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Performance of Chemical WMA Mixtures – A review

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ABSTRACT

In recent years, a new approach called WMA technology is developed, which include reduces binder viscosity and accordingly allows lower temperatures for mixing and compaction. This technology gives several benefits, such as reduce emission, less odor, and energy saving. This study gives a comprehensive review on the use of WMA with chemical technology. In addition, give an introduction to use chemical additives into the bitumen, in order to understand the application of these additives, the problems, benefits and how they act are reviewed.

Key Words: *Warm mix asphalt, Chemical additives, WMA performance.*

1. INTRODUCTION

Warm mix asphalt (WMA) is a new technique widely utilized in highway industry; it provides energy saving and environmental friendly technology. This technology reduces energy consumption, emissions due to a reduction by 25–30°C in temperature of mixing and compaction [1-2]. Many contractors implementing warm mix asphalt (WMA) technology in order to reduce fuel consumption and improve workability [3]. In the United States and Europe, WMA technology gives environmental and economic value. The economic value is identified by fuel saving, reduce in roller passes and long haul distances. The environment value is identified by lower exposure of workers to fumes during production and reducing plant emissions due to the reduced mixture production temperatures. A technology was developed to produce WMA from chemical products, in order that reduce construction temperature, pollution emissions, and to increase of carrying asphalt for long distances. In the United States, WMA technology with chemical additives has developed. The chemical packages will enhance adhesion, coating and mixture workability [4-5]. Chemical Additives do not alter binder viscosity [6-7]. These are as a Liquid surfactant-based additives control the bitumen/aggregate interface to reduce internal frictions. Some of the chemical additives are available as an emulsification agent [8,6,9] when mixing it with aggregate, the water will flash off as steam, and accordingly, will enhance the coating.

2. CHEMICAL WARM MIX ADDITIVES

The initial use of chemical WMA mixtures is started in the USA. Also in the European countries, this technology was beginning to be used. Many manufacturers have developed chemical WMA technologies to be used in pavement industry and maintenance activity. Additives affect WMA mixture performance, whether from positive or negative effects. The process of chemical WMA technology to reduce mixing and compaction temperature does not rely on foaming or reduction asphalt viscosity, but it is an innovative product by using a collection of anti-stripping agents, emulsification agents, polymers and surfactants toward enhancing compaction, workability and coating. These additives reduce the internal friction between binder and aggregate particles during mixing and compaction, but do not rely on the principles of foaming or viscosity reduction [10]. Usually, the virgin asphalt binder is mixed with chemical products before batching it into the asphalt mixer. The chemical package is added as an additive into bitumen in the plant or use as an emulsion. The amount of chemical additive to be used and the temperature reduction will depend on the selected product used [2, 11]. Some of of the chemical WMA technology includes Cecabase® RT Ceca Arkema Group [12], RedisetTM WMX Akzo Nobel Corporate [13], and Evotherm MeadWestvaco Corporation [14].

When chemical packages present as the emulsification agent [8, 6, 9], the water in the emulsion become a steam during mixing the additive with a binder, accordingly will enhance the coating at lower mixing temperature. In addition to that, asphalt viscosity did not alter due to chemical products [6-7]. Chemical additives are surfactants and they add to asphalt of 0.3% by mass of asphalt. These additives improve coating between aggregate and asphalt, which assist in mixture placement at temperatures 20˚C - 30˚C below of conventional HMA [European Asphalt Pavement Association (EAPA) (2010)] [15-16]. Reference [17] showed that chemical additives act on the mixture in reducing the production and compaction temperatures and do not reduce asphalt viscosity, which will improve its compactibility. Reference [18] showed that the chemical products did not alter bitumen physical properties, but they decrease the internal friction between asphalt and aggregate and act as a microscopic interface between them, such as Cecabase and Rediset that are surfactant products enhance compactability, workability of bitumen mixture. [19,15].

Reference [20] showed that Rediset technology give the best results in produced WMA mixture in 120 C when compared to other technologies. Mixture properties like stability, flow and indirect tensile strength values show similar to control mixture produced in 150 C and the values is less scattered comparing to other additives. The following are some of chemical products widely used in WMA:

a. Cecabase is produced in France by Arkema Group, CECA is a division of the Arkema Group develops a patented chemical package [5], [12] it composes 50 percent of raw materials which enhance asphalt mixture workability [12]. It is found as a liquid form, Fig. 1 (a) exhibit the Cecabase®, which is liquid at 25°C and it enables the production asphalt mixture at a reduction in temperature by 20 - 40°C with keeping equal performance to a conventional mixture (HMA), also it is effect on bitumen rheological properties does not changed [12], [21]. Its dosage range between 0.2 and 0.5% of binder weight, it is an active agent injected directly into bitumen [22]. The density of this additive equal 8.30 lbs/gal with 199 C of flash point. Reference [5] state that this additive play as a lubricant through the compaction process. According to the literature, Cecabase is one of the chemical additives, it hardens the bitumen and has no significant effect on binder properties. Adding 0.2 to 0.6% of Cecabase RT additives® in the bitumen improves the workability of an asphalt mix without changing the binder characteristics.

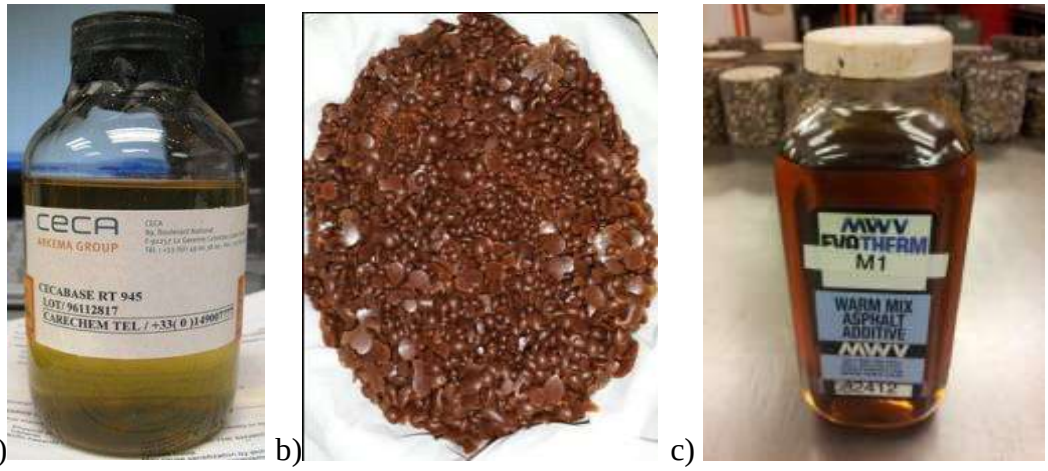

Figure 1. Chemical Additives types, a) Cecabase, b) Rediset, c) Evotherm

b. Rediset is a chemical product introduced in 2007 and is resulted by Akzo Nobel. It plays as a rheology modifier consists of organic additive and cationic surfactants. The surfactants enhance active adhesion between binder and wetting aggregate because it includes an active adhesion promoting. There is no water in this additive, and it reduces the viscosity of the binder [7]. This additive enables to reduce mixing compaction temperatures, it has very wide application such as polymer and rubber modified bitumen, it has an adhesion promoting property and an anti-oxidant effect [23]. It was available in a pastillated solid form; its melting point range between 80° and 95° C, and has a flashpoint of 253° C. Figure 1. (b) Shows Rediset WMX, it is produced to overcome the deficiencies of the available warm technologies that use water. It can solve problems due to exist of water in these mixes, which reduce stiffness, and uncertain low temperature properties in warm mix mixtures. It is a chemical product does not use water and it blended with binder before or during the mixing process so it does not require any modification in plant or it requires slight modification [13]. A 60°F in mixing and compaction temperatures can reduce when using this additive; to produce the warm mixture, a dosage of 1.5 to 2.0% by weight of bitumen can be used. Rediset™ WMX mixture usually does not require any additional ant-stripping agent in the mixture as this product provides anti-stripping properties. In USA, very few field trials of Rediset™ WMX have implemented. In 2009 in Texas, a project using Rediset has implemented.

c. Revix™ is a product used in WMA. In the USA, Mathy Technology and Engineering Services Inc. produced this product. [7] Stated that Revix™ technology will reduce mixing and compaction temperatures and do not relay on viscosity reduction or foaming. A 60 to 80 F reduction in mixing and compaction temperatures can be achieved when using Revix product in asphalt

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mixtures, this additive mixed with binder so it does not need any plant modification. In the USA, in 2007 a successful 9 test sections produced by Revix™ WMA [2].

d. Evotherm® is a chemical additive developed by MeadWestvaco in 2003 in the USA. Several types of Evotherm® were developed in the past decade. Evotherm® added to asphalt at a rate of 0.5% by weight of binder [6], it can be stored in silos at 176°F. A Dispersed Asphalt Technology (DAT) is a system with a unique chemistry used by evotherm for aggregate compatibility [24]. Figure 1. (c) exhibit the Evotherm product. DAT system is a non-proprietary technology, it is a chemical package consist of adhesion promoters, additives, emulsification agents in order to ensure mixture workability, coating and compaction. Temperature production of Evotherm® ranges between 185- 295°F. The chemistry of evotherm tries to improve adhesion between asphalt and aggregate, it is available with a high asphalt residue approximately 70%. A total tonnage of evotherm produced is over 17,000 tons in February 2008 [25]. To construct Evotherm® field sections, the product is used directly, there is no need to modify plant [26].

Evotherm™ is a product of a set of additives and is available in an emulsion form. The 3G Evotherm is the third generation of Evotherm, it is a water free technology, the asphalt binder is mixed with the product before it transport to plant. According to that, no modification changes required at the plant. Evotherm binder performance is the same or higher than HMA, it is possible to incorporate high percentage of RAP and allow lower production temperature without affecting workability, compaction and quality [27, 14, and 6]. According to reference [28], the thin water film that lay between asphalt droplets and aggregate will improves mix workability at temperatures below 195°F. Positive charge of cationic emulsifiers in the Evotherm will absorb into the aggregate surface and will enhance strong asphalt adhesion. Before pumping the Evotherm, the temperatures of oil-jacketed lines should reduce to 200°F to stop the emulsion from breaking in the lines [6].

Evotherm emulsion is mixed with asphalt binder during production. During mixing the emulsion with hot aggregate, water will release in the form of steam. MeadWestvaco identified that the evotherm product will decrease a 100°F in production temperatures. This will save in plant energy of about 55 percent; and will decrease in (CO_2 and SO_2) emissions by a 45%, a 60% reduction in NOx, and a 41% decrease in total organic material, [29].

3. CHEMICAL WMA MIXTURE PERFORMANCE

WMA technologies try to get the suitable mixture performance in term of the strength and durability, which is equivalent or better than HMA performance. For the purpose to evaluate the performance of WMA using Evotherm® technology, many laboratory and field tests have implemented. Some of these studies: McAsphalt Industries Limited examined Evotherm® conducted field studied in the following cities: Aurora, Calgary, Ramara Township, and all Ontario. In addition, Field tests happened in Fort Worth, San Antonio and Texas. At NCAT, an Evotherm® DAT was tested to examine the moisture susceptibility in WMA. The Virginia Department of Transportation (DOT) evaluates WMA projects using field study [30].

In another study, an optimum additive content was studied to find the best percent of Rediset in a high modulus asphalt mixture, the investigation was done to know the required percentage which reduces maximum production and compaction temperatures with maintaining good quality characteristics. From the results, it is apparent that the excess quantity of additive will play as a lubricant, the study concluded that the best percentage depends on the required temperature of WMA compaction [17].

Performance of WMA mixtures reported good results in stiffness, strength, and lower permanent deformation, so the performance gives good results at lower temperature except for the moisture susceptibility, so warm additives enhance the performance [31], [32].

3.1 Rheological tests

Few laboratory studies investigate the effect of rheological properties of modified asphalt binder with warm additives, so there is a need to evaluate chemical additives in WMA mixtures. The properties of modified binder had slightly varied due to the addition of liquid surfactant. The modified bitumen exhibit higher consistency and lower softening point than ordinary bitumen [31], [32]. Reference [33] reported that superior mechanical properties would be achieved if chemical additives were mixed through a wet process. Therefore, the WMA mixtures will be produced at lower temperatures than conventional mixtures and get better performance results, as also Reference [34] proved. The Authors showed that when a bitumen is modified with chemical WMA, an increase in fatigue resistance will happen at medium temperatures, because through rheological tests, a decrease in G*/sin (δ) values was apparent. In addition to that, the modified bitumen with chemical additive shows high surface free energy, thus will increase the adhesion and increase resistance to water action. A study of reference [5] which appeared that the viscosity, phase angle and shear modulus (G*) will not be changed, properties of bitumen remain practically unchanged.

Reference [35] investigated the various percent of Cecabase® RT on the performance of WMA mixtures, it is apparent that the aging factor of HMA is higher than WMA at 163°C, in addition to that, the aging factor of WMA does not affected by the dosage of Cecabase® RT and aging temperature.

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Reference [36] was presented in 2009 in the Journals of ASEFMA, evaluate two percentages of cecabase product (0.30 and 0.50%), it is apparent the viscosity of modified bitumen equal approximately the viscosity of reference bitumen.
In addition, Reference [37] examined the effect of surfactant products on WMA performance by using a simple binder and a compatibility test with an impact compactor. The results indicate these additives slightly adjust bitumen properties.
Reference [38] proved that the basic binder properties like penetration do not affected by incorporate surfactant agent like Rediset. In addition to that, Reference [17] also appear that bitumen viscosity do not affected by the additive. For the three types of binder, it proved that Rediset does not change the binder characteristics. Author Dwight Walker in another study proved that when 1.00% of Rediset applicated in bituminous mixtures, it proved the capability to reduce 50◦C of the mixing and compaction temperature [39].
Reference [40] study the effect of chemical tensoactive additives when mixed with asphalt binders on rheological properties, The chemical additives improve the rheological behavior of asphalt. In the frequency sweep test, the elastic response is improved at low frequencies and in MSCR test, they show a decrease in the accumulated strain.

3.2 Dynamic Modulus Test

Reference [35] evaluates the effect of dosage of Cecabase® RT and the production temperature on the |E*| of WMA, it is appeared that they do not affect |E*| of WMA, and all WMA mixtures showed lower values compared to HMA. The results of |E*| test indicate higher rutting potential for WMA with Cecabase® RT as compared to HMA mixture. A higher rutting resistant means the higher |E*| and better performance.
In NCHRP 9- 43, the Evotherm mixture was evaluated with an anti-strip additive, various anti-stripping dosages was incorporated into HMA and WMA mixtures. All the WMA mixes with evotherm 3G and HMA was tested in rutting and dynamic modulus tests. The results show that WMA has a lower dynamic modulus. Reference [41] stated that at all loading rates and temperatures, the dynamic modulus of the material would be decreased.

3.3 Moisture Susceptibility Test

Reference [6] state that the increase of moisture damage may occur in WMA mixtures due to lower compaction temperature. Most studies pointed that moisture damage is a concern in WMA technology [6], [25], [42] and [43] study the performance of Rediset and they showed it decrease the production and compaction temperatures between 35 and 40◦C. From their study, it is apparent that there is an increase in water sensitivity while other mechanical properties were equivalent to control mixture properties.
Reference [35] shows warm mix asphalt mixtures have lower tensile strength values than conventional HMA but most of these mixtures have TSR value equal the minimum value 80% (AASHTO T283 specification). The temperature and amount of Cecabase® product did not influence the tensile strength, which present that WMA produced with Cecabase® RT have lower fatigue resistance.
In order to examine the performance of WMA contains Evotherm® product, many studies have been implemented such as NCAT's, McAsphalt Industries Limited, and most of Ontario [44]. These studies show that evotherm reduce the air void content. Several Field studies were conducted to evaluate the effect of evotherm in WMA, one of these studies, like the virginia Department of Transportation (DOT) which evaluate three WMA projects, and other studies in Fort Worth, Texas and San Antonio [30].

3.4 Fatigue Test

Reference [35] states that WMA produced using Cecabase® RT have a longer fatigue life than the hot mixtures (HMA), and from the results, it observed that the dosage of Cecabase® RT and temperature does not affect fatigue life. Reference [45] study the behavior of WMA compared to HMA, the mixtures evaluated in tests of moisture sensitivity, fatigue life, and rutting resistance, the WMA mixtures reported equivalent performance while fatigue resistance was superior. In addition, WMA mixture produces less pollutant gases.
WMA with Evotherm 3G was tested at low temperature in DCT, it is observed that WMA at -2°C shows higher fracture energy than control mix (HMA). However, when testing mixes at -12 and -22, WMA shows lower peak load than control mixes (HMA) [41].

3.5 Rutting Test

WMA produced with chemical products were evaluated for rutting resistance. Reference [46] tested warm mixes with different additives, they reported that WMA mixes had similar rutting characteristics to HMA, which indicates that these products do not stiffen or soften the binder. Additionally, they recommend to use the virgin binder with higher G*/sin δ values to enhance the rutting resistance of WMA mixtures. Another study evaluates evotherm in WMA; it represented similar findings of decreased TSR values, rutting, and poorer performance in APA [47]. Reference [48] shows that HMA mixture record as 4.37 MPa and WMA

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record as 9.7MPa so that the warm mix asphalt had lower rutting potential. Reference [35] stated that causes of higher rutting at the early stage of pavement life is due to that WMA had lower aging factor than the control (HMA). In addition to that, the rutting potential of the WMA increase when lower mixing/ compacting temperatures and more Cecabase® RT were used.
The WMA with evotherm additives did not act as well as the HMA in rutting tests such as Hamburg wheel tracking tests and flow number testing [41].
Reference [49] state there is no affinity concerns when tested the WMA with Cecabase and Sasobit, and verify the Sasobit will affects the viscosity of bitumen. Regarding the performance of warm mixtures with this additive, the testing results show that the FN for WMA made with Ceabase® RT are lower than the control HMA. These results are in line with the findings from |E*| which WMA has a higher rutting potential. As mentioned previously, the reason behind was due to lesser aging of WMA during the production. The testing results also indicated that the FN slightly decreases when more Cecabase® RT is added. From the results of the APA test, WMA showed higher rutting depth than the HMA. In addition to that, WMA with 0.5% Cecabase® RT compacted at 100°C showed higher rutting and it consistent with the FN results. In addition, WMA show lower rutting depth when it made with 0.2% Cecabase® produced at 130°C. These results are equal to the FN results; WMA rutting potential is higher because of aging. In conclusion, WMA has worst rutting potential when lower mixing/ compacting temperatures and more Cecabase® RT are used.
Reference [41] showed that WMA behavior in rutting test did not perform as well as the HMA. The reduction in mixing and compaction temperatures will affect the cycles to 5% permanent deformation, however, this is the main effect in the statistical analysis of the cycles to 5% in permanent deformation test. As the aging period increase, the performance was increased in both the WMA and HMA mixes. WMA mixtures tested at 64° C in Hamburg Wheel-Tracking Testing showed worse performance than the HMA. From observation of the field data, no premature failure was present as the use of Warm Mix Asphalts.

4. CONCLUSIONS

In conclusion, this review shows current experience for application WMA with chemical products. There is a need to understand the WMA technology and how it is applied in pavement constructions. From results of various studies, it is obvious that WMA can reduce temperatures of mixing and compaction, improved compactability and reduced fuel consumption. There are similar results of mechanical performance with the control mix HMA, so the shear, fatigue and rutting characteristics were the same to HMA, except moisture damage presented bad behavior. The conclusion is that moisture condition is a concern in WMA technology.

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