

# Warm Mix Asphalt

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## Abstract

Warm mix asphalt (WMA) is a technology that emerges to achieve environmental challenges of reducing greenhouse gas emissions. There are several technologies that allow diminishing the mixing and compaction temperature of the asphalt mixtures while improving workability. The benefits of using warm mix asphalt are not just environmental but also include better working conditions and the capability of introducing greater percentages of recycled materials into the mixture. Foamed asphalt is the most used technology to obtain warm mix asphalt in the United States of America (USA), and the performance of the resultant mixtures could be increased by controlling and improving the characteristics of the foam.

**Keywords:** foamed asphalt, warm mix asphalt, warm mix asphalt technologies, foamed warm mix asphalt additives, foam characteristics

## 1. Introduction

The implementation of engineering controls on asphalt pavement industries during 1997 became an important step in the environmentally friendly technologies in the industry. These controls included diminishing the greenhouse gas emissions and avoiding fumes and odors from the immediate surrounding areas, which represented a big challenge. The scientific community, several agencies and universities have been doing laboratory research of technologies that allow the reductions; these technologies are called warm mix asphalt (WMA). Subsequently some test sections were paved using the new technologies to ensure their success and gathering information of the performance of the pavement produced under those WMA conditions.

The WMA technologies evolved into different processes of production, the principal objective of this is to reduce the temperatures of mixing and compaction. The WMA design is just like the hot mix asphalt (HMA) design using the same practices with materials, proportions, volumetric parameters, mechanical properties, and performance test, among others.

The damage and performance of the pavements produced with WMA technologies are usually measured and compared with the performance of the HMA with parameters related to cracking, rutting, stripping, compaction level, moisture damage, modulus, etc.

Warm mix asphalt is a technology that is growing constantly. This chapter gives a brief description of WMA and presents the usage of a Green water-based additive to control and improve the characteristics of foamed asphalt.

## **2. Foamed asphalt with a Green water-based additive**

### **2.1 The emerging of warm mix asphalt**

The technology itself and its features emerged in Germany during the late 1900s. WMA became an important focus of research when the Kyoto protocol signed in 1997 entered into force in 2002. The same year the WMA term came for the first time in the United States of America (USA). In 2006 in the USA, the Federal Highway Administration and the National Asphalt Pavement Association (NAPA) formed a national WMA Technical Working Group [1]. Coupled with the environmental gains, additional economic and engineering benefits have motivated the improvement of methods to reduce the energy consumption at the asphalt pavement industry [2]. As a result, the developed WMA technologies allow the reduction of the temperatures at which commonly used HMA is typically produced, obtaining temperatures from 20 to 55°C lower [3].

### **2.2 Advantages and benefits**

Since the WMA was conceived, several benefits had been consistently identified and consequently driving the development of new WMA technologies. Here they are presented [4–7]:

- i. Environmental benefits: Less greenhouse gas emissions and fumes to the atmosphere due to the reduction in energy consumption. It is reported that the savings in burned fuel are around 20–35%.
- ii. Paving benefits: The achieve workability facilitates greater hauling distances, an extended paving season, and faster opening to traffic.
- iii. Economic benefits: In good operation conditions, the plant would have economic benefits through the reduced energy consumption.
- iv. The welfare of workers: The exposure to fumes and odors narrows, since there is a correlation between production temperatures and asphalt fume in mix plant and field.
- v. Versatility to produce the same gradation mixtures as the ones that are produced with HMA.
- vi. Potential to incorporate higher percentages of reclaimed asphalt pavement (RAP) over 30% due to the increased workability of the mixture.
- vii. Potential to place thick lifts and open to traffic in shorter times.
- viii. Reduction in the asphalt aging due to the lower temperatures.
- ix. Long lasting.

An important point to highlight is the possibility to increase the usage of RAP in WMA [8] due to the paving industry that is constantly facing the increasing demand for environmentally friendly pavement materials and the requirement of rising costs of raw materials. In connection with green technologies, the use of RAP represents a positive method of recycling and saving with the fact that in the

USA the asphalt pavements are the number one recycled material. The experience had shown that properly designed HMA containing RAP performs as well as HMA prepared exclusively with virgin materials. The increased workability of WMA represents potentially greater dosages of RAP. The improved workability leads to a lower production temperature and less aging of the binder, thus counteracting the stiffer RAP binder. Certain studies even recorded RAP percentages of over 50%. It has been shown that the RAP source and RAP content influence fuel consumption and emissions.

Many studies claim that the use of RAP in WMA pavements can help to offset initial costs, conserve natural resources, and avoid disposal problems. The properties of adequately designed recycled asphalt pavements have been proven to be comparable to all new materials asphalt concrete pavements.

### 2.3 Warm mix asphalt technologies

The WMA technologies are classified by type: organic additives, chemical additives, and those technologies that introduce water into the mix through a water-bearing additive or through a modification into the production process creating the foamed phenomenon. The organic and chemical additives diminish the friction by means of a reduction in the viscosity of the asphalt and by reducing the friction between the asphalt and aggregate, respectively. Foaming relies on the fact that when a given volume of water came in contact to over vaporization temperature-heated asphalt at atmospheric pressure, it expands into steam. When the water is dispersed in the heated asphalt and turns to steam, it results in an expansion of the binder phase and a corresponding reduction in the mix viscosity. The amount of expansion depends on a number of factors, including the amount of water added and the temperature of the binder.

#### 2.3.1 Organic additives

This technology introduces organic additives and waxes to the mix, and when the temperature rises above the melting point of the waxes, there is usually a decrement in the viscosity. As the mixture cools, these additives solidify into microscopically small and uniformly distributed particles, which increase the stiffness of the binder in the same way as fiber-reinforced materials. It is recommended to take care of the selected type of wax in order to avoid possible temperature problems. Specifically, if the melting point of the wax is lower than in service temperatures, this can lead to complications.

Selecting the right wax minimizes the embrittlement of the asphalt at low temperatures. The waxes in this technology are high-molecular hydrocarbon chains with a melting point of 80–120°C and are able to modify the properties of the original binder. The temperature at which the wax melts is in direct relation to the length of the carbon chain.

#### 2.3.2 Chemical additives

In most of the cases, this type of additives is composed of a combination of emulsifier agents, surfactants, polymers, and additives to improve the coating and the mechanical characteristics of the mixtures. They reduce the friction generated between asphalt and aggregate particles making possible to produce the mixture at lower temperatures with better workability and compaction properties. Usually, these additives are mixed with the asphalt before it enters into the mixing drum.

### *2.3.3 Foamed asphalt*

Mechanical foaming has become the most popular method to produce warm mix asphalt at least in the USA. The foaming caused by water-bearing additives includes inorganic synthetic crystals like zeolites. Zeolites gradually deliver their water at contact with heated asphalt producing the foaming effect. According to NAPA almost 65% of all WMA produced in 2017 were manufactured through foaming. The general mechanical process is based on introducing small amounts of cold water that are injected into a stream of the heated binder at temperatures ranging from 160 to 180°C. The process of mixing cold water with hot binder results in a volumetric expansion. Consequently, the viscosity of the binder is reduced which favors the coating of the aggregates and improves the mixture workability.

Although mechanical foaming has been a widely used technique in recent years, there are persisting questions regarding the effects of the water on binder foaming characteristics and foamed mixture properties and performance [9]. There are some parameters that can contribute to determining the efficiency of the process and the mixture.

Recently, at Texas University in the USA, a novel noncontact method to measure the expansion ratio and collapse of the foamed binder during the foaming process and the size and evolution of the number of foam bubbles over time has been developed. Two parameters were proposed for evaluating the effect of water content on foamed mixture properties in terms of workability and performance. The results indicated that the amount of water used in the foaming process had a significant effect on binder foaming characteristics and foamed mixture properties. The optimum foaming water content could be determined through a workability evaluation of foamed asphalt mixtures produced at different foaming contents.

### *2.3.4 Description of the equipment*

The characteristics of the foamed binder are influenced by factors such as binder source, water content, liquid additives, and the foaming properties of binders [10]. The foaming characteristics of the binder are then related to the coating and workability in order to estimate the optimum foamed water content and to validate the performance of the foamed mixture:

- a. Laboratory foamer: a machine to produce foamed asphalt with pressurized air and water. In this foamer, it is possible to use different percentages of water to foam and has the capability to produce mix batches from 16 to 24 kg of aggregates. The pressured water and pressurized air are also variable.
- b. Laser device and camera: the laser device consists of an emitter and detector laser to measure the distance from the device to the asphalt surface on the container; both are mounted on the tripods and aligned vertically and perpendicular to the ground. Both the laser and the camera are connected to a PC in order to obtain the data through time.
- c. Pug mill: is a device for mixing the asphalt and the aggregates (16–24 kg).

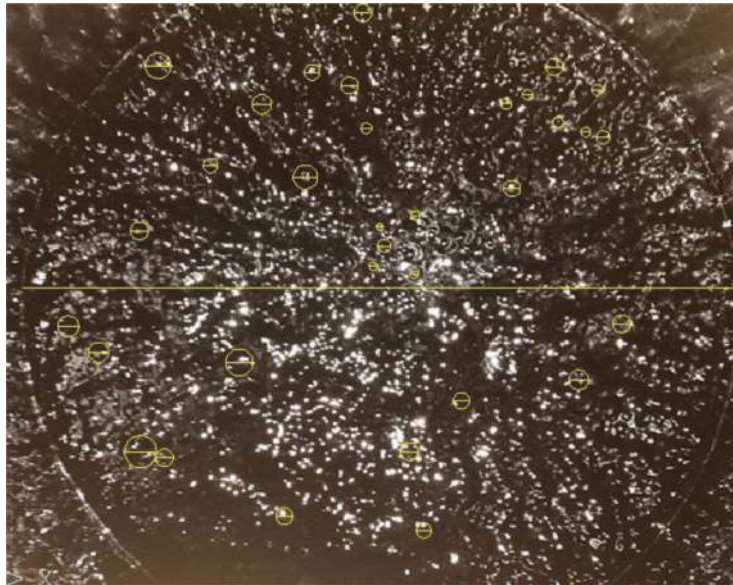
See the equipment in **Figure 1**.

Some asphalts do not have the characteristics to be foamed. They lack a good expansion ratio and bubbles' average lifetime; in some cases there are special additives to promote foamability increasing those parameters (**Figure 2**).

Additionally, the use of digital images has improved the analysis of homogeneity of the bubbles. When the bubbles are analyzed at different times since they were



**Figure 1.**  
*Laboratory test setup for measuring binder foaming characteristics (Lasfalto Laboratory, 2018).*



**Figure 2.**  
*Characteristics of a foam produced in the laboratory, in which bubbles with a homogeneous and stable size are observed (Lasfalto Laboratory, 2018).*

formed, their evolution is observed in terms of expansion ratio, average half-life, and homogeneity. The target is to obtain homogeneous small bubbles, a reasonable expansion ratio, and an average half-life enough to coat the aggregate during the production process.

#### **2.4 Warm mix asphalt with a Green water-based foaming additive**

In this work, the performance of a Green water-based foam additive consisting of a package of neutral organic compounds, adhesion promoters, and water-based design to improve the characteristics of foamed asphalt was evaluated starting from the calculation of the ideal dosage. The results were compared to hot mix asphalt and foamed asphalt mixtures with no additives.

### 2.4.1 Experiment

During the experimental part of this work, a laboratory foamer described in Section 2.3 was utilized, and the characteristics of the foam were determined as explained above. Green water-based additive was used to promote the foaming effect and get the benefits of the WMA technology. The characteristics of the foamed asphalt obtained with the Green water-based additive were compared with the characteristics of foamed asphalt obtained just with water and no other additive. Both samples were foamed using the foamer machine, and the Green water-based additive was added in the water tank. A concentration of 2.1% of water and 2.1% of the Green water-based additive containing a 20% of solids was used. **Table 1** shows the obtained characteristics of the foamed asphalt.

The foamed asphalt specimens were prepared as follows:

- i. The aggregates were dry and heated to a temperature between 130 and 140°C for WMA and 160°C for HMA.
- ii. The Green water-based additive was injected into the foaming chamber, while the asphalt was at a temperature of 130°C for WMA and 160°C for HMA.
- iii. The formed foam was mixed with the aggregate for 3 min at a temperature of 130°C for WMA and 160°C for HMA.
- iv. Based on the NCHRO 807, the foamed WMA was aged at 240°F (115.5°C) for 2 h.
- v. The mixtures were compacted at a Marshall compactor at a temperature of 110–120°C for WMA and 140–150°C for HMA.

The grain-sized distribution of the aggregates was taken by the granulometric curve of the regulation of the asphalt plant of the government of Mexico City. Marshall stability and flow test (ASTM D-1559), tensile strength ratio (TSR) (ASTM T-283), and resilient modulus (UNE-ENR697-26:2006) were performed to evaluate the mixtures.

The study of these parameters allows determining the resistance and durability of the asphalt mixture in the long term as a consequence of the production process.

Two series of three mixes were elaborated: foamed WMA with the Green water-based additive, foamed HMA and foamed WMA.

**Table 2** shows the obtained results. The foamed HMA was used as a reference. Finally, the percentages of adhesion were calculated.

#### 2.4.1.1 Results

The expansion coefficient increased to 50% when the foaming process was produced using the Green water-based additive compared to when the foaming process

Additive	Expansion coefficient	Half-life (s)	Average size (cm)
WMA (water)	4	18	0.16
Green water-based additive	6	70	1.61

**Table 1.**

*Comparison of the characteristics of a water-foamed asphalt and a foamed asphalt using a Green water-based additive.*

Additive	Asphalt (%)	Water or additive (%)	Resilient modulus (MPa)	Stability (kg)	Flow (mm)	TSR (%)	Adhesion (%)
HMA (water)	6	2.2	3800	>1200	<4	93	<50
WMA (water)	6	2.1	2108	>1000	<4	87	<50
WMA (Green water-based additive)	6	2.1	3420	>1000	<4	90	>86

**Table 2.**  
*Laboratory evaluation of the mixtures.*

just used water, but the reduction in the average size diminished as much as 10 times using the Green water-based additive, and the half-life increased almost 4 times. These parameters indicate that the capability of the asphalt to coat the aggregate was substantially incremented because of the augmented contact area produced by the mass of smaller bubbles of asphalt. A notorious size homogeneity in the bubbles was observed and joined with the increased half-life of the bubbles it became in better homogeneity during the asphalt mixture process and prolonged workability of the mixture. In general, the characteristics of the foam are improved by the addition of the Green water-based additive, and these properties were expected to upgrade the properties of the warm mix asphalt elaborated with this foamed asphalt.

The obtaining results of the evaluation of the mixtures elaborated with foamed asphalt show that the resilient modulus and the stability of the WMA elaborated with the Green water-based additive hold a close behavior with a foamed HMA. The resilient modulus of the foamed HMA was 3500 MPa, and similar values were obtained to the mixtures prepared with the Green water-based additive with 3420 MPa. The resilient modulus for WMA foamed with water reaches the value of 2500 MPa which exhibits a less resistant mixture than the HMA and foamed WMA using the additive. In the Marshall test, we do not find significant differences because of the nature of the test. Nevertheless, in the test that indicates the humidity and water resistance that are the TSR values and the adhesion, the results show a desirable performance with the addition of the Green water-based additive reaching the value of 90% for TSR test and increasing the adhesion from <50 to >86%.

The aggregate characteristics made a mixture with the poor affinity between asphalt and aggregate. Even if it is recommended to have an adhesion percentage above 90%, the improvement in adhesion is an evidence of the functionality of the additive.

Mexico City can be considered as a pushful city in terms of selecting green technologies to maintain its paving needs. Since 2008 the asphalt plant belonging to the government of Mexico City and the one in charge of producing most of the asphalt mixture has been delivering WMA with an average production of 400,000 tons per year. Due to the high air pollution levels constantly registered in the urban area, one of the actions taken by the government was the mandatory use of WMA in every paving work at the city from 2010 to date. The registered reduction in fuel consumption has been approximately 20%, and, consequently, the VOC and the greenhouse gas emission have decreased. The Mexican plant had worked with several additives: some reduce the friction between aggregate particles and binder during mixing, and some are water-bearing additives. More recently, the company acquired an Astec Double Barrel facility with the so-called Green System, and the plant to improve the performance and the characteristics of the mixture is working with the Green water-based additive presented above.

### 3. Conclusions

Warm mix asphalt technologies have a great potential in different ways from improving the technologies to the implementation as a regular practice where asphalt mixtures are used. It is extensively recommended to promote this technology taking advantage of all its benefits.

The Green water-based additive showed numerous advantages. The additive increased the contact area of asphalt to achieve a total coating of the aggregate, forming a great amount of small homogeneous bubbles. Workability and lubricity into the asphalt mixture through the formation of microbubbles that results in better compaction to reach the required densities and stabilities were also improved. The performance of the obtained mixture was compared to a foamed HMA reaching similar resilient modulus values. The adhesion of the mixture was also enhanced.

Additionally, and in concordance with the other WMA technics, the Green water-based additive reduced the production of greenhouse gas emissions increasing the hauling and paving seasons and improving the working conditions.

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