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Potential Implementation of Warm Mix Asphalt (WMA) in Pavement Construction in the State of Qatar

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Abstract

Warm-mix asphalt (WMA) technology has been used in many countries around the world, in lieu of Hot Mixed Asphalt (HMA), due to its ability to allow significant reduction in the temperatures at which asphalt mixes are produced and placed, leading to performance that is comparable to HMA. The resultant is a reduction in the viscosity of the asphalt due to the incorporation of WMA technologies, which facilitates the coating of aggregates at lower temperatures (as much as 30°C less temperature) that translates to a reduction in energy consumption and greenhouse gas emissions, which in turn supports sustainable development. WMA technology has been successfully implemented in several countries across the globe, especially in Europe and USA, aiming at saving energy, reducing emissions throughout the production, and paving process, without compromising the in-service performance. This paper discusses how the long-term benefits and sustainability advantages of WMA technology can be harnessed to augment the Qatar roadmap and aspiration towards achieving 25% reduction in greenhouse gases (GHG) by 2030 and achieving Net Zero by 2050.

Keywords: Warm Mix Asphalt (WMA); Sustainability; Emission; Lower energy consumption; Lower emissions; Safer work conditions

1 Introduction

Hot Mix Asphalt Mixes (HMA) are the only asphalt mixes specified in the Qatar Construction Specification (QCS, 2014), and currently used for all the asphalt pavement layers construction in road projects in Qatar. Notwithstanding that, these mixes have demonstrated an acceptable level of short and long-term performance, in most cases; the process of production, placement and compaction of HMA is associated with high levels of greenhouse gas (GHG) emissions. This emanates from the substantial amount of energy or fuel consumption during the asphalt production and construction process, considering the high aggregate heating and plant mixing temperatures for the HMA which can reach up to 171°C for mixes produced with modified stiff binders. Shacat J. et al. (2022) estimated that CO_2 emission equivalency associated with the production of 421.9 million tons of asphalt mixes during 2019 in the USA was 21.7 MMT CO_2e with emission cradle-to-gate intensity of 51.4 Kg CO_2e per ton of asphalt mix.

One of the major challenges experienced in pavement construction using HMA is how to maintain adequate mix temperature during breakdown and intermediate compaction to achieve the required density and in place air voids for stiff HMA with polymer-modified binder (PMB) or Crumb Rubber Modified Binder (CRMB). Moreover, overheating of this binder during storage and mixing of the

HMA may result in premature aging and affect the binder properties and the overall pavement in-service performance.

Several alternative technologies have been considered to mitigate this negative environmental impact and high levels of GHG emission including the following, as indicated in (EAPA, 2014):

- Cold mixes produced using unheated aggregate and bitumen emulsion or foamed bitumen.
- Half-warm asphalt: produced between approximately 70°C and roughly 100°C.
- Warm mix asphalt: produced and mixed at temperatures roughly between 100°C and 150°C.

WMA technology was developed in the late 1990s and is considered an acceptable alternative to the HMA for its ability to allow the reduction of asphalt mixing and compaction temperature by as much as 20°C to 40 °C, leading to lower energy/fuel consumption, lower GHG emission, and in turn create and enable safer work conditions by reducing human exposure to fuel emissions, fumes, and odors, while achieving the required asphalt MAT density at lower compaction temperature.

This is even more critical when paving during cold weather with long haul distances when paving and compacting asphalt mixes with stiff modified binders such as CRMB or PMB. Details of these benefits are discussed in Section 3 of this paper. Warm Mix Asphalt mixes have been implemented successfully internationally for years, including in Europe, United States, and South Africa. Table 1 below, based on European Asphalt Pavement Association (EAPA) document, indicates considerable quantities of WMA have been produced during the period from 2013 to 2020 in these countries. The estimated total quantity of WMA produced in Europe alone during this period is approximately 56 million tons.

Table 1: WMA production period from 2013 to 2020 (Millions of Tons) (EAPA, 2020)

Country/Continent	2013	2014	2015	2016	2017	2018	2019	2020
Europe	3.401	7.33	6.833	7.014	7.241	7.099	8.961	8.678
USA*	69	103	109	106	133	143	150	169
Ontario Canada		0.75	0.9	0.75	No data	No data	No data	No data
South Africa	0.15	0.15	0.2	0.2	No data	No data	No data	No data

* The figures for USA include both WMA and HMA

2 WMA Asphalt Technologies

The production of WMA does not require a major modification of the conventional asphalt plant infrastructure and equipment. However, several proprietary techniques in the form of materials additives have been developed and incorporated into the asphalt mixing process, including foamed bitumen, chemicals, and organic additives, as shown in the following sections. These additives facilitate proper mixing and coating of the aggregates, as well as improve workability and the ultimate compaction of the asphalt mixes.

2.1 Organic Additives

Organic additives are mainly composed of wax or fatty acids amides which helps to reduce the viscosity of the binder. The type of wax must be carefully selected so that the melting point of the wax is higher than expected in-service temperatures (otherwise permanent deformation of the asphalt layer may occur). The following are examples of organic additives used in the industry:

- **Sasobit** is a form of Fischer-Tropsch synthetic which can be added to the mix by blending with the binder in a binder tank in the form of flakes in a molten state or by pneumatically blowing it into the plant mixing drum through a modified feed line in the form of prills. The mixing dosage of Sasobit is between 1% and 2.5% and can help reduce plant-mixing temperatures between 20ºC and 30˚C (D'Angelo J, et. al, 2008).

- **Asphaltan-B** is a refined Montan wax. These materials can be either blended in the bitumen tank at 2.5% of the binder weight or added to the mix in the plant pugmill and can help decrease the production temperature between 20ºC and 30 ˚C (D'Angelo, et. al, 2008).

2.2 Chemical Additives

Chemical Additives are mainly considered to improve workability, compatibility and aggregate coating of the mix at a lower mixing temperature, Evotherm™ DAT is an example of the chemical additives, which is delivered in a dispersed emulsion form. The manufacturer recommends the addition of Evotherm DAT at 0.25 to 0.75 % by weight of asphalt cement. Evotherm can be pumped to the plant with a minimum mixing temperature of 104ºC and compaction temperature of minimum 66ºC. (Aschenbrener, et. al, 2011) and (D'Angelo, et al., 2008).

2.3 Foaming Techniques

The main concept of the foaming technique is to introduce a small and controlled amount of water to the bitumen, which increases the bitumen volume and reduces viscosity and temperature. Additionally, expansion of bitumen will allow proper coating of aggregates at lower mixing temperatures. The foaming is done by adding water directly through injecting nozzles such as WAM-FOAM technique or through foaming agent/additive such as Synthetic Zeolite:

- **Synthetic Zeolites** "are framework silicates with large empty spaces in their structures that allow the presence of large cations, such as sodium and calcium. They also allow the presence of large cation groups (positive ions), such as water molecules. Zeolites contain approximately 20% of water, the material is added to the mixture by 0.3% of the weight and releases small amount of water when exposed to heat, creating a controlled foaming effect, which slightly increases binder volume and reduces viscosity. Examples of Synthetic Zeolite are Alpha-min and Advera, which have been reported to reduce the production temperatures by up to 30ºC. (D'Angelo J, et. al, 2008).

- **WAM-FOAM®** is a process and not an additive; initially developed by Shell in cooperation with Kolo Veidekke in Norway in the late 1990s (D'Angelo, et. al, 2008). The process includes blending of two grades of binder, one nominally soft binder (viscosity grade 1500 Centistoke at 60ºC) and hard binder (about PG58/64-22).

3 Benefits of WMA

3.1 Energy savings and Reduction in Emissions of Greenhouse Gases

One of the crucial benefits of implementing WMA is its positive impact on the environment, reduction in GHG emissions, achieving sustainability advantages, fuel/energy savings, and is considered a step-in alignment with the Qatar roadmap towards achieving the target of 25% reduction in GHG by 2030 and reaching to Net Zero by 2050. Several technical references indicated considerable reduction in asphalt production-and compaction-temperatures of between 20ºC and 30ºC, fuel savings of between 20% and 35%. Reduction of plant gases, including carbon dioxide emissions, between 15% and 60% have been achieved by implementing WMA as follows:

1. D'Angelo J, et al. (2008) indicated that fuel savings with WMA typically range from 20% to 35%. Additionally, they indicated significant reduction in plant stack gas emissions reported

in several European countries. For example reduction in Carbon dioxide CO_2 (15%-40%), sulfur dioxide SO_2 (18%-35) and carbon monoxide CO (10%-30%). The table below lists the reduction in plant stack emissions in different countries.

Table 2: Reduction in Plant Gas Emissions (D'Angelo J, et al., 2008)

Emission	Norway	Italy	Netherlands	France
CO_2	31.5	30-40	15-30	23
SO_2	NA	35	NA	18
CO	28.5	10 to 30	NA	NA

2. Milad, et al. (2022) summarized the reduction in gas emissions using different warm mix additives, processes and techniques based on the review of several references. For example, the highest reduction in carbon dioxide CO_2 was between 17.35% and 60% when using chemical additive (Evotherm) and a reduction of 63% in carbon monoxide CO. Table 3 below summarizes the reduction in gas emission percentages using different warm mix techniques and additives as indicated:

Table 3: Reduction in gas emissions using different WMA additives (Milad, et al., 2022)

Additive/process	CO_2	CO	SO_2	NO_x	VOC
Evotherm (Chemical additive)	17.35%- 60%	19.51-63%	75.2%	20-72.6%	-
Synthetic Zeolites (Foaming)	15.8%	18.4%	9.67%	16.5%	-
WAM-FOAM	31.4	28.5	-	61.5	-
Alpha-min		62.0	83.3	30.8	62.8
Sasobit	-	63.2	83.3	21.2	51.3

3. NCHRP report 779 (2014) summarizes the fuel consumption and stack gas emission measurements for 5 projects in the USA comparing HMA and WMA mixes. The results show an average reduction in the mix, a temperature of 27^{o} C and fuel saving of 22%. It also shows reduction of carbon dioxide (CO_2) emissions because of lower fuel usage.
4. In NAPA report SP106, Shacat, et al. (2022) suggested the fuel saving to be 1,000 Btu/°F/ton of the asphalt mix.

3.2 Approximate Potential Energy Saving and Gases Emission Reduction in Qatar

The amount of energy savings and reduction in GHG emissions depend on several factors including the kind of fuel (natural gas or diesel) used, aggregate types, moisture content (wet aggregates required more heating), production rate, technique used, binder type and weather condition, and should be measured and calculated based on the overall Life Cycle Inventory.

Therefore, further field trials and investigations need to be performed to evaluate the energy fuel saving and reduction in GHG emissions in Qatar in Warm Mix asphalt over Hot Mix asphalt.

However, a very rough estimate of the CO_2e emission reduction forecast and energy saving can be proposed based on several assumptions including the following:

- The approximate forecast total asphalt quantity for PWA Road Projects Department (RPD) for the period from 2023 to 2026 is approximately 7,500,000 tons.
- Considering using WMA in the asphalt base course layers for only 20 % of the total forecast quantity.

- Assuming the same CO_2e equivalent emission intensity of 51.4 Kg CO_2e/ton for material production and transportation estimated based on NAPA SIP-106 report, and based on several technical references, it can be assumed that the average reduction in CO_2e is approximately 25% when using WMA.
- Assume 20°C (68 ° F) reduction in production temperature and energy saving estimated based on the formula suggested in NAPA SIP 106, i.e. 1,000 Btu/°F/ton. This varies depending on several factors such aggregates' moisture and bitumen type, technique used, plant operations and fuel type.

Based on the above assumptions (1-3), the reduction in CO_2e emission can be estimated to be approximately 19,300 metric tons, which is equivalent to approximately 1390 passengers' vehicles, on the consideration that a typical passenger vehicle emits about 4.6 metric tons of carbon dioxide per year as per the US Environmental Protection Agency (EPA). Additionally, based on assumptions 1 and 4 above, the energy saving can be estimated to be approximately 102,000 MMBtu.

3.3 Safer Working Condition

Maintaining safe working conditions and eliminating work-related hazards and injury/illness is a major goal for all entities involved in the pavement construction. The implementation of WMA can help in achieving this target considering the following:

- The lower mixing- and paving- temperatures minimize fume and odor emissions and create cooler working conditions for the asphalt workers. per EAPA, the release of fumes is reduced by around 50% for every 12°C reduction in temperature. (EAPA, 2014).
- Reduction in the exposure of laborers to higher temperatures and fumes that cause burns, irritation, and associated with potential long-term illnesses such as cancer.
- More comfortable work conditions, which will have positive impact on the productivity.

3.4 Plant Mixing and Paving Operations Benefits

Using WMA techniques has multiple benefits on mixing and paving operations; however, these techniques and mix designs should be carefully controlled, implemented and tested to achieve the required quality and performance of the pavement layer equivalent to HMA. Below is a list of major benefits as indicated by D'Angelo J, et al. (2008) and (EAPA, 2014).

- Reduction in viscosity to ensure coating at lower mixing temperature, reduce compaction effort and compact the mix at lower temperatures.
- Decrease in binder aging.
- Increase the haul distance while maintaining the mix workability.
- Reduction in thermal segregation, improved fatigue performance.
- Ability to increase the RAP percentage and use of CRMB to improve sustainability.
- Place thicker lifts and open to traffic in a short period.

4 WMA Materials Selections, Production, Construction and Perforamance Evaluation

The mix design of the WMA can follow the same known procedures of HMA. However the Superpave mix design and volumetric analysis per AASHTO R 35 (2022) is recommended to be used as a mix design procedure. The objective of the WMA is to produce sustainable and environmentally friendly mixes by reducing the mixing temperature and binder viscosity at the same time while achieving strength, durability, and performance similar to of the HMA. To achieve this, major steps need to be considered and further investigated including materials selection, WMA mix design process, production, construction, and performance evaluation.

4.1 WMA Materials Selection

Table 4 summarizes some of the WMA materials selection requirements and findings on WMA based on several references including NCHRP 691(2011), NCHRP 779 (2014) and (AASHTO R 35, 2022):

Table 4: WMA Materials Selection Requirements and Findings

Steps	Requirements and Findings
Mix Design	• The recommended mix design method is Superpave based on AASHTO R35.
Binder Grade Selection	• The same binder grade for HMA can be used; the performance grade binder selection is based on AASHTO M 323 considering environment and traffic loading. • Reduced mixing temperature may produce less aged binder which may result in rutting; however, in many cases stiffer high-temperature binder grade may be needed for satisfactory rutting performance (NCHRP 691, 2011).
Aggregates Properties and Gradation	• No major changes from HMA.
Reclaimed Asphalt Pavement (RAP)	• The RAP and new binders can mix at the lower temperatures used in WMA provided the mixture remains at elevated temperatures for a sufficient time. To ensure good mixing of RAP and new binders, the planned field compaction temperature for WMA exceeds the high-temperature grade of the RAP binder (NCHRP 691, 2011). • Small percentage of RAP to WMA can greatly help in drying the virgin aggregate. • RAP may improve rutting resistance of WMA mixes. • The performance of WMA mixes containing RAP is affected by the degree of mixing between the RAP binder and the new binder and the WMA technology used.
Anti-strip agent	• Essential to improve WMA moisture sensitivity.

4.2 WMA Production and Construction

Table 5 summarizes some of the materials production, construction steps requirements and recommendations based on several references including (NCHRP 691, 2011), (NCHRP 779, 2014) and (AASHTO R 35, 2022).

Table 5: Summary of some of the materials production, construction steps requirements

Steps	Requirements and Recommendation
Mixing Temperature	20-30ºC lower than Hot Mix Asphalt (HMA). The minimum mixing temperature will depend on WMA additive technique, binder grade, level of aggregates coating, moisture condition of the aggregates and performance of the mix (moisture sensitivity and rutting).
Aggregates Moisture Content	Moisture content of aggregates in the stockpiles should be minimized.
Binder Absorption	Based on NCHRP 691 (2011) volumetric properties of WMA mixes with binder absorption ≤ 1% is the same as HMA. On average binder absorption for WMA is less by 0.11% than corresponding HMA, however the reduction depends on the WMA additive or technique and aggregates moisture.
Aggregates Coating	• Testing done as per AASHTO TP195. • Mixing time should be verified to ensure proper coating at low mixing temperature. • ≥95% of the coarse aggregates should be fully coated (AASHTO R035).
Plant Equipment and Operations	Ensure proper plant maintenance for example the following: • Dryer and lifters maintained and burner proper tuning. • Keeping baghouse temperatures high enough above due point to prevent condensation.

	• Mitigate air leak. • Inspect the fines return lines more frequently to ensure that no build-up occurs due to moisture. • Control and reduce aggregates stockpiles moisture to reduce energy required for drying.
Mix Workability/COmpatibility	• Compaction temperature could not evaluated based on binder viscosity. • The recommended compaction can be determined as specified in AASHTO R 35, which specified based on the gyration ratio of 1.25, which is the ratio between the number of gyrations to reach the density (92%) at planned compaction temperature and the number of gyrations to reach the 92% density at planned compaction temperature minus 30ºC. • AASHTO R35 recommends that the planned field compaction temperature for WMA should exceed the high temperature grade of the RAP binder when using RAP.
WMA Construction equipment and operations	Similar to HMA except WMA has a lower compaction temperature and less compaction effort. Additionally, the following should be considered: • High pre-computation by paver screed (i.e. tampers and vibrators) • Perform a test section to establish the compaction procedure and rolling pattern for each mix type

4.3 WMA Performance Evaluation

Table 6 summarizes some of the performance tests, significance, requirements, criteria and related findings of using different materials and methods on the performance of the WMA based on several references including (NCHRP 691, 2011, (NCHRP 779, 2014) , (AASHTO R 35) and (NCHRP 843, 2017):

Table 6: Performance Evaluation Requirements, Criteria and Findings Summary

Performance Evaluation	Requirements and Criteria	Major Technical Findings
Mix Moisture Sensitivity	Major criteria to evaluate the Warm Asphalt mix durability and resistance to moisture damage. Stipulated in AASHTO R 35 and tested in accordance with AASHTO T283. The minimum recommended tensile strength ratio is 0.80	**NCHRP report 691 (Project 9-43A)** Anti-strip agent may be required to improve the moisture sensitivity. WMA technologies with anti-strip additives improved the tensile strength ratio (TSR) of some of the mixtures. The tensile strength ratio remained the same or improved in 67 per cent of the mixtures.
Mix Rutting Susceptibility	Evaluate WMA mix’s ability to resist permanent deformation and rutting **NCHRP report 691 (Project 9-43A):** Rutting resistance is evaluated using Flow number test in AASHTO TP 79. **NCHRP report 843 (Project 9-43A)-**In the report, the rutting is evaluated using the Hamburg Wheel Tracking Test (HWTT) per AASHTO T324 and stipulated different scenarios for the rutting ranking based on rutting resistance index (RRI) and rut depth: Good: Rut depth 2.54 mm at 20000 cycles, RRI=18000, Average: Rut depth 12.5 mm at 20000 cycles, RRI=10,000 and Poor: Rut depth 12.5mm at 10,000 cycles, RRI=5000.	**NCHRP report 843 (Project 9-43A)** The report indicated equal or better Rutting Resistance for HMA and WMA mixes (using Evotherm, Sasobit and foaming) for one of the projects. **NCHRP report 779 (Project 9-47A)** The report indicated that the rut depth for WMA sections were slightly higher than of the HMA mainly for the traffic exceeding 3.5 million ESALs. Also, WMA mixes produced using foaming technique showed better rutting performance than with additives.
Fatigue Performance	Not a major concern for WMA mixes and may improve by implementing Warm Mix asphalt except for some organic additives.	**NCHRP report 843 (Project 9-49)** The reports show that HMA and WMA pavement exhibited comparable wheel path longitudinal cracking. The three WMA techniques discussed

		have similar resistance to wheel-path longitudinal cracking in relatively short service periods. However, in the longer term, the effect of aging on organic WMA technology is more prominent. The chemical and foaming WMA pavements appear to have better resistance to longitudinal cracking than the organic WMA pavements in the long term.

4.4 Proposed Potential Implementation Plan of WMA in Qatar

Notwithstanding the significant experience in implementing different types and techniques of the WMA worldwide, the experience of WMA in Qatar and GCC is still very limited. Previous studies on WMA and a trial done using WMA technology on a temporary traffic diversion on one expressway project in Qatar during 2014 produced no documented data to evaluate the short-and long-term performance of the WMA pavement section.

Further steps are required before the WMA can be fully incorporated in Qatar road projects which will consider also local materials and climatic conditions. These steps can be summarized as follows:

a. Perform several presentations and training to stakeholders involved in the pavement industry in Qatar, explaining the technology, implementation techniques, requirements, and overall benefits of WMA.

b. Compile information on the materials locally available.

c. Compile data on plants and industry-readiness to adopt WMA.

d. Conduct multiple trials to evaluate the performance of the WMA compared to HMA using several local binder grades and types (Neat, PMB and CRMB), using RAP, using different mixing plant fuel types and different mix types. The evaluation will cover materials selection, mix design process, materials production, construction practices, carbon emissions measurement (i.e., using gas meter reading from plant stacks), fuel consumption, cost per ton, performance testing (e.g. Moisture and Rutting Susceptibility).

e. The trials may be performed incorporating different WMA techniques; organic additives blended with the binder can be considered as a starting point.

f. Develop or update the current specifications and guidelines based on the international standards and local materials properties to cover WMA Technologies.

g. Perform a life-cycle cost analysis of WMA taking into consideration the commercial impact of its implementation considering fuel saving and cost of additives.

5 Conclusion and Recommendations

The benefits of using WMA are well-documented worldwide with the major driver for its implementation in Qatar being the reduction of paving costs, improvement of asphalt compaction, allowing asphalt mix to be hauled longer distances, and improvement of the working conditions by reducing exposure to fuel emissions, fumes, and odors. The following summarizes the salient points and recommendations of the papers:

1. WMA is an acceptable alternative to the HMA since it cuts down asphalt mixing-and compaction- temperatures by 20^{o}C to 30^{o}C and enables fuel savings, lower gas emissions, and a safer working environment.

2. In general, WMA can achieve comparable performance to HMA, in terms of aging and fatigue cracking. However, rutting performance is limited to a lower traffic load, and anti-strip may be required to improve moisture sensitivity when modified binders are used for the asphalt mix.
3. Customized WMA specifications need to be developed for Qatar's local conditions after successful implementation and monitoring of pilot projects.
4. The WMA mix design, materials selections, production and construction methods should be developed and incorporated into the next revision of the QCS.
5. Local materials, recycled asphalt pavement (RAP) and Crumb Rubber Modified Binders (CRMB) should be considered in the implementation of WMA in Qatar, to enhance pavement performance in addition to the sustainability and environmental benefits.

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