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Investigating the Potential for Introduction of Warm Mix Asphalt in Kuwait Using the Volcanic Ash

H. Al-Baghli, F. Al-Asfour

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***Abstract*—**The current applied asphalt technology for Kuwait roads pavement infrastructure is the hot mix asphalt (HMA) pavement, including both pen grade and polymer modified bitumen (PMBs), that is produced and compacted at high temperature levels ranging from 150 to 180 °C. There are no current specifications for warm and cold mix asphalts in Kuwait's Ministry of Public Works (MPW) asphalt standard and specifications. The process of the conventional HMA is energy intensive and directly responsible for the emission of greenhouse gases and other environmental hazards into the atmosphere leading to significant environmental impacts and raising health risk to labors at site. Warm mix asphalt (WMA) technology, a sustainable alternative preferred in multiple countries, has many environmental advantages because it requires lower production temperatures than HMA by 20 to 40 °C. The reduction of temperatures achieved by WMA originates from multiple technologies including foaming and chemical or organic additives that aim to reduce bitumen and improve mix workability. This paper presents a literature review of WMA technologies and techniques followed by an experimental study aiming to compare the results of produced WMA samples, using a water containing additive (foaming process), at different compaction temperatures with the HMA control volumetric properties mix designed in accordance to the new MPW's specifications and guidelines**.**

***Keywords*—**Warm-mix asphalt, water-bearing additives, foaming-based process, chemical additives, organic additives.

I. Introduction

ASPHALT pavement is a combination of aggregates containing stone, sand and gravel held together by a product of crude oil called the asphalt cement or the bitumen binder. The ingredients are mixed together to obtain the desirable volumetric and mechanical properties. The manufacturing and preparation of asphalt mixes take place in asphalt production plants. During the production of asphalt, the bitumen binder is heated and mixed with the aggregate, and then the mix is transported to the construction site to be spread and compacted at high temperatures. There are different types of asphalt mixes, HMA where the manufacturing temperature is between 190 °C-150 °C), WMA (140 °C-100 °C) and Half WMA (100 °C-60 °C) and cold mixes (40 °C-0 °C). The commonly used asphalt type worldwide is the HMA [1].

Kuwait highways and roads are mainly covered with asphalt pavements using the HMA technology. HMA technology refers to an asphalt mixture comprising mineral aggregates and bitumen binder that are manufactured at high temperature levels ranging from 150-180 °C [1]. The production process of HMA requires high energy consumption that significantly contributes in releasing greenhouse gases such as CO_2 and other chemical pollutants that impact the atmosphere and air quality [2]. Other health risks related to the manufacturing of HMA includes the generation of odors and fumes in around the manufacturing or project activity areas indirectly effecting employees and adjacent neighborhoods [3].

There are alternative technologies and applications developed by the transportation industry to overcome the environmental and performance challenges of the HMA production. They allow asphalt mixtures to maintain their optimal mechanical and physical properties. One of these technologies is the WMA application, which includes multiple techniques to produce including the foaming process and the process of adding organic and chemical additives to the asphalt mixture during the production phase to lower the compaction temperature [4]. The purpose of this research is to investigate the WMA technologies, performance and benefits with conducting an experimental study on a locally produced WMA samples using a water-bearing additive, zeolite. The experiment will allow us to evaluate and assess the effectiveness and the performance of WMA using a locally sourced volcanic ash at 3% and 6% content which will create the foaming of the bitumen.

II. WMA Technology

The reduction of WMA mixing temperature (20 °C-40 °C below HMA mixing temperature) could be achieved by utilizing various technologies and processes. These technologies involve the addition of organic additives, chemical additives, and water-containing foaming process. They share the main target, reducing the binder viscosity and enhancing mixes workability at lower temperature [5].

A. Foaming Based Process

The foaming-based process refers to the injection of small amount of water to the binder or during the WMA mixing process. The temperature of the WMA mixture evaporates the amount of added water and entraps the created steam into the hot binder [6]. This generates a volume of bubbles expanding through the binder and turning it into a foamed form referred to as foamed bitumen [7]. The volume of the binder increases, as a result, lowering the blend viscosity with a corresponding enhancement to the blend workability [8]. The expansion of the binder resulting from a lower viscosity is induced by the addition of water and the mixing temperature. A controlled

H. Al-Baghli & F. Al-Asfour are with the Construction and Building Materials Program at the Kuwait Institute for Scientific Research, Safat 13109 Kuwait (fax: +965 24989099; e-mail: hbaghli@kisr.edu.kw; fasfour@kisr.edu.kw).

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amount of water added to the binder is preferred to create the foaming effect and eliminate the stripping problems in WMA mix caused by adding more water [9]. Some WMA producers use anti-stripping additives which increase the adhesion between the asphalt binder and aggregates [10]. The foaming-based process, therefore, can achieve a reduction of bitumen viscosity allowing an improved coating of WMA at lower temperatures with the consideration of adding enough amount of water to cause the optimum foaming effect.

The foaming-based process is categorized into two technologies: water-based technology and water-containing technology. A direct controlled addition of pressurized cold water to the hot binder via special designed foaming nozzles is referred as the water-based technology. This method enables the increase of volume binder effectively to improve coating al lower temperatures of 20 °C to 40 °C. There are various water-based foaming systems that are currently in use at HMA production plants such as Maxam AQUABlack, Terex WMA, StanSteel Accu-Shear, Gencor Green Machine and Astec Double Barrel Green [11].

The water-containing technology generates the foaming effect indirectly to the binder via minerals and materials which hold water in their structure such as natural and synthetic zeolite [12]. The next section is a literature review on zeolites which were used in this study as a water-bearing additive.

One of the limitations of foaming process is time. Time in this process is a variable that should be minimized and controlled. The time between manufacturing till compaction is should be shortened to have the desirable workability and performance [11].

B. Zeolites

Zeolites are a group of micro porous aluminosilicate minerals with crystalline structure containing water particles. Zeolites can be found naturally or synthetically. Synthetic zeolites are artificial made from the chemical reagents, mineral materials or some waste by-products of industry such as fly ash [6]. It can hold water by its mass about 18-22% [13]. When zeolite is subjected to heat, water particles are released without changing the volume of the crystalline structure [14]. The heat also vaporizes the water allowing the bitumen to foam.

The addition of zeolite to bitumen has shown a change in the softening point of bitumen. The softening point is defined as the temperature where the bituminous material softens and becomes less viscous. An increase in the content of zeolite will enable the increase of bitumen softening point as well [14]. This means that a more workable asphalt mix is achieved but with lower temperature.

Marinković et al. investigated the optimal content of synthetic zeolite that is required to achieve the reduction of mixing and compaction temperatures of the asphalt mixture which is observed that 5% content of zeolite can achieve the minimal temperature reduction [14].

Studies showed that after the addition of zeolite to asphalt mix conditioning is required to improve the compactibility. WMA mixtures for both volumetric mixture design and mechanical property testing should be conditioned for two hours at the planned compacted temperature according to National Cooperative Highway Research Program (NCHRP) [15]; noting that, water released from zeolite do not extend mixing time. Woszuk and Franus prepared different sample mixes that contain different types and doses of zeolite [12]. Marshal compacted samples showed higher air voids in comparison with reference mixes [12]. However, after one hour of conditioning compactibility and test results showed improvement [12]. The condition time is very dependent on the zeolite structure.

C. Organic Additives

The addition of waxes to the asphalt mix is another technique that achieves reduction to the temperature of the asphalt mixture. As the temperature increases above the melting point of the additive, the viscosity of the mix will decrease. Solidification of the melted waxes occurs shortly during the cooling process of the mixture distributing its particles [15]. As a result, the binder stiffness will increase improving the mixture deformation resistance. The dosage of waxes added varies between 2-4% by the total mass of mix. It has been proven that waxes are able to enhance the binder properties because of their molecular similarity. These types of additives have a very promising future since recent studies are showing desirable results [11]. The wax products that are currently at use to produce WMA are Asphaltan-B, Cecabase RT, Ecoflex, isomerised paraffin, Licomont BS 100, Sasobit, Shell Thiopave and Sübit [7].

D. Chemical Additives

Chemical additives in WMA technology refer to liquid surfactants and polymers. They tend to improve the bitumen coating of the aggregate, mixture workability, compaction and adhesion of the bitumen and aggregates [16]. The content of additives used in bitumen to reduce the mixture temperature depends on the product type used. The products currently in use as chemical additive WMA industry are HyperTherm, Qualitherm, Rediset WMX, and REVIX [8].

III. MATERIALS USED AND SAMPLE PREPARATION

The experimental design detailed in this study included the use of one water-containing additive (zeolite; volcanic ash), one PMB (PG 76H-10) from the Kuwait Company for Process Plant Construction & Contracting (KCPC) modified with polymer Lotader and locally sourced Gabbro coarse and fine aggregates and filler. The specific gravity of the Gabbro aggregates according to the new Kuwait MPW standards and specifications for use in asphalt mixtures is shown in Table I [17]. Gabbro aggregate is intrusive mafic igneous rocks. In addition, one polymer modified binder grade was used according to the new MPW specifications shown in Table I. PG 76H-10 is the bitumen grade that was used in WMA mixtures with zeolite (volcanic ash) and HMA control mixture. The symbol H is a reference to heavy traffic i.e. 10 to 30 million equivalent single axle load (ESALs) [17].

TABLE I
SPECIFIC GRAVITY DETERMINATIONS ON THE USED MATERIALS

Sample Type	Specific Gravity
Gabbro aggregate	2.82
PMB 76H-10	1.037

The zeolite used in this study is a volcanic ash that is sourced from deposits located in the Kingdom of Saudi Arabia. Volcanic ash is composed of pulverized rock, minerals and volcanic glass created during volcanic eruptions. There are yet no specifications for the use of zeolite in the asphalt mixture. The selected particle size of volcanic ash used in this study was between 4.75 mm-1.18 mm to substitute the original Gabbro aggregate of equivalent size. The volcanic ash size within the mix design gradation is considered as a fine aggregate fraction. Due to its finesse the bulk density test was not applicable. The physical properties of the volcanic ash conducted in accordance to ASTM standard for relative density are shown in Table II [18].

TABLE II
PROPERTIES OF THE ZEOLITE

Zeolite	Volcanic Ash
Grain Size (mm)	1.18-4.75
Density (g/cm^3)	2.667
Absorption (%)	12.32
Aggregate Crushing Value (%)	15.77

A type III asphalt mixture was used in the study. The distribution of aggregate size can be observed in Fig. 1. The Marshall method of mix design was used to determine the asphalt mixture design by assessing and evaluating the bulk density, air voids (%), voids in mineral aggregates (VMA) (%), voids filled with bitumen (VFB) (%), flow (0.25 mm) and stability (N) in accordance to the new Kuwait MPW specifications. Marshall Hammer was used to compact the specimens at 75 blows per side. The mixing and compaction temperature of the HMA reference mixture were 175 °C and 150 °C. The obtained optimal binder content for the HMA reference mixture was 4% by the total weight of the mixture. The optimal binder content of 4% was used in the production process of all WMA asphalt mixtures in this study.

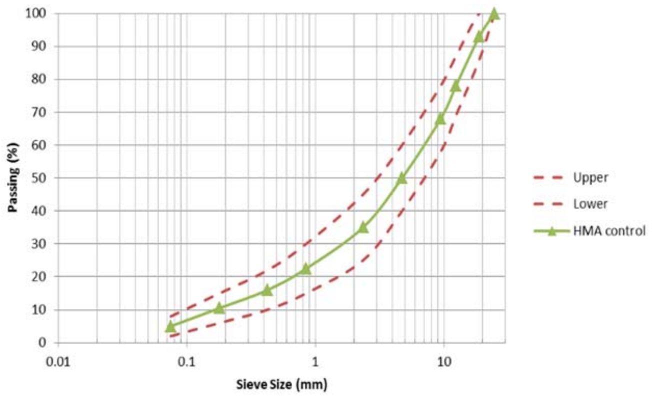

Fig. 1 The distribution of aggregate size

For WMA sample preparations, the volcanic ash was soaked in water for 24 hours before the mixing of the samples started. Two groups of four samples of WMA mixtures were produced at 3% and 6% volcanic ash content by weight of total mix in order to achieve the foaming effect of bitumen. Four samples were produced for the 3% and 6% zeolite content of the WMA mix. The aggregates and PMB were heated at a temperature of 165 °C prior to adding the zeolite to the mix.

The variability of compaction temperature with respect to the addition of saturated volcanic ash was evaluated and assessed. Each sample from every group was compacted at a different temperature. The compaction temperature of samples no. 1, 2, 3 and 4 of the 3% zeolite contents were 125, 130, 137 and 150 °C respectively. For the 6% zeolite content group, the compaction temperature of samples no. 1, 2, 3 and 4 were 100, 115, 116 and 150 °C respectively whereas, the HMA mix samples were compacted at 150 °C.

IV. RESULTS AND ANALYSIS

A. *Compacted Bulk Density*

The results of the compacted bulk density shown in Fig. 2 indicate that the density of the WMA group of 3% zeolite content group samples exceed that of the WMA group of 6% zeolite content group samples. This can be illustrated that the 6% mixture is less workable than the 3% due to a sharp increase of the bitumen viscosity caused by the desired foaming process. The effect of density on voids is approximately 2% extra voids as will be described in the following section. Observing each group separately, the compaction temperature did not affect the values of density significantly.

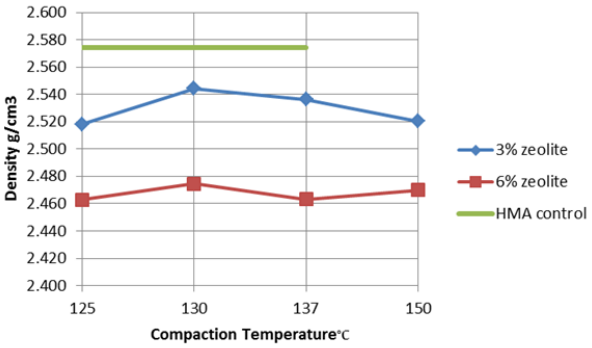

Fig. 2 Bulk density versus compaction temperature for 6% and 3% zeolite content

B. *Air Voids*

The results of air voids shown in Fig. 3 indicate that the total volume of voids between the coated aggregates particles in the WMA group of 6% zeolite content are higher than air voids of the WMA group of 3% zeolite content. The main reason for this is that the lower compaction temperature of the 6% zeolite content influenced the workability of asphalt mixtures. The 6% and 3% zeolite content groups satisfied the air voids requirements of the MPW's new specifications shown in Table III whereas, the HMA control mix result became slightly under the requirement the MPW's

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specifications. The volume of air in the asphalt mixture affects the long-term performance of asphalt where low or high air voids can cause pavement distresses such as raveling, rutting, decreased stiffness, moisture damage and decreased durability [19]. The allowable air voids for wearing course are in the range 5% to 8% range for Kuwait specifications [17].

TABLE III
KUWAIT MPW MARSHALL DESIGN CRITERIA FOR TYPE III WEARING COURSE ASPHALT CONCRETE MIX

	Min.	Max.
No. of compaction blows each end of specimen		75
Stability (N)	11500	-
Flow (0.25mm)	2	4
VMA (%)	14	-
Air Voids (%)	5	8
Aggregate VFB (%)	50	75

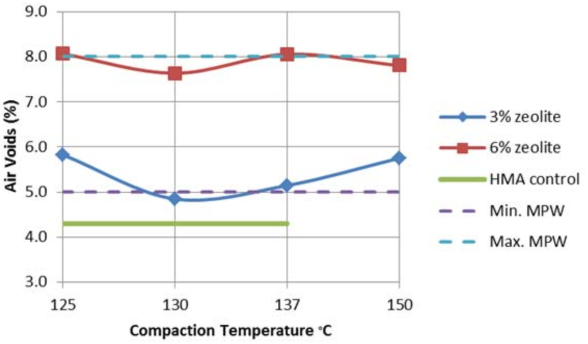

Fig. 3 Air voids versus compaction temperature for 6% and 3% zeolite content

C. Voids in Mineral Aggregates

The results of VMA (%) results shown in Fig. 4 indicate that the volume of void space between the aggregate particles in the WMA group samples of 6% zeolite content (ranging from 15.6% to16%) is higher than those from the WMA group samples of 3% zeolite content group (ranging from 13.3% to 14.2%) influenced by the absorption of the zeolite. The durability of asphalt content is affected by a low VMA where voids are insufficient to allow enough bitumen adequately coat the aggregates particle [20]. The WMA group samples of 6% zeolite content surpass the 14% minimum requirement of VMA specified by the new MPW specifications [17]. Also, it is noted that samples 1 (125 °C) and 5 (150 °C) of the 3% zeolite contents did satisfy the requirement of the MPW specifications.

D. Voids Filled with Bitumen

The results of VFB shown in Fig. 5 indicate that the volume of effective asphalt binder occupying the aggregate particles in the WMA group of 6% zeolite content samples are less than that of the WMA group 3% zeolite content samples and the HMA control mix. However, both WMA groups of 6% and 3% zeolite content along with the HMA control mix satisfied the requirement of the MPW specification [17]. The allowable VFB for the wearing course is in the range 50% to 75% range for Kuwait specifications. The VFB results of WMA group of 3% zeolite content at different compaction temperature were at mid-range of the specification requirement. The WMA group with 6% zeolite content VFB results was at the lower end of the specification requirement. The compaction temperature did not significantly affect the values of VFB in the sample's groups of 3% and 6% zeolite content.

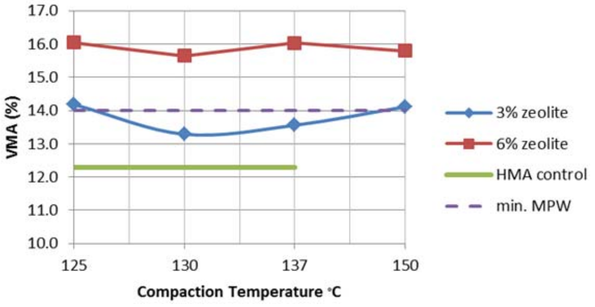

Fig. 4 Flow versus compaction temperature for 6% and 3% zeolite content

E. Stability

The results of Marshall stability shown in Fig. 6 indicates that the stability of the WMA groups of 3% and 6% zeolite content satisfies the minimum requirement of the MPW's specifications, irrespective of at what temperature the sample was compacted. The minimum stability required by the MPW specification is 11500N. The lowest stability recorded was 13435N (sample#1) which contained of 6% zeolite and was compacted at a temperature of 100 °C. The Marshall stability is used to determine the shear resistance of the asphalt mixture during deformation.

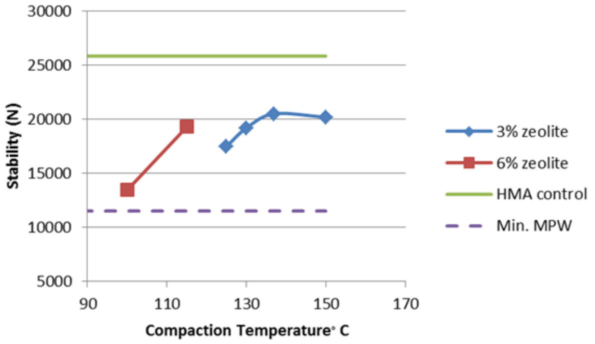

Fig. 5 Marshall Stability versus compaction temperature for 6% and 3% zeolite content

F. Flow

The results of flow (mm) shown in Fig. 6 indicate that only sample #1 (compacted at 100 °C) and sample #4 (compacted at 150 °C) from the WMA group of 6% zeolite content in addition to sample#2 (compacted at 130 °C) from the WMA group of 3% satisfied the Marshall flow at the requirement of the MPW specifications [17]. The reported results for sample #1, sample #4 from the 6% zeolite content group and sample#2 from the 3% zeolite content were 4.0 mm, 3.7mm and 3.9 mm respectively.

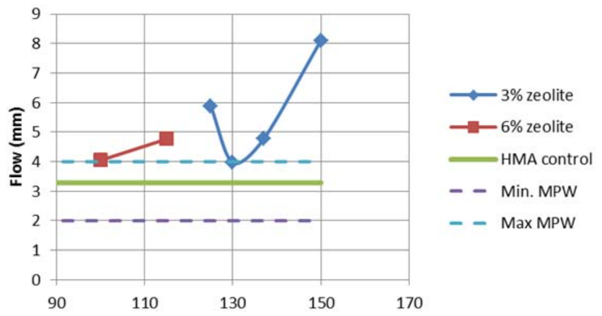

Fig. 6 Flow versus compaction temperature for 6% and 3% zeolite content

V. CONCLUSION AND RECOMMENDATIONS

This laboratory study formed the first step on the path of the WMA concept utilizing the volcanic ash as water-bearing additive to achieve the reduction of the compaction temperature of asphalt along with maintaining the mixture integrity, as a result, will lessen the carbon emissions of asphalt production.

The results of the produced WMA samples with contents of 3% and 6% zeolite content (volcanic ash) indicate that the used technique has shown potential in enabling the asphalt mixture to be reduced at lower temperatures with maintaining the integrity of the mixture.

The volumetric and physical properties of the WMA samples of 3% and 6% zeolite content at different compaction temperature are equivalent to that of the HMA control mixture. At most, they met the primary requirements of the new MPW Specifications.

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