New compactability parameter for comparing warm mix additives

Mark Smith[1, a], **Alan James**[2]

[1] *Asphalt Applications, Akzo Nobel Surface Chemistry AB, Stenungsund, Sweden*
[2] *Asphalt Applications, AkzoNobel Surface Chemistry LLC, Brewster, NY, United States*

[a] mark.smith@akzonobel.com

Digital Object Identifier (DOI): dx.doi.org/10.14311/EE.2016.153

ABSTRACT

There are several methods for assessing compaction of asphalt mixtures offering some insights into compactability and density during and after compaction. This information can be used in pavement design calculations, but is usually too imprecise to assess performance of Warm Mix Asphalt (WMA) additive chemistry. The NCHRP issued a "mix design practices" report 691 which details a gyration ratio method where a mixture's compactability is calculated. This formed the basis of the study where the functionality of WMA additives could be measured via an added "performance ratio".

The research supported and steered development of WMA additive chemistry for the paving industry giving reliable and reproducible results where the degree of performance of WMA additives could be observed.

The research method used 30kg lab batches of asphalt material manufactured using a small scale pug-mill with twin shaft mixers and a Hobart planetary mixer and Marshall Hammer, Cooper gyratory and Infratest roller compactors. The results from each compaction method were compared and then the asphalt gyration and performance ratios were calculated together with mechanical performance measured by Indirect Tensile Strength ratio (ITSR) and Wheel-Track permanent deformation. The research was conducted using the appropriate EU and AASHTO standards together with additional laboratory techniques we have developed giving more reliability in the results. The conclusions facilitated the development of test methods which have been used for research into new Warm Mix Asphalt additives.

Keywords: Additives, Compatibility, Gyratory, Warm Asphalt Mixture, Workability

1 INTRODUCTION

1.1 Incentive

The benefits of lower mixing and paving temperatures: reduced emissions and lower energy consumption are well established. The achievement of the required densities after paving and compaction of the mixture is often the determining factor in setting minimum paving and mixing temperatures, especially in cold weather, cold climates or late season paving.

Technologies applied during the manufacture of the asphalt mixture (mixing techniques, water injection, emulsified binder, additives) can affect the compactability of the mix after paving so that mixes at the same temperature can show different compaction characteristics and **final** densities. As a supplier of warm mix additives and compaction aids based on surface active agents, AkzoNobel is interested to compare the effectiveness of different treatments on compaction. Because the additives may act through different mechanisms it is not possible to predict their effect on compaction through rheological or tribology studies of the pure binder and so tests on actual asphalt mixes are needed. This paper describes a parameter called "performance ratio" derived from laboratory compaction tests with simple calculation which identifies small differences between the effectiveness of different additives.

1.2 Past work.

There have been previous attempts to define parameters which describe the compactability of mixtures. Compaction resistance and work of compaction is determined from fitting an exponential function to the decline of the specimen height in Marshall compaction from the original un-compacted value to a refusal value at infinite blows.[1] The approach distinguishes a mix like SMA which initially compacts easily but reaches a point where compaction becomes very difficult. Similar exponential (logarithmic) relations between compactive effort and density have been found for gyratory compaction. A plot of air voids vs log (gyrations) is almost linear with deviations with very low gyrations and very high (past the point of design density). A Construction Energy Index (CEI) derived from the integration compaction curve (height vs gyrations) from 9 gyrations to N92 number of gyrations to provide 92% density which corresponds to the compaction during the paving operation [2]. (They also consider a traffic densification index which describes the further compaction from 92 to 98%). A similar concept Construction Force Index (CFI) is derived from a gyratory compactor fitted with load cells which directly measure the cumulative force applied from 2 gyrations to N92 [3] and it has been applied to warm mixes [4]

1.3 Target of this work

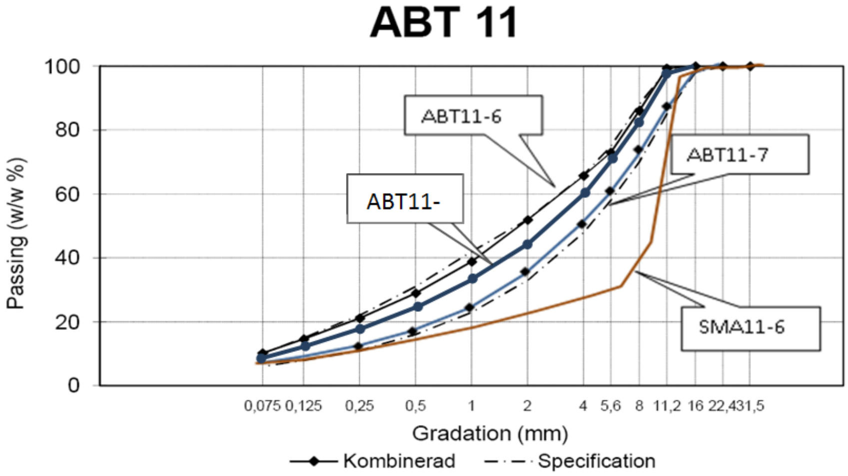
To develop a simple single parameter for compactive effort which could be used to compare compaction aids across a range of laboratory compaction methods. Described in the following sections are the materials used, methods, calculations and followed by examples of the Performance Ratio.

2 Asphalt Mixture

2.1 Aggregate and grading

The aggregate used in the research was Granite from Fröland quarry in Sweden. Several fractions were used in combination to achieve grading’s which follow the recommendations of the Swedish Transport Administration [5]. Several asphalt mixtures were considered, each presenting varying compaction problems. The conclusion was that an 11mm asphaltic concrete - ABT11 (Asphaltic Betong) was chosen for the majority of the project, with also mixtures at the finest and coarsest edges of the grading envelope used to confirm certain observations.

Figure 1 – Illustration of the mixtures we used in our project.



2.2 Binder and additives

The binder used in our project was standard penetration grade bitumen from Shell Germany. The bitumen was tested to have a Penetration of 76dmm EN 1426 and a Softening Point of 47.6°C EN 1427. The ABT11 was manufactured with 5.6% binder at 160°C throughout the project. The research was directed at the evaluation of chemical additives for warm mix. The product Rediset LQ1102CE from Akzo Nobel was mostly used in the development of the test method, and this was added to the bitumen at 0.6% on the mass of bitumen. The additive (LQ) was added into the bitumen and stirred for 1 minute, and then returned to the oven until it had returned to the desired temperature. Other chemical additives were assessed and these are indicated by Additive B, C, & D.

2.3 Asphalt manufacturing

Aggregate fractions were weighed out according to the ABT11 mix design to a batch size of 30kg then heated for 12 hours at the mixing temperatures of 160°C for the reference Hot Mix Asphalt (HMA) prepared from untreated bitumen, and 130°C for the Warm Mix Asphalt (WMA) prepared from treated bitumen The Scantech horizontal shaft “pug-mill” asphalt mixer was also pre-heated to the mixing temperatures and the mixing times are described in Table 1.

Table 1 – Description of asphalt mixing procedure

	Mixing time line		
Mixing with dry aggregate only	5 sec.		
Add bitumen		15 sec.	
“wet” mixing time			40 sec.
Total mixing time	← ------ 60 sec. ------ →		

Once the asphalt was blended the mixture was discharged from below the mixer and placed into large open trays. These were immediately returned to the ovens where the temperatures were adjusted to the desired compaction temperatures of 130°C for HMA and 100°C for WMA. The mixed asphalt was then conditioned for 4 hours in thermostatically controlled – forced ventilation oven for short term aging as advised in accordance to the guidelines and recommendations stated in the Asphalt Institute Superpave design guidelines (Asphalt Institute Superpave Level 1 Mix Design Superpave series No.2 (SP-2)). After the conditioning time, the mixture was removed from the oven then quickly remixed by hand scoop before the material was portioned out to make Gyratory, Marshall, and Plate samples.

3 Compaction

3.1 Compaction methods

Several different compaction apparatus were used during the project and depending on what the samples were going to be used for; the method of compaction was varied between a set compaction sequence and a set resultant density. The compaction moulds were pre-heated to the desired compaction temperature.

3.1.1 Method 1 – Gyratory compactor

Five asphalt tablets per point were made by using a Cooper Technology GYROCOMP (1996) and prepared according to EN 12697-31 (gyro compaction). The tablets measured 150mm in diameter with a thickness of approximately 67mm (depending on achieved density) and weighed 2.5kg. The compaction of the asphalt tablets was to a set density/height of 67mm by 30 gyrations per minute at 1.25° compaction angle and a compaction pressure of 60Mpa.

3.1.2 Method 2 - Roller Sector Compactor

Asphalt slabs were made by using an Infratest 20-4030 Roller Sector Compactor 30kN and prepared according to EN 12697-33, with a modified compaction profile as detailed in Table 2. The Asphalt slabs (320mm x 260mm x 67mm) were compacted to a set densification or compaction sequence with binder content adjustments made for each grading to give 6% air voids or measure the resultant density from the set compaction sequence.

Table 2 - Roller Sector Compactor apparatus set-up

Loading	set densification	
	Measurement	Rate of load
Initial placement	74mm	0.5mm/pass
5 passes	smoothing at constant height	
10 passes	72mm	0.5mm/pass
5 passes	smoothing at constant height	
7 passes	68mm	0.5mm/pass
Release load		- 1kN/pass

During our project we researched permanent deformation of asphalt mixtures using the Wheel tracker device specified in EN 12697-22 and compactability values could also be analysed from data obtained during the EN 12697-33 Roller Sector Compactor sample preparation.

3.1.3 Method 3 - Marshall Compaction

During this study, the ABT11 asphalt material was also compacted via Marshall Hammer with a range of 25 to 100 blows each side and 7 tablets were made for each test point. An example of the results is shown in Table 10.

3.2 Data collection during compaction

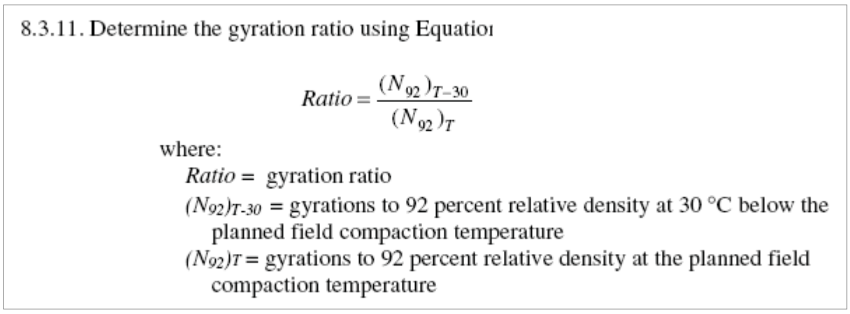
During our project we selected a set density point which was equivalent to 6% air voids. The target of our data collection was to record the energy needed to achieve this set density. Depending on the type of mixture and grading used, the ideal target void content for data collection could vary and this should be decided at the beginning of any further projects. The final density and void content of all specimens was checked using EN 12697-6:2003+A1 Determination of bulk density of bituminous specimens: Method A and D, to verify we had achieved the test target densities.

The data collection can be done in several ways with the simplest being recording and analysing the number of gyrations or plate compactor roller passes to achieve the desired density. The gyratory and plate compactors continuously store data during the compaction and this can be used for more in-depth analysis of compactability like total force calculated from area under the compaction curve or other values earlier mentioned in section 1.2.

4 Compaction analysis

4.1 Description of Gyration ratio

The National Cooperative Highway Research Program (NCHRP) has published a report: 691 “Mix Design Practices for Warm Mix Asphalt” [7]. This report is very supportive and investigative of several problems and discussion topics which are currently circulating, offering some test procedures to support the research and development of WMA.
Included in this report is Appendix A - Draft Appendix to AASHTO R 35: Special Mixture Design Considerations and Methods for Warm Mix Asphalt: test 8.3 Compactability – and this offers a principle of observing an asphalt mixtures ability to compact as the temperature lowers.



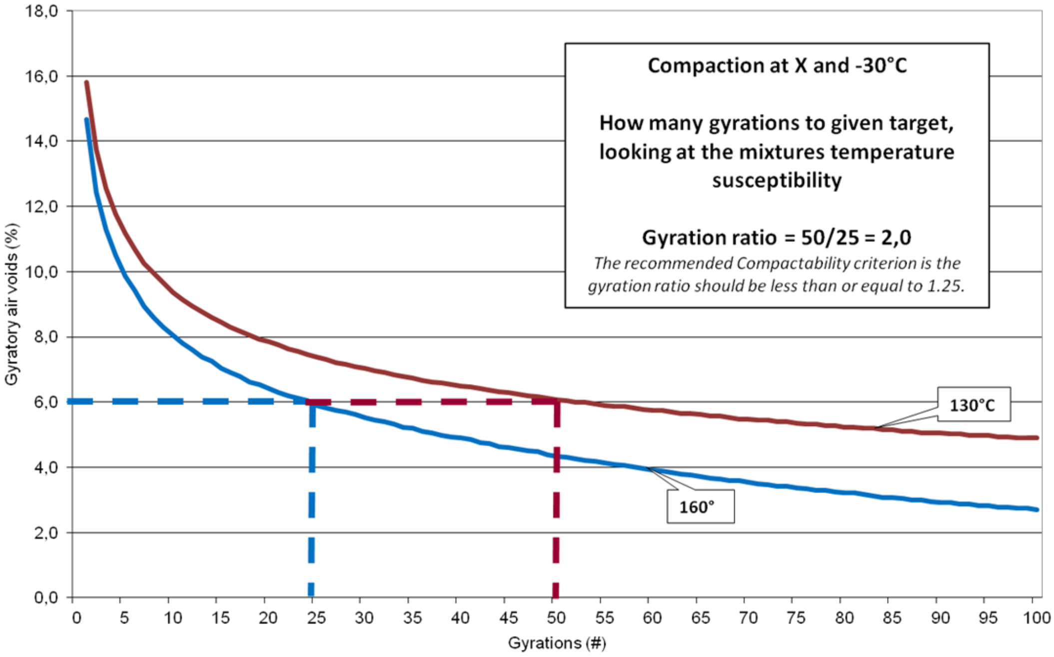
8.3.11. Determine the gyration ratio using Equatio

$$Ratio = \frac{(N_{92})_{T-30}}{(N_{92})_T}$$

where:
$Ratio$ = gyration ratio
$(N_{92})_{T-30}$ = gyrations to 92 percent relative density at 30 °C below the planned field compaction temperature
$(N_{92})_T$ = gyrations to 92 percent relative density at the planned field compaction temperature

This test procedure observes how a mixture is sensitive to temperature. The analysis can be done with and without additives, but it primarily describes the mixtures’ temperature sensitivity. A Mixture with a ratio closer to 1.0 shows less sensitivity to temperature reduction which is expected of a WMA mixture with an additive.
The graph in Figure 2 is to illustrate the concept of temperature sensitivity of the mixture and the expression of a numerical result is for guidance in the warm-mix design phase. In the example in Figure 2, the mixtures’ Gyration Ratio is 2.0, which indicates that by this criterion the mixture is sensitive to temperature reduction.

Figure 2 – Theory behind the Gyration ratio



Compaction at X and -30°C

How many gyrations to given target, looking at the mixtures temperature susceptibility

Gyration ratio = 50/25 = 2,0

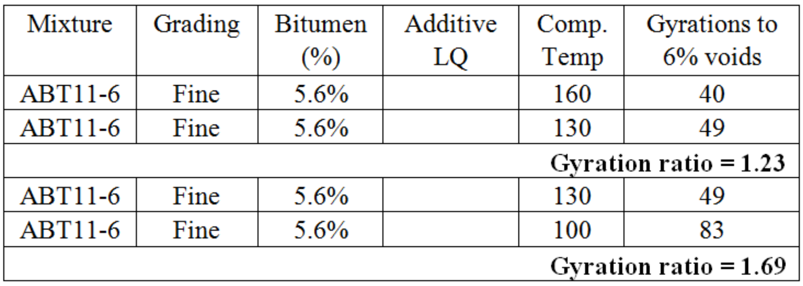
The recommended Compactability criterion is the gyration ratio should be less than or equal to 1.25.

4.1.1 Data analysed via the Gyration ratio

Tables 3 and 4 show a set of results where the mixture parameters are constant except for temperature and the presence of additive. In Table 3, we see the impact of temperature reduction on the number of gyrations to 6% air voids on mixtures without an additive, the results show that the ABT11-6 mixture was sensitive to temperature reduction as the ratio is increasing as the compaction temperature was reduced. The gyration ratio suggests that the mixture compactability was more sensitive to temperature reduction at lower temperatures, so when reducing from 160 to 130°C, the gyration ratio of 1.69 was above the recommended compactability criterion of 1.25. This is an expected phenomenon which is seen in most situations.

Table 3 – Results showing the Gyration ratio

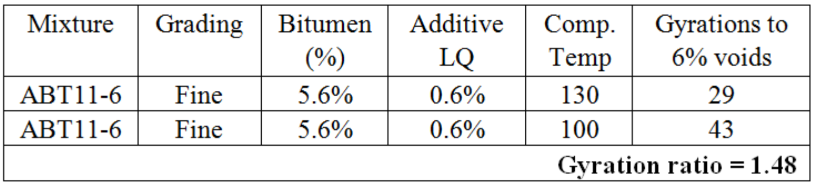
AASHTO R 35: 8.3.12. The recommended Compactability criterion is the gyration ratio should be less than or equal to 1.25.



Mixture	Grading	Bitumen (%)	Additive LQ	Comp. Temp	Gyrations to 6% voids
ABT11-6	Fine	5.6%		160	40
ABT11-6	Fine	5.6%		130	49
					Gyration ratio = 1.23
ABT11-6	Fine	5.6%		130	49
ABT11-6	Fine	5.6%		100	83
					Gyration ratio = 1.69

Table 4 shows the data from the mixtures including the additive Rediset LQ-1102CE which were compacted at 130 and 100°C. The unexpected result was from the mixtures containing the warm-mix additive. With the addition of 0.6% of the additive, the WMA mixtures' gyration ratio is 1.48 which is not in the region of the HMA Gyration ratio of 1.23 as shown in Table 3. These results are inconsistent with the observations we have made in the field during contractor field trials where the warm mix additive is performing as expected, providing compaction like HMA but at reduced temperature.

Table 4 – Results showing the Gyration ratio including additive



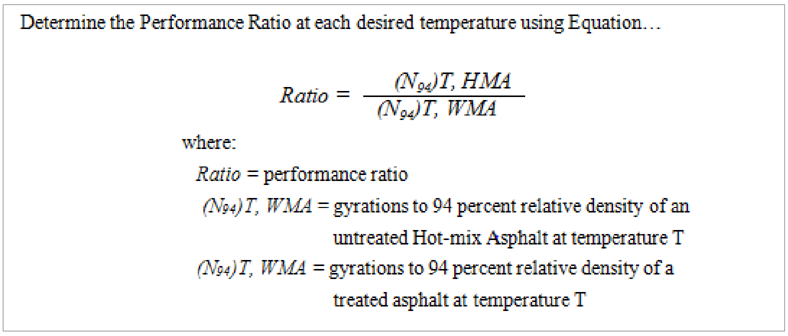
Mixture	Grading	Bitumen (%)	Additive LQ	Comp. Temp	Gyrations to 6% voids
ABT11-6	Fine	5.6%	0.6%	130	29
ABT11-6	Fine	5.6%	0.6%	100	43
					Gyration ratio = 1.48

These results helped us in our validation of new warm-mix asphalt mixtures, but the direct comparison of compactability with and without the additive when all other parameters are constant, was needed. With this in mind, we re-analysed the data in a way that the additive is the focus of attention, and developed the concept of the "Performance Ratio" of the warm-mix additive.

4.2 Description of Performance ratio

We have seen from field experience that asphalt containing compaction aids can often be compacted at 30°C lower than standard asphalt. In order to develop improved additives a simple parameter describing the additives effectiveness needs to be extracted from the laboratory compaction data. Based on the gyration ratio concept, we re-analysed the data from the gyratory compactor for mixtures with and without the additive and simply compared them at the same temperature. This is the basis of the performance ratio, where the compactability of the mixture is recorded in the ratio of energy needed to achieve a set density with and without the warm-mix additive. As the performance of the additive improves, the ratio will increase.

This data evaluation demonstrates how a mixture at a set temperature performs with and without a warm-mix additive. The larger the ratio – the more the warm-mix additive is seen to function in improving the compactability of the mixture.



Determine the Performance Ratio at each desired temperature using Equation…

$$Ratio = \frac{(N_{94})T,\ HMA}{(N_{94})T,\ WMA}$$

where:

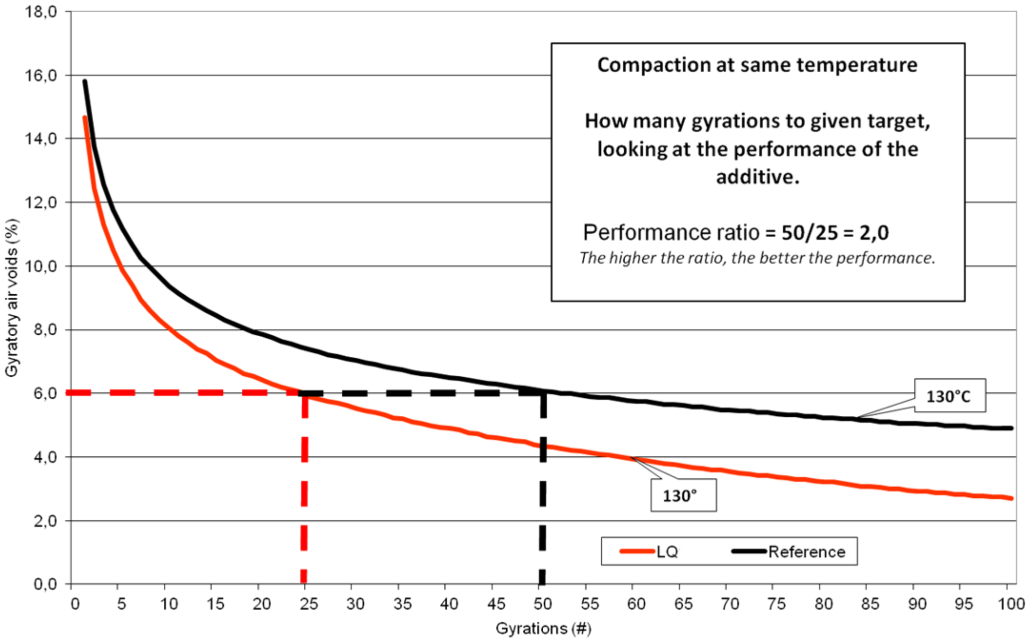
$Ratio$ = performance ratio

$(N_{94})T,\ WMA$ = gyrations to 94 percent relative density of an untreated Hot-mix Asphalt at temperature T

$(N_{94})T,\ WMA$ = gyrations to 94 percent relative density of a treated asphalt at temperature T

The graph in Figure 3 is to illustrate the concept of the performance ratio and the expression of a numerical result for guidance in the warm-mix design phase. In this example, the mixtures' Performance Ratio is 2.0, which indicates the performance of this additive at this test temperature.

Figure 3 – Theory behind the Performance ratio



4.2.1 Data analysed via the Performance ratio

For a particular mix, as the compaction temperature decreases the performance of the sample containing the additive relative to the untreated sample improves and the performance ratio goes up. By focussing on the compactability at low temperatures, the performance ratio becomes a sensitive measure of the effectiveness of compaction aids. The data in Table 5 demonstrates this concept where the Performance Ratio at 100°C is larger than at 130°C showing the increased effect of the additive on compactability at the lower temperature.

Note: - The greater the performance ratio, the greater the performance of the additive.

Table 5 – Results showing the Performance ratio

Fine graded ABT mixture at the edge of the grading envelope

Mixture	Grading	Bitumen (%)	Additive LQ	Comp. Temp	Gyrations to 6% voids
ABT11-6	Fine	5.6%		130	49
ABT11-6	Fine	5.6%	0.6%	130	29
Additive Effect					41%
Performance ratio					**1.70** **High effect**

Mixture	Grading	Bitumen (%)	Additive LQ	Comp. Temp	Gyrations to 6% voids
ABT11-6	Fine	5.6%		100	83
ABT11-6	Fine	5.6%	0.6%	100	43
Additive Effect					48%
Performance ratio					**1.93** **High effect**

4.3 Modifying the Gyration Ratio

Before we selected to work further with the Performance ratio, we considered changing the Gyration ratio formulation by using an asphalt mixture with and without the additive and at different compaction temperatures assuming a 30°C target temperature reduction for the WMA. The results shown in Table 6 show the additive mix giving similar results to the HMA mix at 130°C. This approach combines the mixtures natural compactability properties and those of the additive, thus concealing the performance we really want to focus on. From this, we formulated the Performance ratio, which allowed us to concentrate on the additives ability to compact at a fixed temperature.

Table 6 – Results from modifying two parameters.

Mixture	Grading	Bitumen (%)	Additive LQ	Comp. Temp	Gyrations to 6% voids
ABT11-6	Fine	5.6%		130	49
ABT11-6	Fine	5.6%	0.6%	100	43

5 Additive study

5.1 Effect vs. dosage

Table 7 shows a selection of the results of our work to evaluate different warm-mix chemistries. The data illustrates how the performance ratio can be used in product and dose selection.

Table 7 – Results showing the Performance ratio of the different mixtures

Mixture	Bitumen (%)	Additive	dosage	Comp. Temp	Gyrations to 6% voids	Additive Effect	**Performance ratio**
ABT11-6	5.6%	LQ		100°C	83	21%	**1.26**
ABT11-6	5.6%	LQ	0.2%	100°C	66		
ABT11-6	5.6%	LQ		100°C	83	35%	**1.54**
ABT11-6	5.6%	LQ	0.3%	100°C	54		
ABT11-6	5.6%	LQ		100°C	83	47%	**1.89**
ABT11-6	5.6%	LQ	0.5%	100°C	44		
ABT11-6	5.6%	LQ		100°C	83	48%	**1.93**
ABT11-6	5.6%	LQ	0.6%	100°C	43		
ABT11-6	5.6%	LQ		100°C	83	52%	**2.01**
ABT11-6	5.6%	LQ	0.8%	100°C	40		
ABT11-6	5.6%	B		100°C	83	47%	**1.89**
ABT11-6	5.6%	B	0.5%	100°C	44		
ABT11-6	5.6%	C		100°C	83	37%	**1.60**
ABT11-6	5.6%	C	0.5%	100°C	52		
ABT11-6	5.6%	D		100°C	83	41%	**1.69**
ABT11-6	5.6%	D	0.5%	100°C	49		

5.2 Effect vs. grading

When the grading is changed to a coarse graded mixture, we can confirm from the results that these mixtures can be more problematic in compaction and this is seen in the performance ratio where the ratio shows less improvement with the additive than for the fine graded mixtures.

Table 8 – Other mixtures showing the Performance ratio

Coarse graded ABT mixture at the edge of the grading envelope

Mixture	Grading	Bitumen (%)	Additive LQ	Comp. Temp	Gyrations to 6% voids
ABT11-7	Coarse	5.6%		100	78
ABT11-7	Coarse	5.6%	0.6%	100	64
Additive Effect					18%
Performance ratio					**1.22** **Some effect**

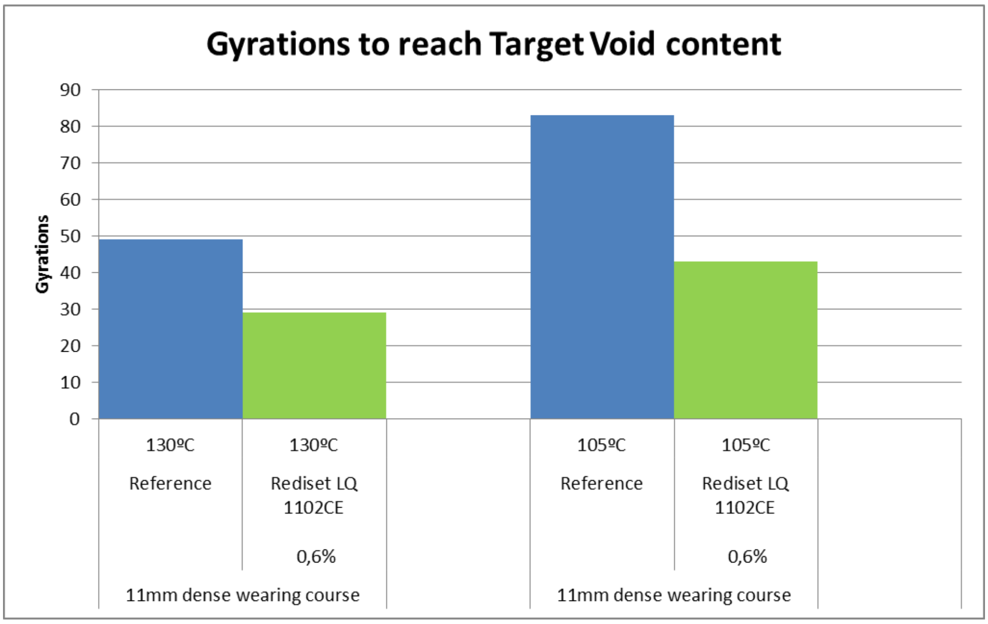
Coarse graded open mixture (SMA) at the edge of the allowed envelope

Mixture	Grading	Bitumen (%)	Additive LQ	Comp. Temp	Gyrations to 6% voids
SMA11-6	Coarse	6.0%		100	62
SMA11-6	Coarse	6.0%	0.6%	100	44
Additive Effect					30%
Performance ratio					**1.41** **Medium effect**

6 Graphical presentation of the gyratory data.

When gyratory compaction data is presented in the form of a chart (Figure 4), the effect of warm-mix additives can be clearly seen. However, while this data representation provides adequate demonstration of the warm-mix effect, more data is needed to look deeper into the performance and fine tuning of the warm-mix additives.

Figure 4 – Commercial representation of test data



6.1 Confirmation of findings from field trials

There is a large percentage of WMA asphalt placed globally which uses warm-mix additives, so we know these additives work. The difficulty is showing this in a laboratory environment and researching improvements. Below are two Swedish trials comparing regular mixtures with WMA mixtures containing additives. Here we see the confirmation that the laboratory performance ratio is indicating correctly additive functionality.

Table 9 – Customer Field trial technical results

	LQ Additive	mixing temp	Comp. temp	Air voids (%)	ITSR (%)
Skanska Sweden, road 68 Lindesberg					
ABb 22mm 50/70 (30 % RAP)	0.6%	140	120	2.1	**94**
Reference		165	155	2.5	**93**
PEAB Asfalt AB, Järfälla					
ABT 16mm 70/100	0.5%	130	110	3.4	**84**
Reference		160	140	3.3	**84**

7 Examples using Marshall Compaction

The Marshall compactor was used to make sample tablets with a range of compactions (25, 50, 75, and 100 blows) and temperatures (100°C and 130°C). Bulk density was measured and plotted against compaction blows in order to read the number of blows needed to achieve 6% air voids.

Table 10 shows the results of the Marshall compactor compared to the Gyratory compactor. In the Marshall compaction we see the Compaction and Performance Ratios' are relatively similar with and without the additive which is not following the results from the gyratory compactor.
This could be due to the different compaction mechanism which has been well documented in for example "Asphalt mixture Compaction and Aggregate Structure Analysis Techniques: State of the art report - Daniel Swiertz, et.al" [6] that the impact forces re-align aggregate thus decreasing the void content. This could be because the particles are shocked into place and not manoeuvred with a lighter loading depending on frictional forces to dictate the final positioning.

Table 10 – Marshall Compaction data vs. Gyratory data

Mixture	Grading	Bitumen (%)	Additive LQ	Comp. Temp (°C)	Blows 6% voids	Gyrations to 6% voids
ABT11-6	Fine	5.6%		130	54	49
ABT11-6	Fine	5.6%		100	70	83
				Compaction Ratio = Gyration ratio =	**1.30**	**1.69**
ABT11-6	Fine	5.6%	0.6%	130	42	29
ABT11-6	Fine	5.6%	0.6%	100	58	43
				Compaction Ratio = Gyration ratio =	**1.38**	**1.48**

Note: - The greater the performance ratio, the greater the performance of the additive.

Mixture	Grading	Bitumen (%)	Additive LQ	Comp. Temp (°C)	Blows 6% voids	Gyrations to 6% voids
ABT11-6	Fine	5.6%		130	54	49
ABT11-6	Fine	5.6%	0.6%	130	42	29
				Performance Ratio =	**1.29**	**1.69**
ABT11-6	Fine	5.6%		100	70	83
ABT11-6	Fine	5.6%	0.6%	100	58	43
				Performance Ratio =	**1.21**	**1.93**

8 Examples using plate compaction data

The Roller Sector Compactor provides comparable compactive characteristics to asphalts compacted in the field by using a two-directional kneading action and varying compaction forces during the compaction sequence. The laboratory compaction apparatus is adjustable by many parameters, temperature, compactive force, sample height, roller arc speed, and sample plates can be made with many compaction profiles with target densities or fixed compactive forces.
Compactions made with the Roller Sector Compactor show differences expected within laboratory testing, however, they are not as amplified as the gyratory compactor, thus the ratios are smaller.
During the project, tests were conducted with either a set compaction sequence which allows the resulting densities to be compared or a set compaction density which will indicate the energy needed to achieve that point.
In Table 11 are some results from laboratory compactions using the Infratest plate compactor and a set density compaction profile of 6% voids as stated in Table 2. What we found was that the plate compactor is adjusting the force continuously during the compaction to reach the intermediate set densities we pre-programmed, so the total number of passes for each mixture is not remarkable different and unlike the data seen in the gyratory compactor. The load data was then analysed and from this data it is apparent that the total loads exerted is seen to be different (as shown in Table 12) and the Performance Ratio will indicate the performance of the additive.

Table 11 – Plate compactor results, number of passes

Mixture	Compaction sequence	Bitumen (%)	Additive LQ	Comp. Temp (°C)	passes 6% voids
ABT11-6	Fixed Density	5.6%		130	53
		5.6%		100	58
		5.6%	0,5%	130	50
		5.6%	0,5%	100	54
				Gyration ratio =	**1.09**
				Performance Ratio =	**1.07**

Table 12 – Plate compactor results, total load used

Mixture	Compaction sequence	Bitumen (%)	Additive LQ	Comp. Temp (°C)	Total load k kN
ABT11-6	Fixed Density	5.6%		130	85
		5.6%		100	102
		5.6%	0,5%	130	61
		5.6%	0,5%	100	66
				Gyration ratio =	**1.20**
				Performance Ratio =	**1.54**

Note: Gyration and Performance ratios indicated in table 11 & 12 are expressed with roller passes in exchange for gyrations.

The Infratest roller plate compactor can also allow tests to be conducted with a fixed compaction profile. This has been used to show the additives functionality in tests where all parameters are the same except for the reference mixture is compacted at 145°C and the WMA has 0.6% additive and compacted at 120°C. The void content was measured and the results showed 3.4% voids for the WMA and 5.8% voids for the reference mix.

9 Physical properties

9.1 Wheel-track permanent deformation results

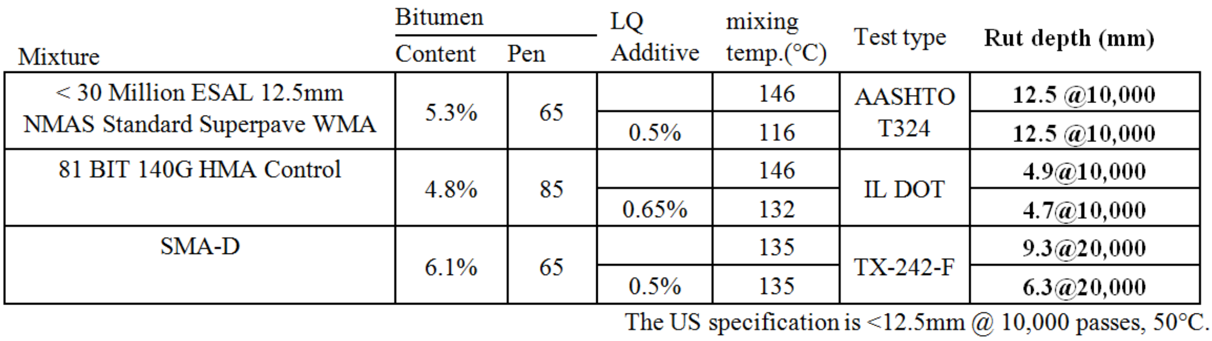
Mixes may compact or deform under traffic leading to rutting. Additives which improve compactability at placement densities and temperatures should not lead to rutting at road densities and temperatures. To support our research the physical properties were tested for regular hot-mix and warm-mix asphalt. The plates which were made in the compactability study suited perfectly for additional permanent deformation testing in the Wheel track device. The tests indicate little additional risk of rutting in mixes containing compaction aids compared to untreated mixes. The mixture and compaction parameters were the same and we found the results followed the expected performance. During the mixing and short term aging stages, the reference binder can become more oxidised which is one explanation for the 1.9% less rut depth compared to the warm-mix samples.

Table 13 – Wheel-track permanent deformation results

Mixture	LQ Additive	mixing temp.(°C)	Comp. temp.(°C)	**Rut depth (mm)**	Prop. Rut depth (%)
Reference ABT11-2		160	130	**6.4**	10.0
ABT11-2 LQ-WMA (6.2% Shell)	0.6%	135	100	**7.6**	11.9

Wheel-track on LQ additive has also been performed by many external sources. In Table 14 we highlight some of these which support the confirmation of the performance of warm-mix additives and the ability to study these in a laboratory environment using the Performance Ratio.

Table 14 – Customer Wheel-track permanent deformation results



Mixture	Bitumen		LQ	mixing	Test type	**Rut depth (mm)**
	Content	Pen	Additive	temp.(°C)		
< 30 Million ESAL 12.5mm NMAS Standard Superpave WMA	5.3%	65		146	AASHTO T324	**12.5 @10,000**
			0.5%	116		**12.5 @10,000**
81 BIT 140G HMA Control	4.8%	85		146	IL DOT	**4.9@10,000**
			0.65%	132		**4.7@10,000**
SMA-D	6.1%	65		135	TX-242-F	**9.3@20,000**
			0.5%	135		**6.3@20,000**

The US specification is <12.5mm @ 10,000 passes, 50°C.

10 Conclusion

Being able to predict asphalt performance in a laboratory environment has always been the key to successful pavements and economical manufacturing. Warm-mixes have introduced many new challenges where researchers have found it more difficult to confirm on a laboratory scale technologies which function in full scale manufacturing.

It is now more encouraging that laboratory testing will show results which are more in conjunction to what is found on the field and development of improved warm-mix additives is easier. Our research indicated that there are similarities in laboratory compaction from the Roller Sector Compactor and Gyratory compactors, but not from the Marshall compaction. The Gyration ratio of the asphalt mixture suggested by NCHRP is an essential parameter to include in research and with the addition of the additives Performance Ratio we can see in the laboratory the benefit and performance of Warm-mix additives and develop new improved additives to support the developing warm-mix asphalt manufacturing market.

11 References

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