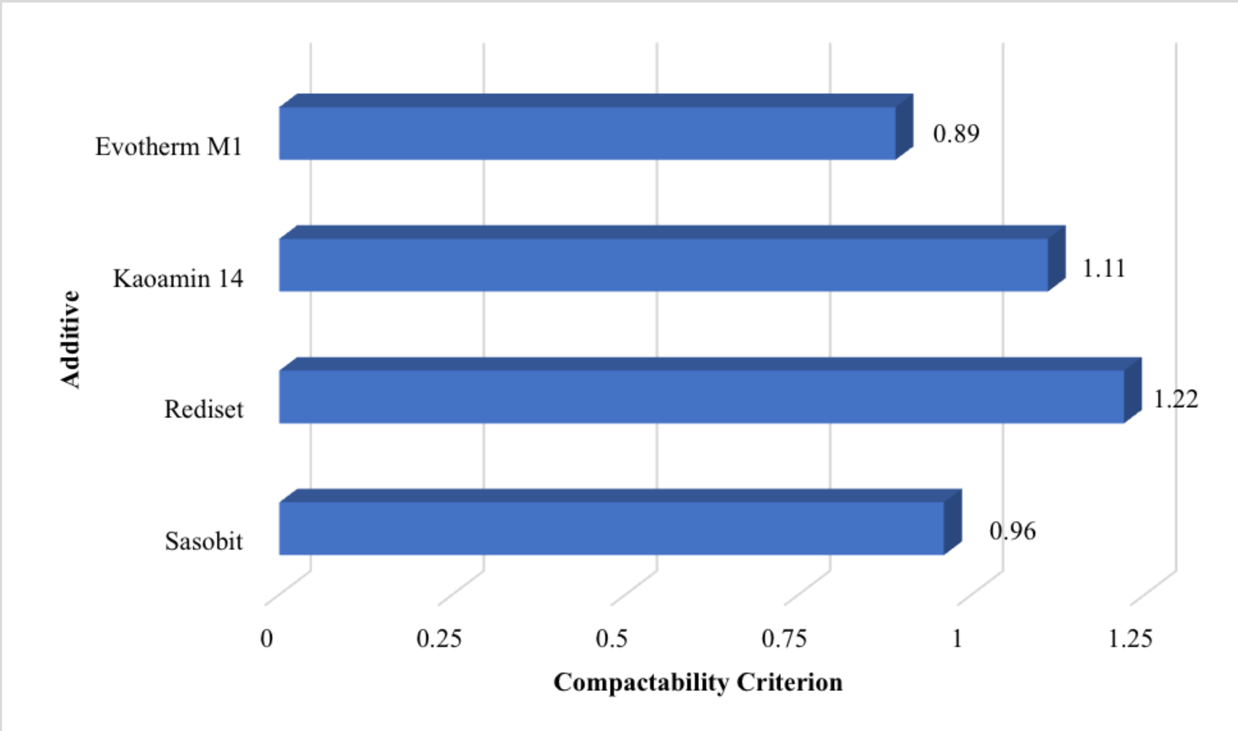

Figure 6: Compactability ratio criterion for each additive

7. Conclusions

Based upon the laboratory tests performed on the asphalt mixtures and asphalt binder with the additives Rediset, Kaoamin 14, Sasobit and Evotherm M1 and the control HMA mixture without the additive, the following conclusions are made with respect to each additive:

1. Evotherm M1:
   - Reduced the G* of the control asphalt binder from 1.65 to 1.26 at a temperature of 64 °C in the DSR test, which means that the stiffness of the modified asphalt binder will lower significantly and the mixture will be more susceptible to rutting.
   - The modified mix has less probability to stripping due to the TSR of 96.1 %.
   - In the compactability test, a value of 0.89 was obtained proving that the additive is less susceptible to a temperature of 240 °F at the time of compaction.
   - It has a higher probability that rutting occurs with mixes that use Evotherm M1 as compared to other additives.
2. Rediset:
   - At the time the asphalt binder was modified with the additive Rediset in its solid state, it was observed that there was no problem with the homogenization when they were mixed.
   - Reduces the viscosity the most from 380 to 270 cp at a temperature of 135 °C.
   - Does not alter the stiffness of the asphalt binder.
   - The compactability test showed that the mixture has more probability to be susceptible at a compaction temperature of 240 °F.
   - The moisture susceptibility test showed that the mixture has more probability to moisture damage, TSR of 86.94%
3. Sasobit:
   - Sasobit was the least susceptible to permanent deformation with a FN of 188 with an estimated traffic of 15 MESAL.

- The additive Sasobit was capable of altering the PG of the asphalt binder allowing a PG 64-22 to work as a PG 70-22.
- The rut depths are lower as compared to the HMA and the reduction in the temperature does not seem to affect the rutting resistance of the mixture.

4. Kaoamin 14:
   - Of all the additives, Kaoamin 14 is the second additive that reduces the viscosity of the asphalt binder the most.
   - According to the rheological properties, the PG 64-22 reduces the stiffness if this additive is added.
   - The moisture susceptibility test showed that the additive has a low stripping probability in the asphalt mixture.
   - The FN test showed that the rutting is less likely to occur in the mixture.

In terms of the overall performance of the additive in each test, the following conclusions were made:

- Due to the reduction in viscosity of the asphalt binder, the aggregates in each mixture were fully coated and the mixture and compaction at lower temperatures did not affect the mixture.
- The compactability test criterion was met by the four additives which obtained a ratio less than 1.25, validating that the specimens with the asphalt binder modified with the additives can be compacted at a temperature of 240 °F without affecting its performance.

8. Acknowledgements

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