Warm Mix Asphalt / Low temperature asphalt

Warm mix asphalt produced with liquid additive Increasing mix compactibility

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Abstract

Our company, leader in chemical's additive for road construction, has worked since 2006 on the development on warm mix asphalt and half warm mix. With this process of liquid additive (product based on vegetal's chemical from pine tree) for bitumen, millions of tons of warm mixes asphalt have been produced and applied with lots of different traffics, climates, roads structures and aggregates. The development of Warm Mix Asphalt (WMA) requires the control of the performances at laying temperatures to ensure those at service life. A simple lowering of mixing temperature can reduce the workability and the compactability of asphalt mixture. So, several technics such as liquid additive and foaming are proposed to avoid or reduce this laying issue This article presents in details the benefits of the warm mix asphalt's technic with liquid additive and specially the gain of compaction versus others technics. To study the compaction a new way to use the shear gyratory press has been applied, considering that the classic exploitation of gyrator's data (i.e. considering the void content at a given number of gyrations) is not relevant to evaluate the effect of the temperature's decrease. The idea is to use the Compaction Energy Index (CEI), area using the giratory's curve and calculated to obtain a level of compaction, and compare it between different technics. Moreover, the lab's trials for compaction have been done at different temperatures (ie 135°C, 110°C and 90°C) to see the limit of the compactibility of the mix. As it, the use of our liquid additive is clearly the best option in terms of compactibility to balance the reduction of temperature. Thus, it gives for a warm mix asphalt compacted at 90°C results equal as a hot mix asphalt compacted at 155°C.
Keywords: Compactability, Warm Mix Asphalt (WMA), Compaction Energy, Evotherm®

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1. INTRODUCTION

In the early 2000's, warm mix asphalt (WMA) was broadly commercialized in Europe and the USA as a means to reduce plant and job site emissions of both particulate matter and organic vapors. Soon after field trials in North America and Europe began, the engineering community in those regions discovered that WMA technologies provide a host of other benefits beyond the reduced environmental impact [1]. Among the benefits during mix production are lowered fuel consumption, less equipment wear, and reduced binder aging. During pavement construction, it was established that many WMA technologies enable improved compaction, thereby allowing longer haul times, extended paving seasons, and improved pavement durability. These production and construction benefits translate directly into economic benefits, such as lower materials costs (by including higher recycled content), decreased operating costs, and reduced equipment maintenance. Within a few short years of commercial introduction, warm mix technology was employed across the globe with all classes of aggregate mineralogy and gradation, with the entire gamut of bituminous binders, with every configuration of plant and paving equipment, and in every climatic region of the world where asphalt pavements are built. Most importantly, since its adoption at the turn of this century, long-term pavement performance studies have shown that WMA pavements are equal or superior in durability to corresponding hot mix asphalt pavements.

By 2011, there were 19 WMA technologies being offered commercially in North America alone [2]. However, most of these early entries into the market did not find a lasting place due to complexities in mix plant production operations and constructability challenges in the field, both of which led to decreased durability in the finished pavements. These short-lived technologies included many products based on waxes and low-melting plastomers, as well as zeolites, wet-sand, and other in-situ foaming strategies.

Since more than 10 years, Ingevity, an US chemical company, and partners are working on the development of warm mix asphalt (WMA) with liquid additive. With Evotherm® products, coming from pine chemical, millions of tons of WMA have been produced and applied with all type of traffics, aggregates, climates, bitumen. In the USA, WMA represents about 39% of total 2017 asphalt mix production [3], in France in 2018, it represented only about 15% of the total production (5 millions of tons) [4]. In both regions, these total tons of WMA production are dominated by two technologies in the commercial landscape: liquid additive technologies and water-injection foaming technologies. This article discusses results of a study of the benefits of liquid additive WMA and foamed WMA in terms of improved compaction relative to hot mix asphalt. To study the compaction a new way to use the shear gyratory press has been applied, considering that the classic exploitation of gyrator's data (i.e. considering the void content at a given number of gyrations) is not relevant to evaluate the effect of the temperature's decrease. The idea is to use the Compaction Energy Index (CEI) area using the giratory's curve and calculated the level of compaction, and compare it between different technics.

2. STUDY METHODOLOGY - DESCRIPTION OF THE CEI

The advantages of the WMA with liquid additive is to improve the compaction. For that, there are different methods. A classic one is to use the gyratory press (PCG). The idea is to control the percentage of compacity at a number of rotations determined. For example, for an asphalt concrete AC16 Surf, the compacity must be between 92 y 95% at 60 laps. The fact that the PCG is generally compressing all king of materials with 60 laps, it is very difficult to discriminate materials or technics and to see huge difference in terms of lab results.

Another way (not used in France for the moment) to determine the compaction is to see the quantity of energy necessary to achieve a percentage of compaction. So, it is possible to see the compaction energy (see figure 1, the CEI for Compaction Energy Index) developed by Bahia e all [5] and described in some articles [6].

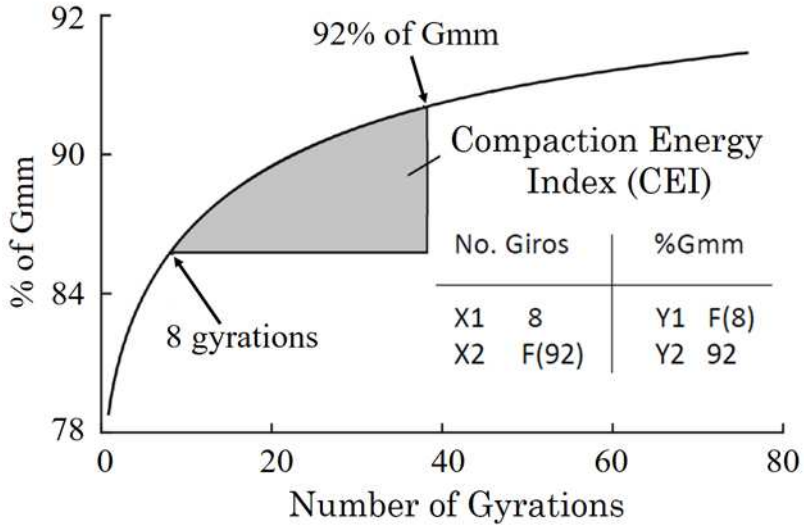

Figure 1: CEI obtained from gyratory curves

As demonstrated in the seminal work of Bahia et.al., the CEI approach enables one to establish compactability as a function of key variables, such as binder content in conjunction with gradation and the type and quantity of sand (manufactured or natural). In this study, the CEI methodology was used to study the compactability of liquid additive WMA and foamed WMA technologies. Moreover, the methodology was applied to the WMA mixtures at three compaction temperatures: 140°C, 110°C, and 90°C. Referring to Figure 1, the perfect mix asphalt regarding this method could be defined as the easiest to compact which means the lowest CEI possible.

Of course during this lab study, calculation of the CEI was the focus, meanwhile respecting all others performances expected by the norms/standards (modulus, rutting, immersion test, fatigue test…). To be clear, we also precise that the compaction examined during this study has not to be confused with a manual workability of the mix. For example, good results of compaction for a mix asphalt does not necessary mean good workability.

3. JOB MIX FORMULATION AND ASPHALT MIX DESIGN

The main objective of this article is to compare different technics, with some very simple calculations of areas (CEI) the energy necessary to obtain a level of compaction of 92% so 8% of voids content.

The mix design is a Grave Bitume (GB) 0/14, EB 14 base 35/50 (NF EN 13108-1), without RAP content, using a 35/50 bitumen and limestone aggregates.

Table 1: mix asphalt design

Mix Design EB 14 (Aggregate Gradation, Binder Content, and Percent Liquid Additive WMA)						
% Filler	% Aggregate 0/2	% Aggregate 2/6	% Aggregate 6/10	% Aggregate 10/14	% Bitumen 35/50	% Liquid Additive WMA[(a)] w/w bitumen
2,5	31	13	0	29	4,5	0,4

(a) Two liquid additives were used: Evotherm® WM30 and Evotherm NG

4. MIX PRODUCTION AND COMPACTION TEMPERATURES

The EB 14 mix design was used to make twelve different mixtures, which varied in temperature and in the type of WMA technology used. Six hot mix asphalt samples were produced at 165°C followed by compaction at 155°C. The liquid additives were included in these formulations because many contractors regularly use the liquid additives during the winter to aid compaction during cold weather. Similarly, in one of the hot mix formulations, water was injected into the bitumen to make a hot-foamed asphalt. In some countries, sometimes hot-foamed bitumen is used when producing mixtures containing high levels of reclaimed asphalt pavement (otherwise known as high-RAP mixtures). The EB 14 mix design was also used to make six warm mix asphalt samples. These were produced at 145°C (bitumen was kept at 160°C) and then allowed to cool to 140°C, 110°C and 90°C prior to compaction.

Table 2: production of hot mixes

Production of the hot mix EB 14						
	Mix reference	Mix asphalt with WM30	Mix asphalt with NG	Foam asphalt	Foam asphalt with WM30	Foam asphalt with NG
T° of fabrication	165°C					
T° of compaction	155°C					

Table 3: production of warm mixes

Production of the WMA mix EB 14						
	Mix reference	Mix asphalt with WM30	Mix asphalt with NG	Foam asphalt	Foam asphalt with WM30	Foam asphalt with NG
T° of fabrication	145°C					
T° of compaction	140°C					
	110°C					
	90°C					

5. RESULTS AND DISCUSSIONS

For the mixtures produced at 165°C, table 4 shows the calculated energies of compaction for the six mixtures compacted at 155°C. Using the CEI calculation, it was observed that 0.4% Evotherm WM30 w/w bitumen resulted in a 11% decrease in the energy required to compact the mixture to 92% of Gmm (3890 CEI versus 4358 CEI for the hot mix reference). Evotherm WM30 was introduced to the WMA market around 2007. The foamed mixture (CEI = 3939) gave about the same (10%) decrease in CEI versus the HMA reference mixtures. Notably, use of the Evotherm NG, a recently-introduced, new-generation Evotherm liquid additive, gave a 40% reduction in the energy needed to compact from the density at 8 gyrations to the density at 92% of Gmm.

The compactability of the hot foamed mixture was substantially increased by adding Evotherm® to the bitumen prior to foaming, mixture production, and compaction. The CEI of the foam-only mixtures was 3939 compared to CEI values of 2597 and 2600, respectively, for the foamed mixtures wherein the bitumen contained 0.4% w/w Evotherm® WM30 and Evotherm® NG.

Table 4 : comparison of compactibility of mixtures

Results of CEI		
Technology used	Temperature of compaction = 155°C	
	Energy necessary (= CEI, figures without units) to obtain 92% of compaction	Delta (in %) versus reference produced at 165°C
Hot as reference	4358	-
Hot + Evotherm® WM30	3890	-11%
Hot + Evotherm® NG	2601	-40%
Hot foam	3939	-10%
Hot foam + Evotherm® WM30	2597	-40%
Hot foam + Evotherm® NG	2600	-40%

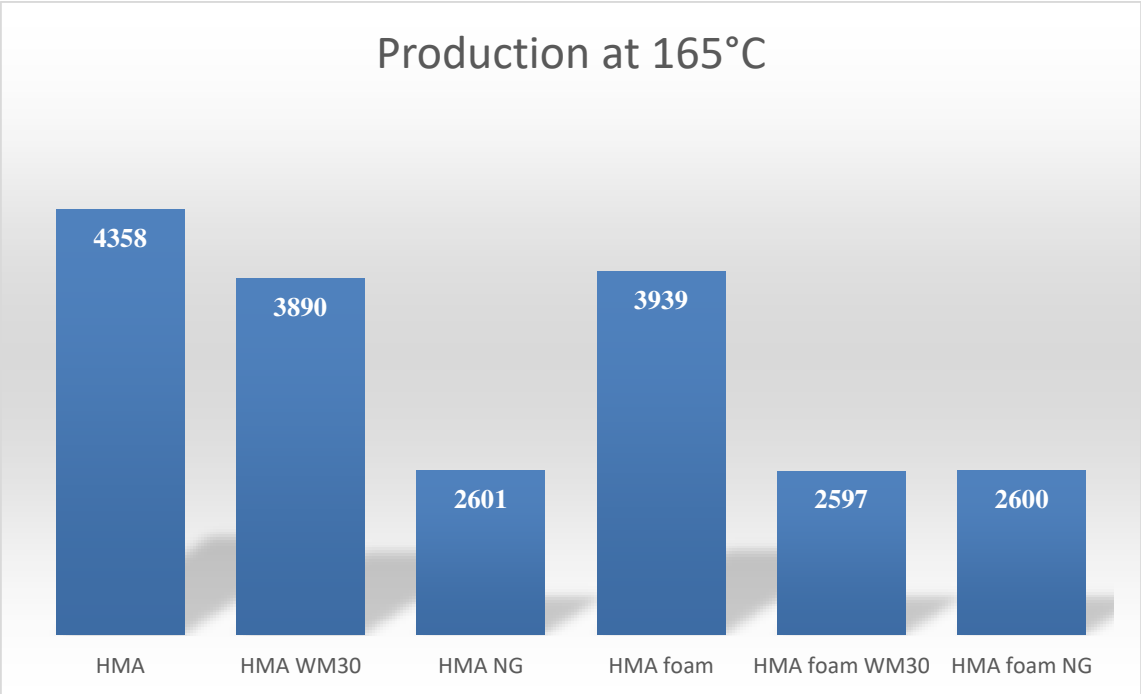

Figure 2: Graphic Analysis of the Results with Mixtures Produced at 165°C & Compacted at 155°C.

From the results in Table II and Figure 2, production at 165°C and a compaction with the gyratory press at 155°C, different points can be highlighted.

- The mechanical (foamed bitumen) or chemical (liquid additive) treatment bring a significant benefit in term of compaction versus the hot reference without any treatment. The mixes are at least 10% easier to compact than the HMA reference mixture.
- At a temperature of compaction 155°C, in term of compaction, the foam bitumen mixture gives similar results to the mix asphalt using Evotherm® WM30.
- Two mixtures showed very significant improvements in compactability versus the HMA reference mixtures. Both the conventional HMA mixture containing 0.4% Evotherm® NG and the hot-foamed mixture containing Evotherm® NG gave CEI values 40% below the HMA reference. These results indicate that double treatment, foamed bitumen with liquid additive may provide improvements above foaming alone.

For the warm mixes asphalt produced at 145°C, followed by Compaction at 140, 110, and 90°C. Table 5 shows the results of applying the CEI methodology to mixtures prepared under WMA conditions.

TABLE 5: CEI Calculations for Six WMA Mixtures Compacted at 140, 110, and 90°C

Results of CEI						
Technology used to produced WMA	Temperature of compaction					
	140°C		110°C		90°C	
	CEI	Percent change vs HMA [(a)]	CEI	Percent change vs HMA [(a)]	CEI	Percent change vs HMA [(a)]
WMA without any treatment	5074	+16%	5505	+26%	7436	-
WMA using Evotherm® WM30	3481	-20%	4449	+2%	5583	-
WMA using Evotherm® NG	3220	-26%	4441	+2%	5234	-
WMA using foam	4211	-3%	5760	+32%	6823	-
WMA using foamed bitumen + Evotherm® WM30	4012	-8%	4626	+6%	6369	-
WMA using foamed bitumen + Evotherm® NG	2956	-32%	4098	-6%	5849	-

(a) Percent change from hot mix reference (produced at 165°C) (CEI =4358)

The percent change of the warm mix formulations compactibility at 90°C versus the HMA produced at 165°C and compacted at 155°C was not calculated since all mixtures exhibited higher CEI values than the hot mix asphalt reference (i.e., they were far above the CEI value of 4358 for the HMA reference).

Figure 3 shows a graphical representation of the results tabulated in Table 5. In Figure 3 it is easy to assess the temperature at which the WMA formulations are equal to or better than the hot mix reference in terms of compactability. The hot mix reference exhibited a CEI value of 4358 when compacted at 155°C. That CEI value is the red dotted line in Figure 2. Any warm mix formulation with a CEI value below that 4358 value is easier to compact.

The concept of Equivalent Compaction Temperature (ECT) can be introduced to describe the temperature at which a warm mix formulation exhibits equivalent compactability as the identically formulated HMA reference mixture (compacted at some elevated reference temperature, which in this study was 155°C).

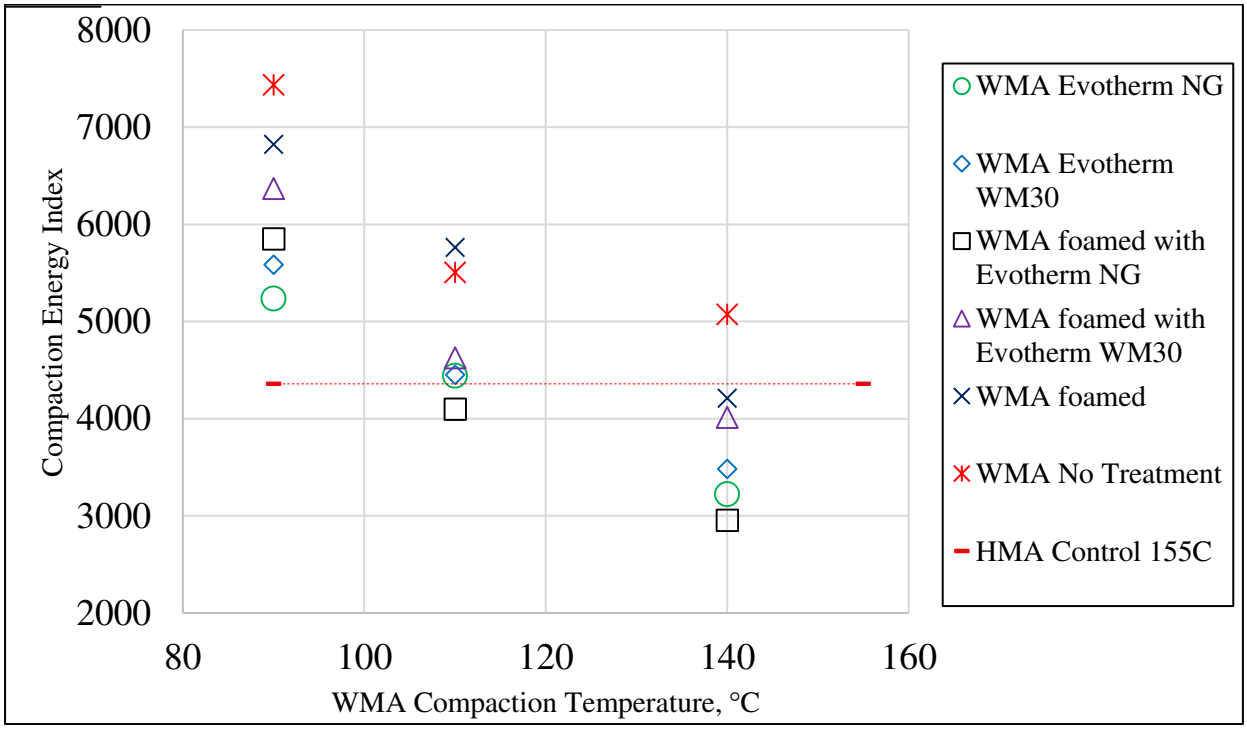

Figure 3: Trends in Compactability Based on CEI Values as a Function of Temperature

Table 6 shows the Equivalent Compaction Temperatures for the WMA technologies used in this study. Evotherm NG whether foamed or used simply as a bitumen liquid additive gave the lowest ECT values of 111-112°C.

Table 6: Equivalent Compaction Temperatures (ECT)

	WMA with WM30	WMA with NG	WMA with foam	WMA with foam and WM30	WMA with foam and NG
ECT	117°C	112°C	137°C	128°C	111°C

The results for the WMA technologies, produced at 145°C and compacted at 140°C, 110°C and 90°C lead to several different conclusions.

- For mix production at 145°C and compaction at 140°C, it is clear that WMA treatment is required for densities to be achieved. Production at 145°C without use of any liquid additive or foaming will yield an unworkable mixture that is even more difficult to compact than hot asphalt at 160°C (+ 16% energy necessary to achieve the same levels of compaction).
- For compaction tests carried out at 140°C, three techniques stand out strongly and seem very advantageous from the point of view of the input energy required to reach target voids contents. The bitumen additive using the two Evotherm additives, as well as the foaming of an additive bitumen using the new generation Evotherm (NG).
- Among the various techniques studied with this EB 14 mixture design using the mix and compaction conditions described above, the results indicate that adding Evotherm (regardless of product) provided quantifiable improvements to compaction at reduced temperatures. Indeed, the energy required to achieve the level of compaction equivalent to a hot mix asphalt reference at 160°C are 20% to 26% lower, respectively, using Evotherm WM30 and Evotherm NG.
- For mix production at 145°C and compaction test at 110°C, the beneficial effects of foaming were not realized, and if fact the foamed mixture at 110°C required more energy to compact than the hot mix reference at 160°C. In contrast the results indicate that even at a compaction of 110°C the Evotherm WM30 and Evotherm NG mixtures maintained their compactability equivalence to the hot mix reference at 45°C higher (i.e., 155°C).

6. CONCLUSIONS

By using the area calculations described in the CEI methodology, it is easy in the laboratory to deduce the Equivalent Compactability Temperature (ECT). Indeed, we can define this temperature ECT, as being the temperature at which an asphalt mixture is being compacted with an equivalent energy expenditure from the Superpave gyratory as that exhibited by a hot mix compacted at 155°C (taken as a reference level).

By measuring the compaction energy index, it is possible to compare the temperatures at which an asphalt mixture can be compacted with the same ease as a control HMA at elevated temperatures, for example, 155°C, as in this study. The compaction benefits of warm mix asphalt technologies can be demonstrated in the laboratory in this way.

This study was focused here on the compactibility aspect of the mix asphalt, while respecting the other mechanical performances required in the standards. This aspect of compactibility / workability should not however be seen as manual handling of asphalt. Many areas of improvement are currently explored to increase this aspect and promote the many occasions encountered especially on urban sites (such as sidewalks, ...). Of course, this study, in order to be as complete as possible, will continue to work on other types of granular materials and other types of bituminous materials. It will also be good to look at the addition of 20% of asphalt aggregates in the formulas (national average) of asphalt in order to appreciate their behavior.

This article, in addition to the many existing publications on warm mix asphalt as well as the various research programs and other experiments, will remove the obstacles and reluctance to a constant growth of warm mixes in France and in Europe in order to exceed current values of national production (around 15% of the annual French production) and tend towards much higher figures.

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