# A STUDY OF THE PERFORMANCE OF WARM MIX ASPHALT MANUFACTURED USING A CHEMICAL ADDITIVE

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## ABSTRACT

*For sustainability and environmental reasons, interest in the use of warm-mix asphalt is increasing throughout Europe. Lower mixing temperatures result in reduced energy use at the mixing plant and reduced carbon emissions. However, in order for customers to accept its suitability as a direct replacement for conventional hot-mix asphalt, it must be shown to have equivalent performance.*

*This study of a warm-mix asphalt comprises laboratory tests and site trials. The warm-mix asphalts were manufactured using a modified bitumen at a temperature 35 °C lower than the original hot-mix asphalts. The bitumen was modified using a chemical additive that reduces the surface tension of the bitumen, thus facilating lower mixing and compaction temperatures.*

*In the laboratory study, aggregates from one asphalt production facility were used and the performances of three different mix types were measured. The mix types tested were AC 20, AC 14 EME2 and SMA 10. The parameters that were chosen for the laboratory analysis were ease of compaction, indicated by the evolution of the voids content in the gyratory compactor; rut-resistance in the laboratory wheel tracker; ITSM stiffness modulus, and water sensitivity in the Duriez test. Samples were also taken from site trials to measure water sensitivity.*

*Laboratory tests were also performed on the modified bitumen to show the effect of the additive on its penetration, softening point and surface tension.*

**Keywords:** Warm, asphalt, temperature, surfactant

## 1. Warm Mix Asphalt

Depending on the mix type and bitumen used, traditional hot-mix asphalt (HMA) is produced at temperatures typically ranging from 140 to 180 °C (284 to 356 °F). At these high temperatures, the bitumen becomes less viscous (more fluid) allowing full aggregate coating to be obtained during the mixing process and good workability during laying and compaction. The main goal of "warm-mix asphalt" (WMA) or "low-temperature asphalt" technologies is to reduce these temperatures without sacrificing the performance of the end product. The main benefits of WMA technologies are:

1. Reduced mixing and paving temperatures;
2. Reduced fuel use at the mixing plant;
3. Reduced greenhouse gas emissions, odours, dust and fumes;
4. Enable the use of higher RAP contents;
5. More comfortable working conditions for the paving crew;
6. Longer service life due to reduced oxidative hardening of the bitumen; and
7. Ease of compaction, which allows for longer haul distances and an extended paving season, when the mixes are produced at the more normal hot mix temperatures.

There are many different methods being used throughout the world for the production of WMA. There are also different classification systems, but the three main technologies that are being used in Europe at the moment are:

1. Chemical (surfactant) additives;
2. Wax (organic) additives; and
3. Foaming Technologies (water based and water containing).

While there are many advantages for each of these processes, there are still some concerns related to the water sensitivity and the rut resistance of the end product. It has been reported that some foam and wax based WMA mixtures have a potential to be more susceptible to moisture damage [1, 2]. Moisture sensitivity can cause bitumen stripping from the aggregate and necessitate the addition of an adhesion agent or hydrated lime to prevent premature failure. Concerns over the rut resistance of WMA mixtures are linked to one of its benefits, reduced oxidative hardening of the bitumen during the mixing process. As the degree of oxidative hardening of the bitumen is reduced in WMA mixtures, they may have reduced deformation resistance compared to hot mixes [3].

## 2. Chemical Additives

Chemical additives include emulsification agents, surfactants, additives and adhesion promoters that improve coating, mixture workability and compaction at lower temperatures. The added amount and the temperature reduction achieved depend on the specific product being used. The chemical additive can be in the form of an emulsion, liquid or solid additive. Liquid additives are either blended into the bitumen at the bitumen terminal or added into the bitumen line at the hot-mix plant, just before use. The latter process results in relatively minor modifications to the asphalt plant and requires no modifications to the laboratory mix design process – a significant advantage over the foaming technologies.

The additive chosen for this study is the **CWM®** chemical additive, produced by Chemoran Ltd, Oranmore, Co. Galway. CWM is in liquid form and the amount typically added ranges from 0.2 to 0.5 % (by the mass of the bitumen), depending on the application. Use of the additive does not affect the penetration value or the softening point value of the original bitumen, as can be seen from Table 1.

**Table 1: Effect of CWM on bitumen pen and softening points**

| Bitumen Grade | Penetration (dmm) | Softening Point (°C) |
|---|---|---|
| 35/50 | 36 | 53.8 |
| 35/50 + 0.4 % CWM | 36 | 53.4 |
| 40/60 | 48 | 50.4 |
| 40/60 + 0.4 % CWM | 47 | 50.4 |
| 70/100 | 82 | 45.0 |
| 70/100 + 0.4 % CWM | 84 | 46.0 |
| 160/220 | 186 | 39.0 |
| 160/220 + 0.4 % CWM | 186 | 39.2 |
| PMB | 84 | 73.2 |
| PMB + 0.4 % CWM | 85 | 73.8 |

CWM is a surfactant that reduces the surface tension at the bitumen-aggregate interface. Results of surface tension tests performed on a sample of 40/60 pen bitumen[1], plotted in Figure 1, show that the drop in surface tension is more pronounced at the typical warm mix mixing and compaction temperatures of 100 and 130 °C [4]. It is reputed by its manufacturers that this reduction in surface tension creates a "lubrication effect" that enables the bitumen to coat aggregate and enables the resulting mix to be compacted at lower temperatures than for standard hot mixes; CWM also promotes adhesion between the bitumen and the aggregates.

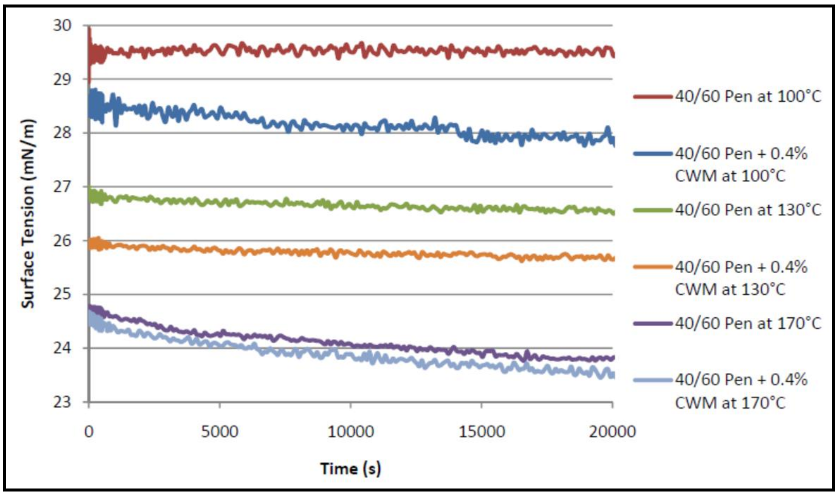

**Figure 1: Plot of surface tension of bitumen with and without CWM**

Full-scale trials have shown that the CWM additive allows mixing temperatures to be reduced by 30 to 40 °C (54 to 72 °F) without any plant modifications. To date, it has been successfully used in many countries including Ireland, UK, France (Figure 2), Poland, Croatia, Hungary, Canada and the USA.


**Figure 2: Laying environmentally friendly warm mix in France.**

## 3. Experimental Laboratory Study

As WMA technologies are still at an early stage of development, laboratory and full scale studies are being performed to gain a fuller understanding of their mechanistic behaviour and to assess their long-term performance capabilities. In May 2011, the Atlantic Bitumen Asphalt Laboratory commenced a comprehensive study of the laboratory and on-site performance of a range of asphalt mix types manufactured at lower temperatures using the CWM additive. The purpose of this study was to compare the performance of these warm-mix asphalts with the performance of equivalent hot-mix

[1] Due to the logistics of transporting the sample of bitumen + CWM to the test laboratory, the sample was two weeks old before being tested.

asphalts. The results presented here are for mixes produced using an aggregate from one asphalt manufacturer and are part of an ongoing study of CWM modified warm mixes manufactured using aggregates from a range of sources. Three different mix types, made using three different bitumens, were chosen in order to test the CWM warm-mix additive over a range of asphalt products. The three mix types were:

1. AC 20 dense bin 40/60 rec (EN 13108-1);
2. AC 14 EME2 bin 10/20 des (EN 13108-1)[2]; and
3. SMA 10 surf PMB 65/105-60 des (EN 13108-5).

A limestone aggregate was used for the three mix types. An imported high PSV coarse greywacke aggregate was also used for the coarse aggregate fraction of the SMA 10 mixes. The aggregate grading and bitumen content of the three mix types are shown in Table 2 below.

**Table 2: Aggregate Grading and Bitumen Content for the three mix types**

| Sieve Size (mm) | AC 20 dense bin | SMA 10 surf | AC 14 EME2 bin |
|---|---|---|---|
| 20 | 100 | - | 100 |
| 14 | 80 | 100 | 99 |
| 10 | 62 | 90 | 75 |
| 6.3 | 48 | 37 | 53 |
| 2 | 30 | 23 | 32 |
| 0.250 | 12 | 10 | 11 |
| 0.063 | 7.3 | 6.1 | 6.9 |
| Aggregate Density | 2734 kg/m³ | 2720 kg/m³ | 2736 kg/m³ |
| $B_{act}$ | 4.7 | 5.3 | 5.5 |
| Binder Content * | 4.9 | 5.5 | 5.7 |
| * Binder contents corrected to aggregate density of 2650 kg/m³ i.a.w. Cl. 5.3.1.3 of EN 13108-1 and Cl. 5.2.3 of EN 13108-5. | | | |

The laboratory performance tests used were those currently specified by the National Roads Authority (NRA) in Ireland for the hot-mix asphalt versions of these three mix types [5]:

a) compaction testing using the gyratory compactor (EN 12697-33);
b) rut-testing (EN 12697-22 Small Device, Procedure B at 60 °C/140 °F);
c) water sensitivity, Duriez test (EN 12697-12, Method B); and
d) ITSM stiffness testing (EN 12697-26, Annex C at 20 °C/68 °F).

The mixing and compaction temperatures used are shown in Table 3 below. The mixing temperatures for the hot mixes are specified in EN 12697-35 and the compaction temperatures are specified in the relevant test method standards.

**Table 3: Mixing and Compaction Temperatures**

| | Hot Mix Specimens | | Warm Mix Specimens | |
|---|---|---|---|---|
| Mix Type | Mixing Temperature | Compaction Temperature | Mixing Temperature | Compaction Temperature |
| AC 20 dense bin 40/60 | 175 °C / 347 °F | 150 °C / 302 °F | 140 °C / 284 °F | 115 °C / 239 °F |
| AC 14 EME2 bin 10/20 | 185 °C / 365 °F | 180 °C / 356 °F | 150 °C / 302 °F | 145 °C / 293 °F |
| SMA 10 surf PMB | 170 °C / 338 °F | 145 °C / 293 °F | 135 °C / 275 °F | 110 °C / 230 °F |

[2] AC 14 EME2 is the official designation used in Ireland for a 0/14 mm EME mixture, as it is classified as an asphalt concrete (AC) in accordance with EN 13108-1.

The mixing and compaction temperatures for all of the warm-mix asphalts were 35 °C (63 °F) lower than those of their conventional hot-mix counterparts. In addition, and in order to better evaluate the effect of CWM on the warm-mix asphalt mixtures, a third set of test specimens, called the "non-modified warm-mixes", were also manufactured at the warm-mix temperatures but without the addition of the CWM modifier in the bitumen. For this study, the CWM additive was dosed into the bitumen at a rate of 0.4 % by mass of the bitumen (as recommended by the manufacturer for standard asphalt mixes) and mixed under low shear for 10 minutes. The asphalt materials were mixed in a 20 l Hobart mixer in accordance with EN 12697-35. Pilot work on the water sensitivity tests had identified a need to exercise care in dispersing the additive in the bitumen.

## 3. Results of the Gyratory Compaction Test

The gyratory compactor is used to test the ease of compaction or "compactibility" of a mix. During this study, the settings for the gyratory compactor were a pressure of 0.6 MPa, an angle of inclination of 1 degree and a gyration speed of 12 revolutions per minute. (These settings were determined in accordance with Annex A of EN 12697-31.) The mould diameter was 150 mm and 5000 ± 10 g of asphalt mixture were added to the mould. The results are presented in Figure 3 below. Each result represents the average of three specimens.

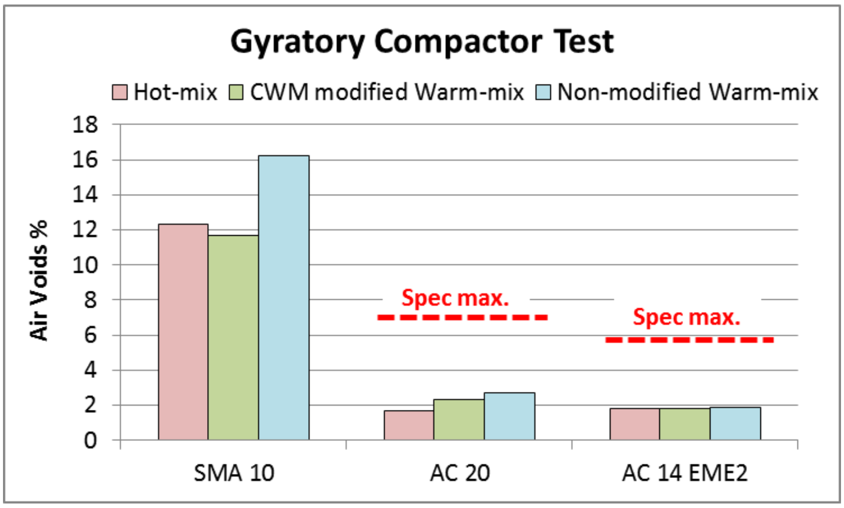


**Figure 3: Results of Gyratory Compactor Test for the three mix types**

An ANOVA was performed to analyse the data with Air Voids as the response variable and Mix Type and Temp Type as the factors. (For the ANOVAs performed in this study, "Mix Type" represents the AC 20, SMA 10 and AC 14 EME2 mixes and "Temp Type" represents the Hot mix, CWM modified warm mix and Non-modified warm mix.)

**Table 4. ANOVA Results for Gyratory Compactor**

| Source | DF | Seq SS | Adj SS | Adj MS | F-stat | P-value | Significant * |
|---|---|---|---|---|---|---|---|
| Mix Type | 2 | 778.16 | 778.16 | 389.08 | 319.13 | 0.000 | Yes |
| Temp Type | 2 | 17.00 | 17.00 | 8.50 | 6.97 | 0.005 | Yes |
| Error | 22 | 26.82 | 26.82 | 1.22 | | | |
| Total | 26 | 821.99 | | | | | |
| * Significant at the 5 % level of significance | | | | | | | |

From the above results, it can be concluded that the "Temp Type" is having an effect on the Air Voids obtained in the Gyratory Compactor [p-value 0.005]. A Tukey post-hoc procedure showed that there was no significant difference between the sample averages of recorded air voids for the hot-mix and the CWM modified warm-mix specimens [p-value 0.9997] but that there was a difference between the sample averages of recorded air voids for the CWM modified warm-mix and the non-modified warm-mix specimens [p-value 0.0105].

## 4. Results of the Rutting Test

The rut-resistances of the three mix types were measured by performing the wheel-tracking test using the "Small size device, Procedure B", in accordance with EN 12697-22 at 60 °C. The slab specimens were manufactured using a laboratory slab compactor, as specified in EN 12697-33. However, as neither EN 12697-22 nor EN 12697-33 specify a target voids content or a compaction procedure (pressure and number of passes), it was decided to try to replicate the compaction effort that occurs on site. Based on typical compaction rollers used on site and on assumed contact patch areas for both on site and laboratory compaction using the slab compactor, the pressures applied in the twin pistons of the laboratory compactor were as shown in Table 5. An assumed eight passes of a tandem roller was equivalent to sixteen passes of the laboratory roller.

**Table 5 – Pressures Applied to Materials on Site and Pressure Settings on the Laboratory Slab Compactor**

| Mix Type | Pressure on site (bars) | Pressure in pistons of slab compactor (bars) |
|---|---|---|
| AC 20 dense bin | 17.9 | 2.78 |
| SMA 10 surf | 11.1 | 1.71 |
| AC 14 EME2 | 29.3 | 4.55 |

The slabs were then tested in the wheel tracker at 60 °C. The results are summarized in Figure 4 and 5 showing rut depths after 10,000 cycles and rut rates in micro-meters per cycle, respectively; the average voids contents are noted in brackets on the bar charts. Each result represents the average of six specimens. As this test method (EN 12697-22 “Small size device, Procedure B”) has only recently been introduced in Ireland, specification limits have not yet been set for the rut depth or rut rate.

The low average air voids content of the AC 20 of 1.8 and 1.1 % for the hot-mix and CWM modified warm-mix specimens, respectively, may be lower than what is normally achieved on site. This may be explained by the high bitumen content used for this mix and its dense grading curve, but it may also indicate that the compaction levels being achieved by the laboratory slab compactor are higher than those typically achieved on site.

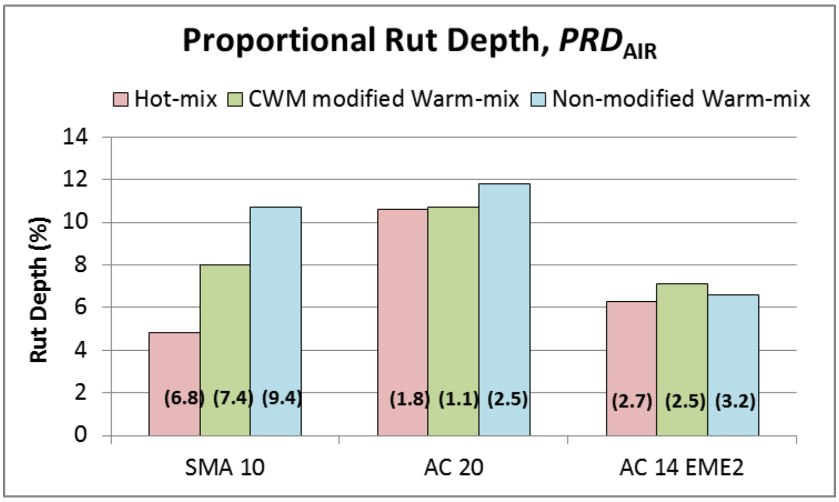


**Figure 4: Proportional Rut Depth results from the wheel tracker test**

The results of the ANOVA to analyse Rut Depth as the response variable and Mix Type and Temp Type as the factors are shown in Table 6.

**Table 6. ANOVA Rut Depth Results from the Wheel Tracker Test**

| Source | DF | Seq SS | Adj SS | Adj MS | F-stat | P-value | Significant * |
|---|---|---|---|---|---|---|---|
| Mix Type | 2 | 193.996 | 193.996 | 96.998 | 33.570 | 0.000 | Yes |
| Temp Type | 2 | 71.041 | 71.041 | 35.521 | 12.300 | 0.000 | Yes |
| Error | 49 | 141.562 | 141.562 | 2.889 | | | |
| Total | 53 | 406.599 | | | | | |
| * Significant at the 5 % level of significance | | | | | | | |

From the results, it can be concluded that the “Temp Type” has an effect on the Rut Depth values obtained [p-value 0+]. The Tukey post-hoc procedure showed that a significant difference existed between the sample averages of recorded

Rut Depth for the hot-mix and the CWM modified warm-mix specimens [p-value 0.0122], and that a significant difference existed between the sample averages of recorded Rut Depth for the CWM modified warm-mix specimens and the non-modified warm-mix specimens [p-value 0.1380].

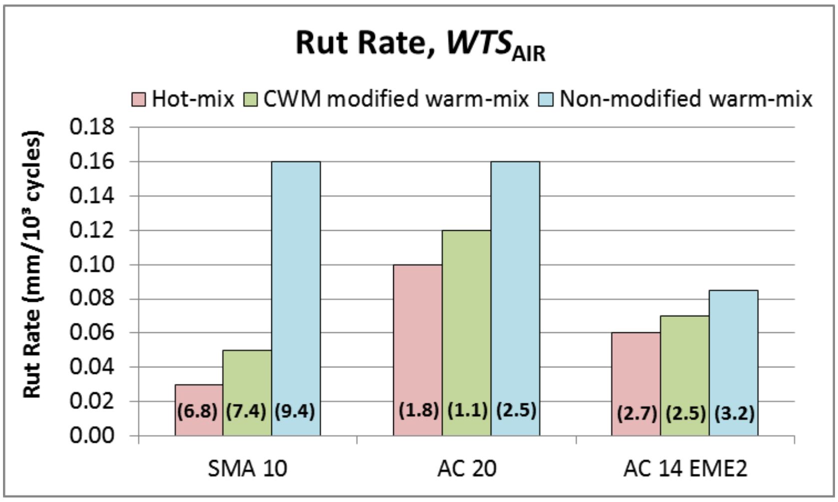


**Figure 5: Rut Rate results from the wheel tracker test**

The ANOVA for the Rut Rate date is shown in Table 7.

**Table 7. ANOVA Rut Rate Results from the Wheel Tracker Test**

| Source | DF | Seq SS | Adj SS | Adj MS | F-stat | P-value | Significant * |
|---|---|---|---|---|---|---|---|
| Mix Type | 2 | 0.037 | 0.037 | 0.018 | 24.140 | 0.000 | Yes |
| Temp Type | 2 | 0.056 | 0.056 | 0.028 | 36.550 | 0.000 | Yes |
| Error | 49 | 0.037 | 0.037 | 0.001 | | | |
| Total | 53 | 0.129 | | | | | |
| * Significant at the 5 % level of significance | | | | | | | |

From these results, it can be concluded that the "Temp Type" has an effect on the Rut Rate values obtained [p-value 0+]. A Tukey post-hoc procedure showed that no significant difference existed between the sample averages of recorded Rut Rate for the hot-mix and the CWM modified warm-mix specimens [p-value 0.1050] but that a significant difference existed between the sample averages of recorded Rut Rate for the CWM modified warm-mix specimens and the non-modified warm-mix specimens [p-value 0+].

So, while it can be concluded that the performance of the CWM modified warm-mix specimens is equal to that of hot-mix specimens, in terms of Rut Rate, its performance, in terms of Proportional Rut Depth, is less than that of the hot-mix specimens. Such findings have also been reported for other laboratory studies of various types of warm mixes and the decreased oxidative ageing of the bitumen during the mixing process has been suggested as a reason for the increased rutting potential [1]. However, no such findings have yet been reported for material laid on site.

## 5. Results of the Stiffness Test

The procedure for performing the Indirect Tensile Stiffness Modulus (ITSM) test is described in EN 12697-26, Annex C. EN 12697-22 specifies what equipment can be used to prepare the test specimens in the laboratory but it does not specify a compaction procedure. For this study, all of the ITSM test specimens were compacted using the gyratory compactor. The air voids achieved using the gyratory compaction test (reported in Section 3 above) were attainable within the linear range of the relationship of voids content versus the logarithm of the number of gyrations for the SMA 10 mix. However, for the other two mixes, AC 20 and AC 14 EME2, they were not. Instead, the hot-mix test specimens were compacted to target air voids contents that are typically found on site for these hot-mix materials. Then, in order to perform a fair comparison, the same compaction effort that was used for the hot-mix specimens was also used to prepare the CWM modified warm-mix and Non-modified warm-mix test specimens. The resulting stiffness moduli are shown in Figure 6 with the average air voids contents for each mix type shown in brackets. Each result represents the average of three specimens. In the NRA Specification for Road Works, there is only a stiffness modulus requirement for EME2 mixtures and it must be not less than 5,500 MPa.

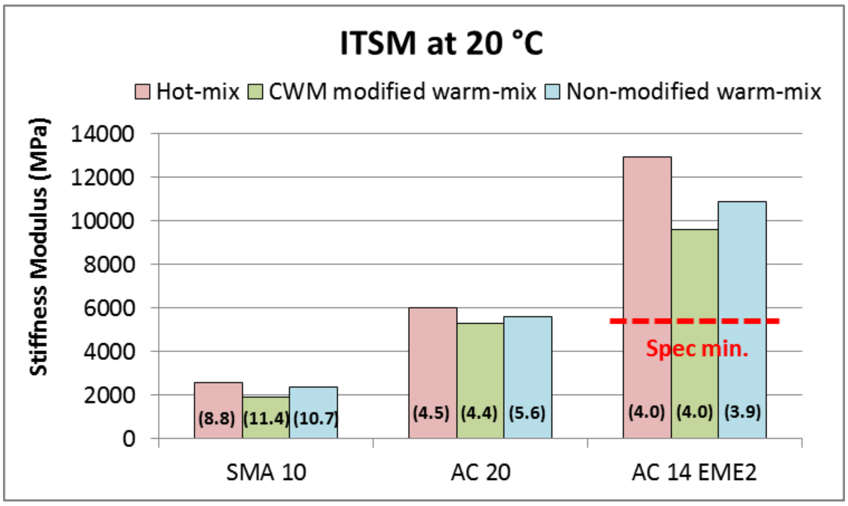


**Figure 6: Results of ISTM Stiffness Modulus Tests**

The ANOVA performed to analyse the data with Stiffness Modulus as the response variable and Mix Type and Temp Type as the factors is shown in Table 8.

**Table 8. ANOVA Stiffness Modulus Results from the ITSM Test**

| Source | DF | Seq SS | Adj SS | Adj MS | F-stat | P-value | Significant * |
|---|---|---|---|---|---|---|---|
| Mix Type | 2 | 344168314 | 344168314 | 172084157 | 595.260 | 0.000 | Yes |
| Temp Type | 2 | 8833422 | 8833422 | 4416711 | 15.280 | 0.000 | Yes |
| Error | 22 | 6360033 | 6360033 | 289092 | | | |
| Total | 26 | 359361770 | | | | | |
| * Significant at the 5 % level of significance | | | | | | | |

From the above results, it can be concluded that “Temp Type” has an effect on the stiffness modulus values [p-value 0+]. The Tukey post-hoc procedure showed that a significant difference existed between the sample averages of recorded stiffness moduli for the hot-mix and the CWM modified warm-mix specimens [p-value 0.0001] and that a significant difference existed between the sample averages of recorded stiffness moduli for the CWM modified warm-mix and the non-modified warm-mix specimens [p-value 0.0304]. As can be seen from Figure 6, the biggest difference between the stiffness moduli of the hot-mix and CWM modified warm-mix specimens was noticed for the AC 14 EME2 mixes. However, the average stiffness modulus of the CWM modified warm-mix AC 14 EME2 was still well in excess of the minimum value of 5,500 MPa specified by the NRA [5].

## 6. Results of the Water Sensitivity Test

The results of the Duriez Dry Strengths and Duriez Wet/Dry Ratio are shown in Figures 7 and 8, respectively. Each result represents the average of three specimens tested. The average air voids contents of the specimens are noted in brackets on the bar chart. The Duriez Dry and Wet Strength values for the AC 20 CWM modified warm-mix asphalt are for specimens that were allowed to cure for 14 days, as explained in Section 7.

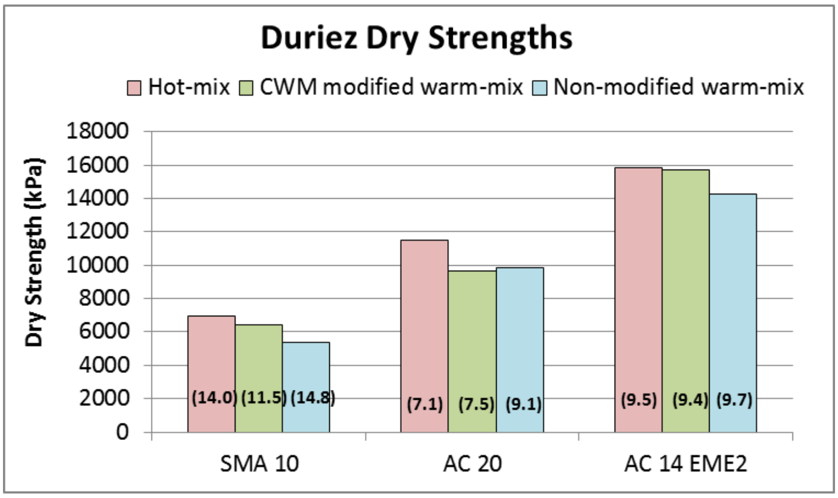


**Figure 7: Duriez Dry Strength Results**

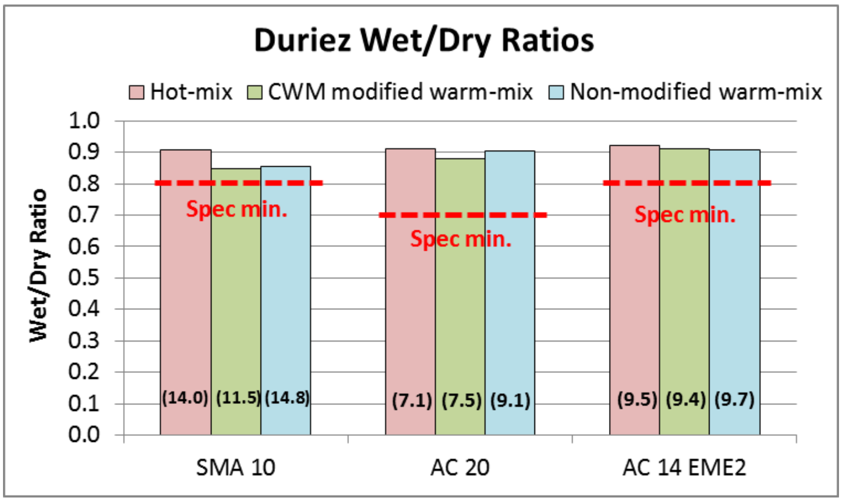


**Figure 8: Water Sensitivity Ratio Results**

The results of the ANOVA to analyse Duriez Dry Strength as the response variable and Mix Type and Temp Type as the factors are shown in Table 9.

**Table 9. ANOVA Duriez Dry Strength Results from the Water Sensitivity Test**

| Source | DF | Seq SS | Adj SS | Adj MS | F-stat | P-value | Significant * |
|---|---|---|---|---|---|---|---|
| Mix Type | 2 | 365750237 | 365750237 | 182875119 | 365.850 | 0.000 | Yes |
| Temp Type | 2 | 11793213 | 11793213 | 5896606 | 11.800 | 0.000 | Yes |
| Error | 22 | 10997087 | 10997087 | 499868 | | | |
| Total | 26 | 388540537 | | | | | |
| * Significant at the 5 % level of significance | | | | | | | |

From the results, it can be concluded that the "Temp Type" has an effect on the Duriez Dry Strength values obtained [p-value 0+]. Once again, the Tukey post-hoc procedure showed that no significant difference existed between the sample averages of recorded Duriez Dry Strength for the hot-mix and the CWM modified warm-mix specimens [p-value 0.1936] but that a significant difference did exist between the sample averages of recorded Duriez Dry Strengths for the CWM modified warm-mix and the non-modified warm-mix specimens [p-value 0.0171].

As the ratio of two normally distributed random variables would not itself be normally distributed and because the sample size is so small (only 9 observations), it is not possible to justify performing a parametric ANOVA on the Duriez Wet/Dry Ratios. Therefore, a non-parametric Friedman Test was performed.

**Table 10. Friedman Test of Duriez Wet/Dry Ratios**

| Source | S | DF | P-value | Significant * |
|---|---|---|---|---|
| Mix Type | 5.17 | 2 | 0.076 | No |
| Temp Type | 5.64 | 2 | 0.060 | No |
| * Significant at the 5 % level of significance | | | | |

From the results of the Friedman Test, "Temp Type" is not having an effect on the Duriez Wet/Dry Ratio [p-value 0.076]. Therefore, it can be concluded that there was no significant difference between the sample averages of recorded Duriez Wet/Dry Ratios for the hot-mix and the CWM modified warm-mix specimens.

Based on all of the above results, it can be concluded that the warm-mix specimens produced using the CWM additive display water sensitivity values equal to that of the hot-mix specimens.

## 7. Effect of curing

CEN technical committee TC227 have recently recognised that some hot mix asphalts gain in strength during the early stage of their service life due to bitumen hardening. Consequently, the next revision of EN 12697-22 will contain a requirement to cure laboratory prepared specimens for at least 14 days before testing [6]. For this reason, it was decided that the effect of curing on the stiffness modulus and water sensitivity of the CWM modified warm-mix asphalts should also be investigated in the study.

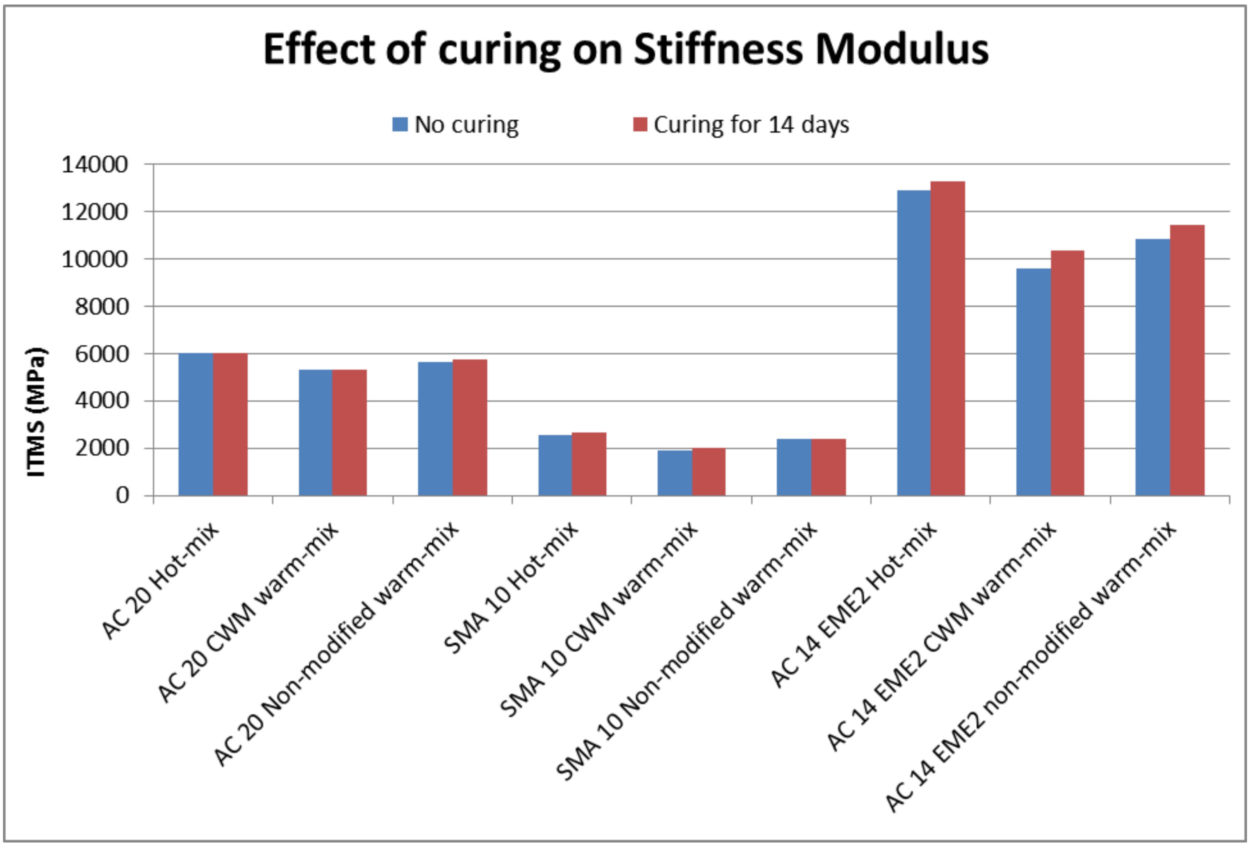


**Figure 9: Effect of curing for 14 days on ITSM**

The results, plotted in Figures 9, show that curing for 14 days had little effect of the ISTM stiffness of the materials tested. However, curing was found to have an effect on the water sensitivity of the AC 20 CWM modified warm-mix specimens. The Duriez Wet/Dry Ratio for the AC 20 warm-mix asphalt increased from 0.74 to 0.88 when it was allowed to cure for 14 days before being immersed in water. As shown in Figure 10, the Duriez Ratio of 0.88 matched very closely the Duriez Ratio of 0.91 that was obtained when samples of CWM modified AC 20 CWM modified warm-mix asphalt were taken, from behind the paver, during a full scale site trial.

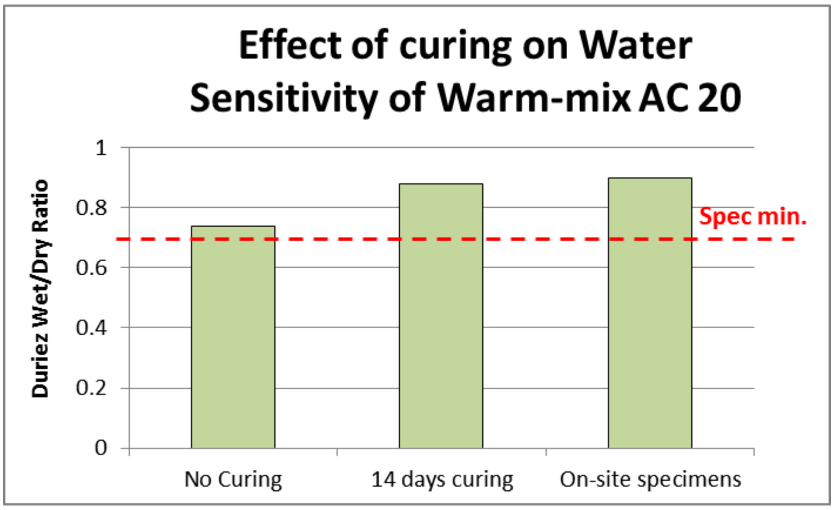


**Figure 10: Duriez Wet/Dry Ratios for AC 20**

The effect of curing on the water sensitivity of the laboratory prepared specimens may help to explain why some practitioners have reportedly obtained lower water sensitivity ratios, for some asphalt mix types, with laboratory prepared specimens compared to specimens of the same material taken from site. CWM is a surfactant and it may be better dispersed throughout the asphalt mixture in plant mixed materials. However, in laboratory prepared warm-mix specimens, the CWM surfactant may not be as well dispersed and, thereby, may remain active for longer. Consequently, laboratory prepared specimens may require more time for the chemical additive to dissipate before the specimens are placed in the water bath. It should be noted that clause 6.5.3 of EN 13108-20 allows asphalt manufacturers to use either laboratory prepared specimens or plant produced specimens, when type testing asphalt products for CE Marking.

## 8. Conclusions

The first part of a wider study to compare the performance of CWM modified warm-mix asphalt with hot-mix asphalt has been completed by the Atlantic Bitumen Asphalt Laboratory. All of the specimens tested were made using aggregate from one asphalt manufacturing facility. The results obtained show that CWM modified warm-mix asphalts perform equally as well as the hot-mix versions of the same asphalt mixtures when tested using the Gyratory Compactor, Wheel Tracker Rut Rates and Water Sensitivity (Duriez) Test.

An increase in Proportional Rut Depth was only noticed in the SMA 10 mix. An increase in rutting potential may be related to the decrease in oxidative hardening of the bitumen during the mixing process. This phenomenon has also been found in laboratory studies of other WMA products [1]. The decrease in oxidative hardening may also be leading to the lower ITSM stiffness modulus values. This reduction was most noticeable for the AC 14 EME2 mixes but the average ITSM stiffness modulus obtained for the CWM modified warm-mix AC 14 EME2 test specimens was still well above the specified minimum value. Moreover, the CWM modified warm-mix specimens for the three mix types tested satisfied all of the performance requirements specified by the National Roads Authority. The most significant difference between the CWM modified warm-mix specimens and the non-modified warm-mix specimens is the levels of compaction achieved. This shows that the CWM additive is acting as a compaction aid at the reduced (-35 °C) mixing temperatures.

The tests have shown that CWM can be used with a range of commonly used paving grade bitumens, including polymer modified bitumens and for a range of asphalt mix-types. Further work will continue with the use of aggregates from other quarry sources. Fatigue tests will also be performed to measure the extent that the reduction in oxidative hardening leads to a longer service life for warm mix asphalts.

## REFERENCES

[1] Evaluation of Potential Processes for Use in Warm Mix Asphalt, Hurley, G.C. and B.D. Prowell, Journal of the Association of Asphalt Paving Technologists, Vol. 75, pp 41-85, 2006.
[2] Interstates 55 and 57 in Missouri 170,000 tons of Warm Mix, Fort, J.P, G. Graham & S. Sinn, European Roads Review 18, pp 14 – 20, France, Spring 2011.
[3] Talking Asphalt: What about warm mix? Walker, D, Asphalt Magazine, Asphalt Institute, USA, May 2011.
[4] Teclis Analysis Report, Lyon, France, 2011.
[5] Specification for Road Works, Series 900, National Road Authority, Ireland, March 2011.
[6] EN 12697-26: 2011, Bituminous mixtures - Test methods for hot mix asphalt - Part 26: Stiffness, CEN, Belgium, 2011.