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## Road and Rail Infrastructure III

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## ENVIRONMENT PROTECTION BY USING NEW TECHNOLOGIES FOR ASPHALT MIXTURES

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### Abstract

The asphalt paving industry is constantly exploring technological improvements that will enhance the material's performance, increase construction efficiency, conserve resources, and protect the environment. Current and impending regulations on greenhouse gas emissions, fumes/odors and energy conservation are making attractive the reductions in asphalt mix production and placement temperatures. Warm mix asphalt (WMA) refers to asphalt concrete mixtures that are produced at temperatures approximately equal to 100°C – 140°C bellow temperatures typically used in the production of hot mix asphalt (HMA). The goal of WMA is to produce mixtures with similar strength, durability, and performance characteristics as HMA using substantially reduced production temperatures. This paper aims to presents a laboratory study performed on a few Romanian asphalt mixtures manufactured in both technologies (hot and warm). The performances of these asphalt mixtures (WMA) are studied by their characteristics like Marshall flow and stability, stiffness and permanent deformation. All these tests are performed according to European Norms. The results are presented like comparative graphs and the conclusions will establish which is the performance of WMA.

*Keywords: warm mix asphalt, CO<sub>2</sub> reduction, bitumen additives, mixture stiffness*

### 1 Introduction

The asphalt paving industry is constantly exploring technological improvements that will enhance the material's performance, increase construction efficiency, conserve resources, and protect the environment. Current and impending regulations on greenhouse gas emissions, fumes/odors and energy conservation are making attractive the reductions in asphalt mix production and placement temperatures.

In these conditions, the concept of warm mix asphalt (WMA) has a good opportunity. Warm mix asphalt is produced at temperatures in the range of 20 to 40°C lower than typical hot mix asphalt (HMA). WMA represents a group of technologies that allow a reduction in the temperatures at which asphalt mixes are produced and placed. These technologies tend to reduce the viscosity of the bitumen and provide complete aggregate coating at lower temperatures. The same mechanisms that allow WMA to improve workability at lower temperatures also allow WMA technologies to act as compaction aids. Improved compaction or in-place density tends to reduce permeability and bitumen hardening due to aging, which tends to improve performance in terms of cracking resistance and moisture susceptibility. WMA technologies also have the potential to be beneficial during cold-weather paving or when mixtures must be transported long distances before placement. The smaller differential between the mix temperature and ambient temperature results in a slower rate of cooling. Since WMA can be compacted at lower temperatures, more time is available for compaction. Classification of asphalt mixtures based on manufacturing temperature is presented in table 1.



**Figure 1** Typical mixing temperature for asphalt mixtures

**Table 1** Manufacturing temperatures

Technology	Mixing temperature [°C]	Technology principle	Influence on bitumen
“HOT MIX”	120 – 190	Hot bitumen	
“WARM MIX” (“WMA”)	100 – 140	Organic additives	Bitumen and mixture rheology are modified
“COLD MIX”	No heating	Bitumen emulsion	Reduce bitumen viscosity

Development of this technology appear in Europe, in 1997, at the same moment with the Kyoto agreement negotiations, which purpose was to reduce pollutant emissions by industrialized countries by 5,2% between 2008 – 2012, comparatively with those from 1990. Since then on the construction market appears a lot of products and technology processes which promise to implement the directives from Kyoto Agreement, products and technologies that are currently the subject of several laboratory studies internationally.

Also, it is possible by reducing temperatures mixing and placing, using additives which lower bitumen viscosity, to improve the compaction characteristics of asphalt mixture layer, by assuring a better density. This will lead to a permeability reduction of asphalt mixture layers, to a better aging behavior with favorable effects on fatigue resistance and moisture degradation of structure layers.

## 1.1 Review of the Existing Warm Mix Asphalt Systems

### 1.1.1 Foaming techniques

In the presence of hot bitumen, a small quantity of water (~ 2% by mass of bitumen) changes from liquid to vapors. The rapid expansion of the water, from liquid to vapors, creates thin-film bitumen bubbles filled with water vapors referred to as foamed bitumen. In a foam state, the viscosity of the bitumen is reduced allowing full aggregate coating at lower mixing temperatures. The characteristics of foamed bitumen are described in terms of expansion ratio (volume of foam compared to volume of liquid) and the half-life of the foam which provides a description of the stability of the foam in time.

### 1.1.2 Bitumen emulsion

The bitumen emulsion technique was developed in North America and it consists of mixing a specific high residue bitumen emulsion with hot aggregate at a reduced mixing temperature. As the emulsion is mixes with the hot aggregate the water flashes off as steam. The bitumen emulsion is specifically designed for the WMA process and includes additives to improve coating, workability and adhesion. It has been reported that mixture workability remains excellent at relatively low temperatures (< 80°C) [1],[ 2], which is a specific benefit of this WMA system.

### 1.1.3 Organic additives

Organic additives in the form of wax have emerged successfully from an extensive program of laboratory and field trials as a bitumen modifier that enables mixing and compaction at reduced temperatures. Organic additives are often referred to as “intelligent fillers” as they

provide reduced viscosity at mixing/placement temperatures and increased viscosity at service temperatures, which is an added benefit specific to this type of WMA system. Furthermore, these additives increase the viscosity of the binder, thus providing increase in resistance to deformation at high ambient temperatures. These type of additives act as a compaction aid if the amount is small – less than 1,5% and they can improve bitumen properties if the amount is higher than 3%.

#### 1.1.4 Chemical additive

Warm mix asphalt systems involving the use of chemical additives or surfactants are not relying on the reduction of the binder viscosity, but rather the improvement of the coating capability of the binder at a lower mixing temperature. The WMA systems using this approach are relatively new and their development is promising. Certain chemicals are added to the binder in a manner similar to anti-stripping agents in a concentration as low as 0.3 % by mass of the bitumen. These chemicals can be pre-blended in bitumen or added at plant pumping installation.

## 2 Laboratory studies

Experimental study aimed that through laboratory results to highlight asphalt mixture performance when WMA technology is used. To evaluate mechanical performance of asphalt mixtures, the cylinder specimens (100.6 mm diameter and 63.5 mm high) were produced with 50 blows compacting energy per side by Marshall Compactor, and the slabs were prepared on wheel-roller machine. The size of the slab samples was 300 mm in length, 300 mm in width and 50 mm in thickness. This study was carried out on two types of asphalt mixtures for wearing course designed according to Romanian Norms: an asphalt mixture – noted by “HMA” and an asphalt mixture produced with Rediset organic additive (WMA type) – noted by “WMA”. The materials (aggregates, filler and bitumen) used to prepare the asphalt mixtures and the asphalt mixtures recipes are the following:

- crushed rock from Cerna:
- 8/16: 30% by mix
- 4/8: 22% by mix
- 0/4: 32% by mix
- filler from Holcim: 9.4 % by mix;
- bitumen 50/70 plus: 6.6% by mix;
- organic additive (Rediset): 2% by bitumen – used for WMA mix.

The organic additive used is a wax (brown flakes) added in bitumen, dissolving easy when bitumen is hot, without any special mixing equipment. To highlight the performance of “warm mix” mixture type, in Roads Laboratory of Faculty of Railways, Roads and Bridges (Technical University of Civil Engineering of Bucharest) were conducted these tests:

- Marshall test on cylindrical specimens, according to SR EN 12697-34, at 60°C test temperature for Marshall stability and index flow;
- Test applying Indirect Tension to cylindrical specimens IT-CY, according to SR EN 12697-26 Annex C and SR EN 12697-24 Annex E, at 20°C test temperatures from which result asphalt mixture stiffness;
- Cyclic Compression test on cylindrical specimens, according to SR EN 12697-25, for triaxial compression, at 50°C test temperature from which result resistance to permanent deformation;
- Wheel Tracking test on slabs, according to SR EN 12697-22, small device, method B in air at 60°C test temperature from which result resistance to permanent deformation.

The European standards for bituminous mixtures (EN 13108-1 to -7) do not preclude the use of WMA. The standards include maximum temperatures for particular mixtures, but there

are no minimum requirements. The minimum temperature of asphalt mix is declared by the manufacturer. The standards also allow usage of additives if the performance of asphalt is equivalent to reference mixture. In tables 2 and 3 are presented temperatures used at preparing and compaction of asphalt mixture and bitumen properties. In figures 2, 3 and tables 4, 5, 6, 7 are presented the results obtained through experimental program.

**Table 2** Temperatures used at preparing and compacting of asphalt mixtures

Temperature, °C	Technology	
	“hot mix”	“warm mix”
Aggregates	180	150
Bitumen	170-175	170-175
Mixing	180	160
Compaction	170-175	125&150

**Table 3** Bitumen characteristics

Characteristic	Bitumen type	
	50/70 plus	50/70 plus with wmx additives
Penetration, at 25°C, 1/10 mm	51	48
R&B point, °C	52	56
Penetration index	-1.0	-0.5

**Table 4** Physical – mechanical characteristics

Characteristic	Asphalt mixture type		
	HMA	WMA1	WMA2
	Compaction temperatures		
	160 .. 165 °C	125 °C	150 °C
Density, kg/m <sup>3</sup>	2327	2326	2374
Water absorption, %	5.5	5.52	4.23
Marshall Stability (S), kN	9.85	7.69	12.15
Marshall Flow (l), mm	3.6	2.9	3.0
Marshall Index (S/l), kN/mm	2.74	2.65	4.05
Stiffness, IT-CY, 20°C, MPa	3416	2803	3530

In the future it is a requirement to consider the impact that our actions will have on the environment, especially with regards to the preservation and sustainability of the environment for the future generations. The most obvious environmental advantage with regards to the use of warm mix asphalt for road construction is decreasing the temperature in the production of WMA, which will lower fuel usage and decrease emissions directly connected to fuel use (table 8). This should lower the emissions of greenhouse gases (CO<sub>2</sub>) and traditional gaseous pollutants (CO, NO<sub>x</sub>, and SO<sub>2</sub>).



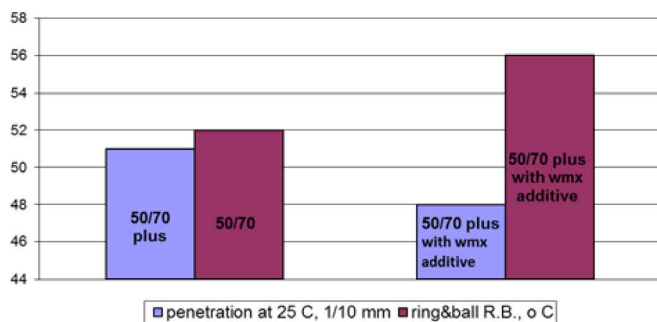


Figure 2 Working technology influence on bitumen properties

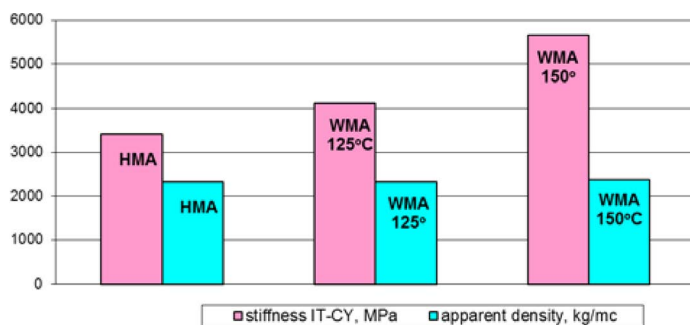


Figure 3 Working technology influence on asphalt mixture properties

Table 5 Resistance to permanent deformation (method I)

Type of mixture	Parameters of equation on (quasi) linear stage II Method I ( $\epsilon_n = A_1 + B_1 n$ )		Creep rate $f_c = B_1$	Initial creep modulus, $E_n = \sigma / \epsilon_n$ , kPa
	$A_1$	$B_1$		
HMA	5129.1	0.0478	0.0478	1243
WMA	11420	0.039	0.039	407

Table 6 Resistance to permanent deformation (method II)

Type of mixture	Parameters of equation on (quasi) linear stage II Method II ( $\log \epsilon_n = \log A + B \log n$ )		Calculated permanent deformation	
	A	B	$\epsilon_{1000}$	$\epsilon_{10000}$
HMA	3096.71	0.0463	4828	5599
WMA	9440	0.0208	10899	11433

Table 7 Resistance to permanent deformation from Wheel Tracking test

Characteristics	Type of mixture	
	HMA	WMA
Proportional rut depth at $10^4$ load cycle (%)	2.56	2.34
Wheel Tracking slope (mm/ $10^3$ load cycle)	0.029	0.025

**Table 8** Calculated reduction of CO<sub>2</sub> emission at the one of the mixture plant in Romania

Indicators	HMA	WMA
Fuel consumption (l)	1.426	1226
CO <sub>2</sub> emission (t)	3.342	2.685
Mixture quantity (t)	155	140
CO <sub>2</sub> emission per ton of mixture (kg CO <sub>2</sub> /t)	21,56	19.18 (-11.04%)

According to the measurements, this gives a plant stack emission reduction of:

- CO<sub>2</sub> in the range of 15% to 40%;
- SO<sub>2</sub> – 20% to 35%;
- volatile organic compounds (VOC) up to 50%;
- carbon monoxide (CO) – 10% to 30%;
- nitrous oxides (NOX) – 60% to 70%.

### 3 Conclusions

Warm mix asphalt is a promising approach to production and placement of paving materials. Research work worldwide is evidently demonstrating that WMA systems are providing significant benefits with regards to the environment, in facilitating paving practices and, with regards to field performance. Significant evaluation work has been completed and the benefits associated with WMA are well documented. However, there is still a significant challenge ahead to move WMA from trial projects to main stream pavement products. All WMA systems are either proprietary processes or based on specific commercial products. Specifications that allow fair competition between the various WMA systems remain to be developed. Using the “warm mix” technology, the working temperatures can be reduced by keeping the initial physic – mechanical characteristics of the asphalt mixtures obtained through warm technology “hot mix”.

Warm mix type mixture has a poorer behavior at permanent deformation resulted from traxial compression test because of the additive which decrease bitumen viscosity, but still fits in demand of norm. For example,  $\epsilon_{10000}$  values is double in case of “warm mix”. In return, adding of additive in asphalt mixture improve the resistance to permanent deformation from Wheel Tracking test by about 10%.

Increasing the compaction temperature, it can be noticed an improvement of the physic – mechanical characteristics obtained through the technology “warm mix”, and also the results have satisfactory values. Still, the best results are obtained for a compaction temperature of 150°C. Close values of the physical – mechanical characteristics of the mixtures achieved through “hot mix” technology and “warm mix” technology are obtained for the compaction temperature of 125°C. Although the laboratory results appear to indicate some small changes in the performance of the mixtures, they do not consider aging effects and the performance functions are based on conventional mixture data, and therefore need to be validated by field data before any conclusions can be drawn.

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