Foamed Bitumen in Half-Warm Asphalt: A Laboratory Study

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ABSTRACT

In the last decade, techniques to reduce the production temperature of asphalt have become very popular. In this respect there are three main classes of techniques. First the techniques referred to as warm techniques, where mixing temperatures are generally reduced to around 120 – 130 °C. In these methods the aggregates are generally dry before mixing. Second, there are a number of techniques referred to as semi- or half-warm techniques, and in this case the mixing temperatures are below 100°C. And third, we have the cold paving technology producing asphalt at ambient temperature. With the last two techniques, the aggregates still contain considerable amounts of moisture as the heating temperatures are not sufficiently high to dry them. Moreover, these techniques depend on the presence of water. Of course, the savings in energy and emissions are considerably larger, when there is no need to fully dry all the materials.

In 2006, Nynas together with the Belgian Road Research Centre started a project to evaluate the performance of hot versus warm and semi-warm produced asphalts. Two warm techniques were selected, the addition of waxes and the addition of zeolites, and one half-warm technique. In the half-warm technique, foamed bitumen is used combined with wet aggregates and a mixing temperature of 90°C. The project also includes the construction of field sections for the three techniques.

This publication focuses on the laboratory evaluation using the half-warm technique with foamed bitumen, wet aggregates, and a mixing temperature of 90°C. Several parameters were varied, including the total moisture content of the aggregates at mixing, the time lag between mixing and compaction of the asphalt, the influence of adding an active filler, the effect of foaming the binder versus just adding hot bitumen to the mixture. The evolution of the mechanical properties after mixing and compacting the asphalt was also investigated.

1. Introduction

Initially, foamed bitumen was mixed with aggregates at ambient conditions. When compared to unbound base layers, the use of foamed bitumen gives a clear improvement. On the other hand, when compared to hot mix asphalt, cold mix asphalt with foamed bitumen has inferior performance and cannot be used for wearing courses intended for high traffic. This has initially restricted the use of foamed mixes to base stabilization and cold in-place recycling (Van de Ven et al., 2007)

To improve the performance of the foaming technique and to broaden its use, a number of special techniques were developed. Most of these techniques use higher aggregate temperatures, typically up to 80-100°C. Under these conditions, foamed bitumen (at 140-160°C) is added to the aggregates. The equilibrium temperature of the mixture after mixing commonly results in a mixture temperature of approximately 80-95°C. As the aggregates do not need to be completely dried and since production temperature is still below 100°C, the techniques are referred to as semi- or half-warm techniques (Jenkins et al., 2001, Landa et al. 2004, Goos et al. 2006, Molenberg et al. 2006, Olard et al. 2006, Olard et al.2009)

In this paper the laboratory study conducted on half-warm mixes with foamed bitumen is presented in detail. The following parameters were varied and evaluated: the initial moisture content of the mix, the time between mixing and compaction, the use of bitumen as such or as foam, the need for an active filler, and in this respect, two types of active filler were evaluated. Mechanical properties of the prepared mixes were also investigated with a special attention to possible curing effects. Since mixtures prepared with foamed bitumen contain a certain amount of moisture when compacted, it is believed that a curing period is necessary to allow further drying of the compacted samples and to reach the final performance of the mix. In addition, the presence of active filler can also have an impact on the curing. Performance properties like indirect tensile strength and indirect tensile strength ratio were followed as a function of curing time.

2. Experimental

2.1. Materials and mix design:

The study was made with a mix type AB-4C, which is specified in the standard specifications of the Flemish region (SB250-v2.1). This is an asphalt concrete mix for top layers, AC 0/10 according to the European standards. For mix design, use was made of the PradoWin software of BRRC (see ref.). With the characteristics of the different constituents as input data, this software predicts the volumetric composition and void content of the mix for a given mix composition. Table 1 shows the dry mix composition. The grading of the mix is shown in figure 1. The binder is Nyfoam 50, which also fits a paving grade bitumen 50/70 (acc. to EN12591), added in 5.84 % by mass in the mix (6.2 % by mass on the aggregate mass). In case an active filler was used, 1% of the standard filler was replaced by 1% of active filler.

Table 1: Composition of the reference mix AC 0/10 (dry aggregates)

Type	Component	Density (g/cm^3)	Volume (%)	Mass (%)
Filler	Duras II	2,61	7,7	7,4
Stone	porphyry 4/6.3	2,71	19,9	20,0
Stone	porphyry 2/4	2,71	22,4	22,5
Stone	porphyry 6.3/10	2,71	16,6	16,7
Sand	porphyry 0/2	2,72	25,1	25,3
Sand	Round sand	2,62	8,4	8,1

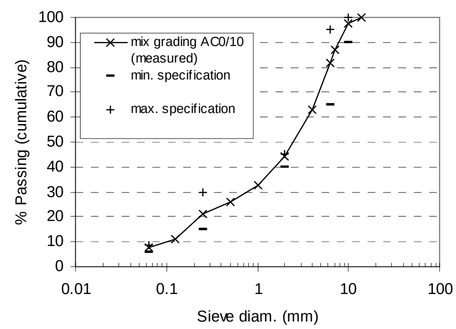

Figure 1: grading of the mix AC 0/10

2.2. Laboratory production of foamed asphalt:

Compared to hot mix asphalt, the production of half-warm foamed mixes in a laboratory is different and requires some additional steps:

- First of all the bitumen needs to be foamed, and in this study a Wirtgen laboratory foam unit was used. The optimum water content of the foam needs to be determined, based on a compromise between expansion ratio and collapse time of the foam. The procedure is explained in Cruz et al., 2006. For the laboratory study described in this paper, the water content of the foam was fixed at 3% and this parameter was not varied anymore.
- Secondly, to have the desired bitumen percentage in the mixture, a relation between foaming time and bitumen amount needs to be established before starting the asphalt mixing process. By adjusting the foaming time, the desired amount of binder can then be added to the asphalt mix. This procedure is only accurate if the bitumen and water content in the foam are stable.
- As the foam unit, used in this study, is suited for foaming larger quantities of bitumen, it would be unpractical to prepare the mix in small quantities. The quantity prepared in one batch in the laboratory was about 40 kg of asphalt. This means that from one batch, a large number of test specimens could be compacted in the gyratory compactor. Consequently, when comparing specimens, the time between mixing and compaction is an additional parameter.
- In addition, the aggregate fractions are in this procedure wet, and the water content of the aggregate fractions needs to be controlled carefully.

To summarize, there are more parameters that play a role, which are also more difficult to control accurately.

The foamed asphalt mixes were prepared using a Guedu asphalt mixer. The foamed bitumen was directly transferred from the foaming unit into the asphalt mixer. To control the moisture content of the aggregates a special procedure was followed: First all aggregates were completely dried, then a calculated water content was added to the mixture of stone and sand fractions, and subsequently this mixture was stored at 90°C for 12 hours. During storage at 90°C the aggregates were kept in a closed container, but with a small hole to avoid pressure build-up. This procedure was followed to allow the water to be absorbed inside the pores of the aggregate material, which corresponds better to field conditions. After these 12 hours, the water content was again verified (by weighing), and was, if needed, corrected to the desired amount. Then the damp aggregates and sand were transported in the asphalt mixer. Foam was added and mixed for 2 minutes, afterwards the dry filler, if desired combined with active filler, was added and mixing was continued for 3 minutes. In figure 2 the bitumen foaming equipment and the asphalt mixer are shown. Both equipments are mobile so that the foam can be directly injected into the asphalt mixer.

Figure 2: Wirtgen laboratory foam unit, together with the asphalt mixer

2.3. Test methods:

The water content of the loose mixture was measured using two methods:

1. The weight loss of a loose mix sample was recorded, during storage for 12 hours at 110°C, a time interval that should be sufficiently long to dry the mixture.
2. A sample of the loose mix is first submerged in methanol for about 1 hour, at ambient temperature. During this period the methanol extracts the water from the sample. Afterwards the methanol (and extracted water) is evaporated (at 90°C, for 1 hour), and the weight loss of the sample is recorded.

The second method is faster compared to the first method, and there may be a difference in case an active filler is used, because in the second method the tendency for an active filler to react with the rest water may be less. The water content of compacted cores was also evaluated, by following the weight loss, after storage at controlled conditions of humidity and temperature (15°C and a relative humidity of 40-55%). This was followed for a long time (about 10 weeks), after which they were considered completely dry.

To evaluate the compactability, the gyratory compactor was used according to the European standard (EN 12697-31). The mix preparation procedure followed EN 12697-35. According to this standard, the reference temperature (temperature at which compaction starts) of the hot mix asphalt type AC 0/10 is 150 °C (case of a bitumen B 50/70).

The water sensitivity of the mix was investigated by means of the indirect tensile strength (ITS) test (EN 12697-23), before and after conditioning in water according to EN 12697-12. Six cores are needed to perform the water sensitivity test. Three cores are subjected to the ITS test without conditioning. The three other cores are conditioned according to EN 12697-12, before being subjected to the ITS-test. The ratio of the ITS after and before conditioning (ITSR) is a measure for the water sensitivity of the mix and indirectly for the adhesion between binder and aggregate. As water sensitivity is very dependent on the degree of compaction, the tests were performed on cores with a low degree of compaction, to simulate the worst case in field situations. In this study, the gyratory cores used for indirect tensile testing were compacted to 25 gyrations, because we have indications from field trials with warm mix techniques, using wax modified binders or zeolites, that compaction to 25 gyrations is representative for the lowest degree of compaction in the field. This will be verified for the half- warm foam technique once the field sections are constructed.

Indirect tensile strength and indirect tensile strength ratio were followed as a function of curing time. This curing was simulated by storing the samples in a climatic chamber at a temperature of 15°C and a relative humidity of 40-55%. These conditions are chosen as close as possible to average outside conditions in order to prevent the impact of artifacts.

3. Results

3.1. Compactability:

For the two warm techniques studied in this project, using waxes and using zeolites, the compactibility could be established with the gyratory compactor (De Visscher et al., 2008, Soenen et al., 2008). For these warm techniques, every sample compacted in the gyratory compactor was mixed in a separate batch, using a small volume asphalt mixer. For the foam technique however, this was not possible, as explained in 2.2. When a batch of foam mix was made, each time a large number of asphalt cores were compacted, with increasing time intervals between mixing and compacting. In table 2, an overview of the respective cases for foamed mixes, with the respective parameters that were varied, are given. The differences between the various batches of case 1, are explained below.

Table 2: Overview of test cases and test runs preparing reference and foamed asphalt

Asphalt batch	*Use of foam*	*Use of an active filler*	*Moisture content aggregates (in % of the aggregate mass)*
Ref. mix at 150°C	No	None	Dry
Ref. mix at 90°C	No	None	Dry
Case 1-batch 1	Yes	1% filler A	2.5
Case 1-batch 2	Yes	1% filler A	2.5
Case 1-batch 3	Yes	1% filler A	2.5
Case 1-batch 4	Yes	1% filler A	2.5
Case 2	Yes	None	2.5
Case 3	No	1% filler A	2.5
Case 4	No	1% filler B	2.5
Case 5	Yes	1% filler B	2.5
Case 6	Yes	1% filler A	1.0

* case 1-batch 1 differs from batches 2, 3 & 4 in the storing conditions of the loose mix before compaction.

After evaluation of the first batch, case 1-batch 1 in table 2, it was observed that the compaction levels of various cores prepared from the same asphalt batch, decreased when the time between mixing and compaction increased. During this time the loose asphalt was just left in the partly covered asphalt mixer at 90°C, and immediately before taking a sample the mixer was run for a few minutes. The variation in compaction was attributed to an evaporation of the moisture from the mixer. Because of this observation, a different procedure for storing the loose asphalt at 90°C was used for all later test runs. In this procedure only the first samples (compacted up to 2 hours after mixing) were taken directly from the asphalt mixer, while samples intended for compaction at a later stage were all taken from the mixer within 1 hour after mixing, and subsequently stored in separate cans at 90°C, covered with aluminum foil. This procedure was followed in order to be able to record all weights carefully and to follow for each individual core the weight loss before it was compacted.

In figure 3, densities obtained after 25 gyrations are shown as a function of time between mixing and compacting. These densities are calculated from the sample weight and the dimensions after 25 gyrations. The first two tests in this figure refer to the density of the reference mix (without bitumen foaming) at a compaction temperature of respectively 150°C and 90°C. In the reference cases, all components were fully dried and the mixing temperature was approximately 15 °C higher than the compaction temperature. The red lines refer to the densities obtained in the reference case at 150°C.

The densities reported in figure 3 are average values of at least two consecutive tests, and the times reported are median times. The error bars represent the standard deviation between the different repeats.

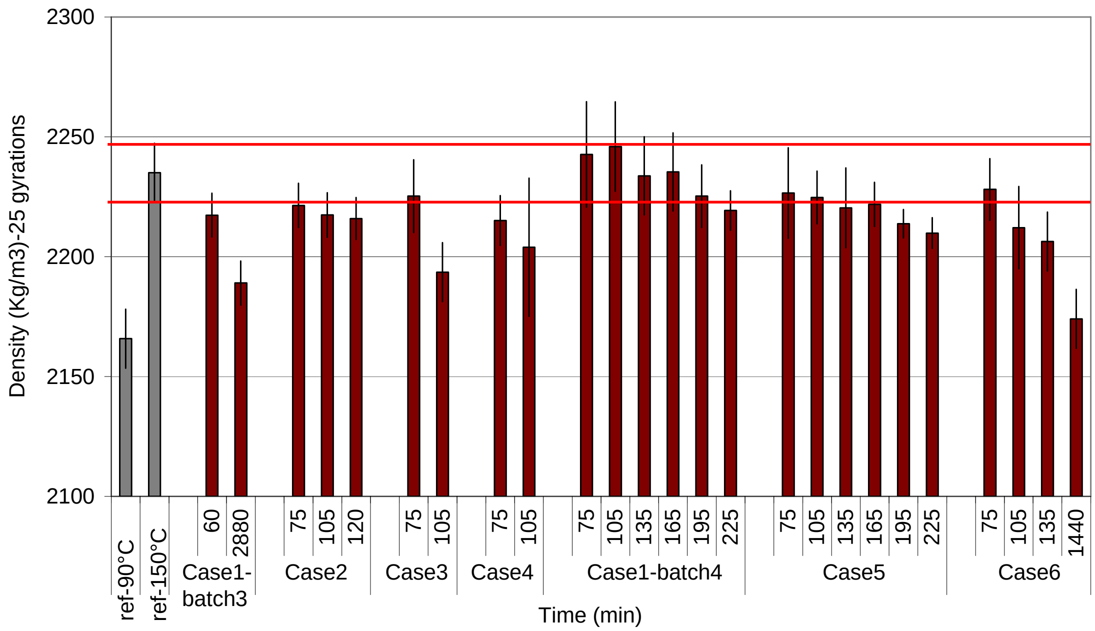

Figure 3: Densities recorded after 25 gyrations, the time refers to the time the mix was stored at 90°C between preparation and compaction

From figure 3, it is clear that there are time effects in the compactability of the asphalt cores. Cores that are compacted more quickly after mixing have a higher density than cores compacted after longer times. This observation is important and for the preparation of test samples, it is of course an extra parameter that needs to be taken into account, when working with this type of mixes. However the reproducibility of the tests is rather poor, for example case 1-batch 3 versus case 1-batch 4. This is most likely related to differences in the evaporation of water prior to the compaction test, even though the loose mix was stored under similar conditions.

In figures 4 & 5 the compactabilities at 60 and at 200 gyrations are also plotted. Related to the field experience with this type of mix, the densities obtained after 200 gyrations correspond to locations with very heavy compaction, while the density obtained after 60 gyrations can be considered as representative for a normal/good compaction level on site, and after 25 gyrations relate to the places with lowest compaction levels.

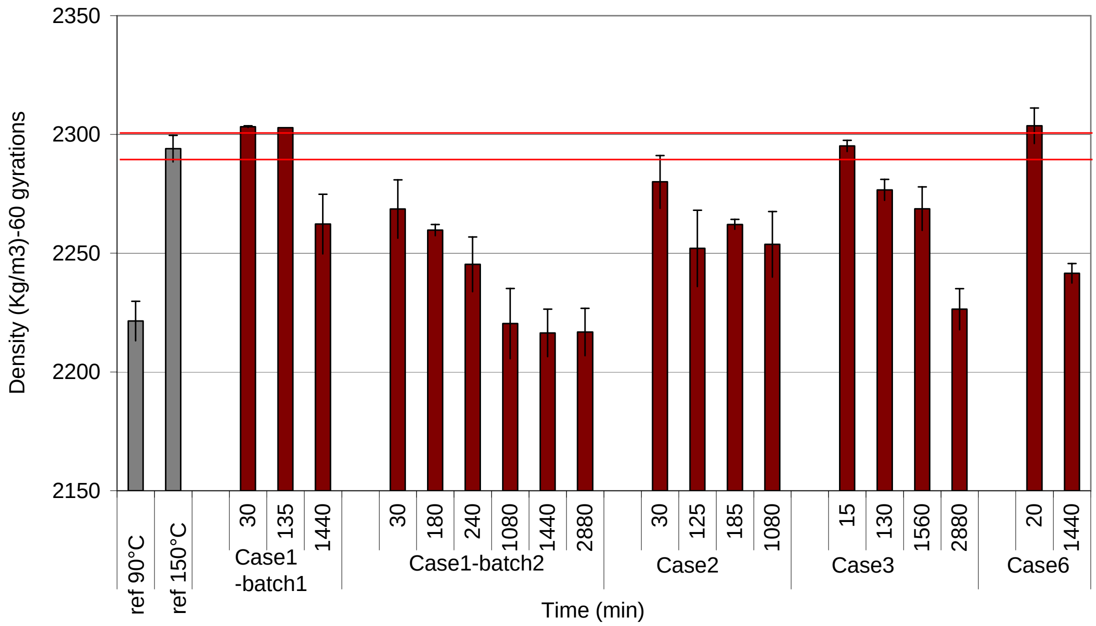

Figure 4: Densities recorded after 60 gyrations, the time refers to the time the mix was stored at 90°C after preparation and before compaction

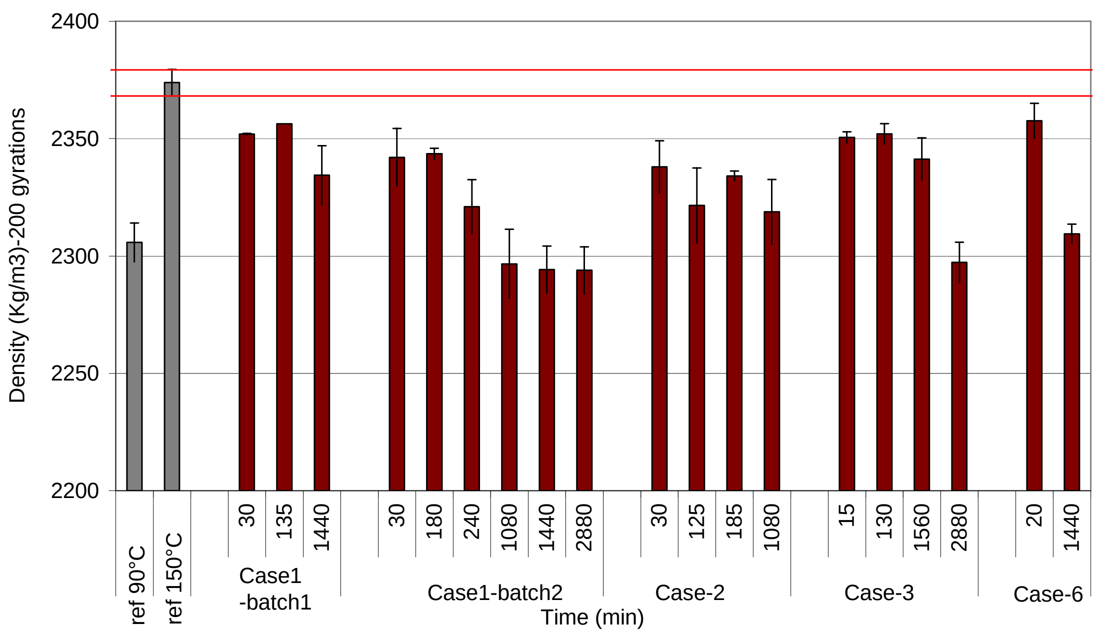

Figure 5: Densities recorded after 200 gyrations, the time refers to the time the mix was stored at 90°C after preparation and before compaction

From figures 3, 4 & 5, the following observations can be made:

- There is clearly a time effect in the degree of compaction obtained. The degree of compaction is generally higher for cores prepared after short times and decreases when the mix is stored before compacting it. At short times the compaction of the mixes with foamed bitumen is always better than the compaction of the reference mix at 90°C. After 1 day storage or longer, the degree of compaction is either still somewhat better or very close to the one obtained for the reference mix at 90°C. Time effects are also present in the case of using unfoamed bitumen and wet aggregates (case 3 and case 4).
- There is also an influence of the number of gyrations on the relative (compared to the reference cases) degree of compaction obtained: At 25 gyrations, the degree of compaction of the reference mix at 150°C can be reached using the foamed asphalt when the time between mixing and compaction is short. It is hard to define this time range exactly, but it seems that this compaction level can be reached up to 2 to 3 hours after mixing. However, it should be noted that this time window is established for laboratory tests and may differ when large scale sample amounts are considered. At 60 gyrations, the degree of compaction of the reference mix at 150°C can be reached in most cases, while at 200 gyrations, the compaction level of the reference mix at 150°C can no longer be reached using the foam technique.
- In the compaction tests, the variability between test runs, even if all investigated variants and the storing conditions of the loose mix are kept the same, is rather large. Therefore, it is not possible under these test conditions to evaluate the additional parameters that were varied. These include; adding the binder as such or using foam, replacing 1% filler fraction with 1% of an active filler, or changing the initial water content of the wet aggregates from 2.5% to 1%.

3.2. Variation in binder content:

Because of the more elaborate procedure to add accurate amounts of binder when preparing foamed asphalt mixtures, the binder contents of some of the cores were measured. The results are shown in table 3. The binder contents were measured on gyratory compacted cores (about 1kg of asphalt) according to EN-12697-1.

From table 3 it is clear that there is a high variation between the individual cores of one asphalt batch. This variation is high according to EN 12697-1, where the repeatability limit r should be of the order of 0.3 %. The repeatability limit is the maximum difference between two test results with a probability of 95 %, so only 1 out of 20 repeated measurements should give a value more than 0.3 % different than the first measurement. In table 4 however, 2 of the 4 repeats already show a difference larger than 0.3 %, and in one case even 0.6%.

Considering the average binder content, this is still close to the target binder content of 6.2%. It is not clear yet why the variation in binder contents of individual cores made from the same mix is so high. But certainly this observation will have an effect on the repeatability of test results made with individual cores.

Table 3: Binder contents of samples taken from various test runs

Asphalt batch	% Bitumen	Asphalt batch	% Bitumen
Case 1-batch 1	6.4	Case 3	6.2
“	6.0	“	6.1
Case 1-batch 2	6.0	Case 4	6.2
“	6.1	Case 1-batch 4	6.1
Case 2	6.0	Case 5	6.2
“	6.6		

3.3. Water content:

It was shown in 3.1 that the time interval between mixing and compacting the sample has a considerable effect on the density that can be obtained. As during that time interval changes in the water content of the sample take place, it is important to study this effect in more detail. The changes in water content as a function of time were therefore followed, according to the two procedures described in section 2.3, for the loose mix stored at 90°C. This is represented in figure 6A.

It is clear that the moisture content decreases when the loose mix is stored at 90°C. The data indicate that the two methods give very similar results. But it should be noted that even if the initial water content of the aggregate fraction, in figure 6A, was 2.5%, the water content of the first samples, taken directly after mixing, has already decreased to 1.2%. So in general, the moisture content of the mix decreases rapidly with time.

In addition, moisture contents of the compacted cores were also determined by measuring the weight changes of compacted cores, between the moment of compaction and after two months at ambient temperature. These values are shown in figure 6B. They show the same trend, but the values are smaller: obviously since there is also water evaporating during compaction, which is not taken into account and secondly it is possible that these data underestimate the real water content, because it is assumed that the cores are completely dry after 2 months. But figure 6B also reveals, especially at short times, large differences between the various cases and batches, and as was noted in section 3.1, these variations may explain the large variability that was observed in the compaction tests of section 3.1.

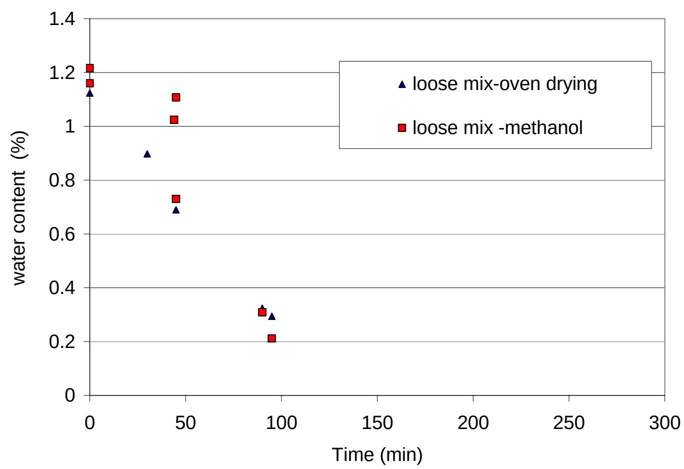

Figure 6A: water content of the loose mixture versus time the mixture is stored at 90°C, these data are taken from case 2.

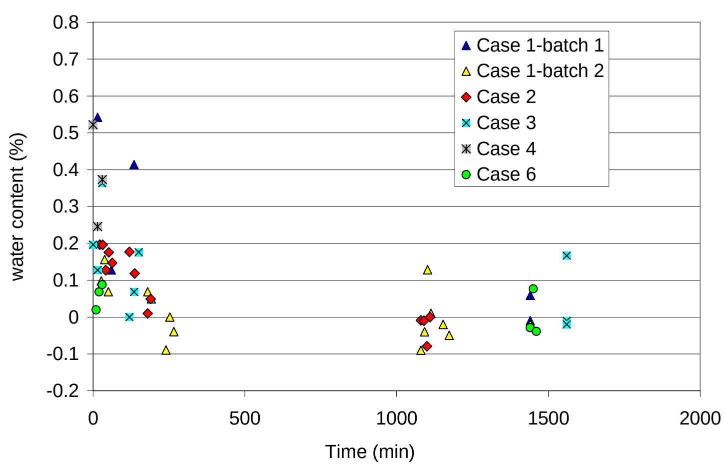

Figure 6B: water content of the loose mix versus time, the water content is determined from compacted cores, by measuring the weight loss of the compacted cores between the moment of compaction, and after 2 months at ambient temperature.

Figure 7 illustrates more in detail and under controlled conditions of temperature and humidity the loss of moisture of some gyratory compacted cores in the days following compaction. In this test the cores were stored in a climate chamber at a temperature of 25 °C and a relative humidity of 30 to 40 %. To recalculate the water content at the moment of compaction, it is assumed that the core is dry after 35 days. Core 1 was compacted 12 minutes after mixing, while cores 8, 9 and 10 were compacted after a longer period. This is seen in the initial water content, which is lower for the three last specimens.

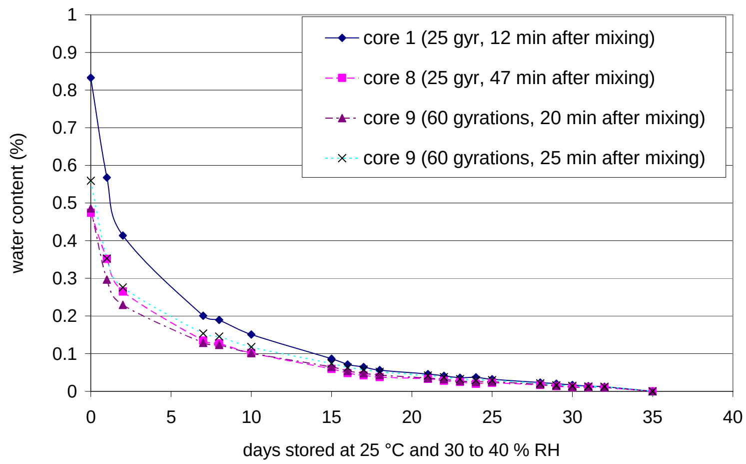

Figure 7: Evolution of the water content of cores prepared using foamed bitumen and wet aggregates (cores from case 1-batch 3).

3.4. Water sensitivity

The water sensitivity was investigated by the method described in 2.3. Since the water content of compacted samples changes in the period after compaction (see fig. 7), it was expected that this would have an impact on the results of the water sensitivity test. Therefore, for all the tests reported, the curing time (time between compaction and testing) is indicated. And since, as described in 3.1, the level of compaction is dependent on the time interval between mixing and compaction, also this time interval was as much as possible kept constant.

It is expected that the use of foamed bitumen improves compaction and aggregate coating. If this is the case it would be reflected in the water sensitivity. Therefore we compared a mix produced with foamed bitumen to the same mix, prepared in identical conditions, but without foaming the bitumen. This is shown in table 4 for two active filler types; 1 % of filler A and 1 % of filler B. The table shows two sets of data for the mix with 1 % of filler A using foamed bitumen, which gives an idea of the reproducibility (same case, but different batches). From these limited data, we have to conclude that the reproducibility is poor: the ITSR differs by 15 %. But it should be noted that also the void content differs by more than 1%. So in fact the “poor” reproducibility of the ITS-R values may be related to the “poor” reproducibility of the compaction at 25 gyrations. In section 3.1 the rather poor reproducibility of the compaction tests was related to differences in the moisture content at the moment the samples were compacted.

From table 4 it is quite obvious that there is an improvement in the water sensitivity by foaming the binder in both cases, if samples are compared at a similar level of applied compaction energy (which is 25 gyrations). The ITSR increases with foaming, from 43% to 52%, when considering the first set of results. Also in the case of filler B, foaming the binder has a positive effect on the water sensitivity, again when comparing specimens compacted with the same compaction energy. The results may also indicate a difference between both types of active fillers: For the foamed mixes, the interpretation is rather difficult because of the difference between case 1-batch 3 and 4, but for the unfoamed mixes, the mix with filler A is more sensitive to water conditioning, 43% versus 61%. However, from table 4 it is not possible to evaluate if the result in water sensitivity is the consequence of the difference in compactability (void content) or of a difference in binder aggregate-adhesion due to a chemical action of the active filler.

Table 4: Effect of foaming on the results of the water sensitivity tests

	with 1% filler A			with 1 % filler B	
	foamed	foamed	Unfoamed	foamed	unfoamed
	case 1-batch 3	case 1-batch 4	case 3	case 5	case 4
Voids (%)	7.2	6.1	7.3	5.9	7.1
ITS-R (%)	52	67	43	71	61

The water sensitivity tests were carried out 10 days (±1) after compaction

The effect of using an active filler is further evaluated in table 5: tests made without filler additive are compared with tests made with 1 % of active filler A and B respectively. However, for the interpretation of the results, it should be noted that all the tests made in table 5 were performed after 30 days (±2) of "curing" compared to 10 days for the data presented in table 4. In the remainder of this paragraph, it will be shown that the ITSR increases within this time frame. From table 5, we can conclude that the water sensitivity, and to some extent also the compactability, are improved when using an active filler. Again, it is not clear if the better result in water sensitivity is due to a better compaction or is due to a better binder aggregate-adhesion.

Table 5: Effect of active filler on the results of the water sensitivity tests

	no active filler	with 1% filler A	with 1 % filler B
	case 2	case 1-batch 4	case 5
Voids (%)	6.9	6.5	5.9
ITS-R (%)	56	72	81

The water sensitivity tests were carried out 30 days (±2) after compaction

To investigate the effect of curing of compacted samples, series of water sensitivity tests were made after various periods of curing, with active filler A (case 1-test 4) and with active filler B (case 5). From the results plotted in figure 8, we can clearly conclude that the ITSR increases with curing time. It is not possible to determine if the values reached their maximum after a period of two months. Additional measurements after longer curing periods would be necessary to determine the maximum level that can be achieved. Small differences are visible between the case with active filler A or B. On average, the results appear to be slightly better for the case with filler B. But as there is also a difference in void content between both series, as well as a slight difference in binder content, it is not possible to conclude that the type of filler is the parameter that makes the difference.

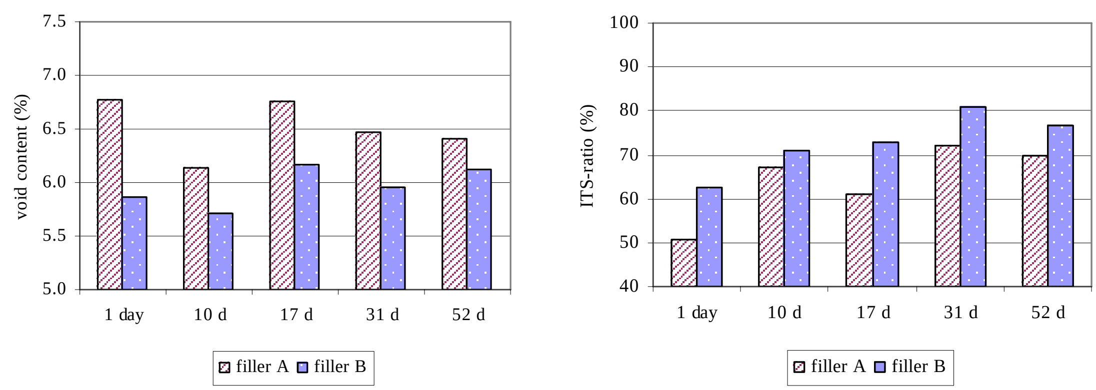

Figure 8: Effect of curing period, in days, on the water sensitivity test results for two types of active filler

Finally, figure 9 shows the effect of the initial water content of the aggregates (case 1-batch 4 versus case 6). For the case with 1% water content, the tests were made after 3 curing intervals; 10 days, one month and 2 months. But, the large variation in void contents between the various curing times does not allow assessing the decrease in initial water content of the aggregates from 2.5% to 1%.

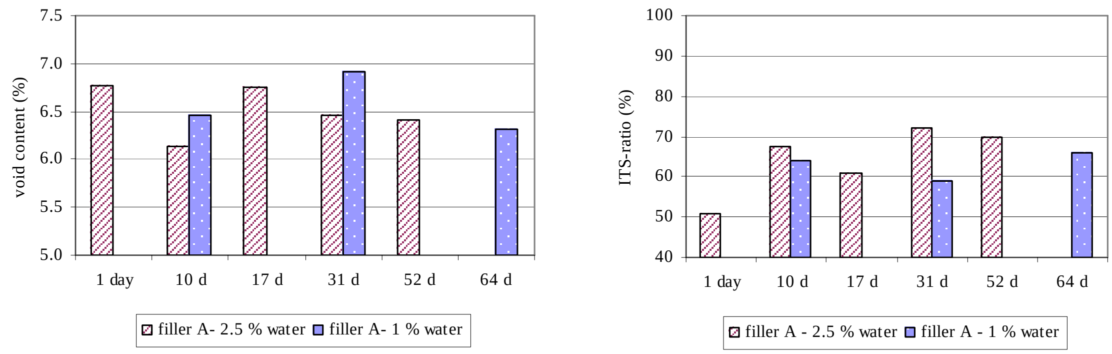

Figure 9: Effect of curing period, in days, on the water sensitivity test results for two different water contents

4. Conclusions

In general, compared to the laboratory production and testing of standard hot mix asphalt, the production and testing of foamed mixes is more elaborate and more parameters need to be taken into account:

- To have the desired bitumen percentage in the mixture, a relation between foaming time and bitumen amount needs to be established for the foam unit;
- The optimal water content of the foam needs to be determined;
- The aggregate fractions are wet, and their water content needs to be controlled;
- The test results show that after mixing, water evaporates rapidly from the loose mixture, so the time between mixing and compaction is a parameter that needs to be taken into account when preparing these mixes. This also includes that a procedure of how to store the loose mixture before compaction is needed and can have an impact;
- Since in this study, it was not practical to prepare 1kg asphalt batches, larger amounts, about 40 kg per batch, were prepared. From one such an asphalt batch, a number of small (±1kg) test specimens were compacted and used in the water sensitivity tests. So, the storage time of the loose mix was an inevitable extra parameter;
- And even after compaction of these mixes, there is again a time effect, referred to in this paper as curing. This study demonstrates clearly that after compaction, moisture slowly evaporates from the compacted core. The time interval between compaction and testing, can therefore have an influence on the test result. And also here the conditions under which the asphalt cores are stored prior to testing can become important;
- And finally it was observed that the binder contents between individual cores compacted from the same asphalt batch vary considerably;

Consequently, there are more parameters in foamed mixes compared to standard hot mix. When known, these parameters can be recorded, but they are very difficult to control. Combined with the large variation in binder content, it is clear that the variability between test results in foamed mixed is larger compared to hot mix.

Regarding the gyratory compaction tests, these tests clearly show the effect of changing the time between mixing and compaction. And in addition, these tests also show that at 25 gyrations, the degree of compaction of the reference mix at 150°C can be reached using foamed asphalt when the time between mixing and compaction is short. At 60 gyrations, the degree of compaction of the reference mix at 150°C, can be reached in most cases, while at 200 gyrations, the compaction level of the reference mix at 150°C is no longer reached. Other parameters, like foaming the bitumen, using an active filler, the type of active filler and the initial moisture content (1% or 2.5%) were varied, but their effects on gyratory compaction data were small compared to the variability of the test results, so it was not possible to draw further conclusions.

The water sensitivity tests show clearly that there are curing effects, the indirect tensile strength ratio increases when the time between compaction of the asphalt and testing is longer. The ITSR tests also show an improvement in the water sensitivity by using foamed bitumen, compared to just adding the (non-foamed) bitumen, and by using an active filler. On the other hand, an evaluation of the ITSR tests does not allow differentiating the type of active filler, or the initial water content of 2.5% or 1%.

Finally, it should be noted that all these observations are, until now, made on laboratory tests, and still need to be confirmed / evaluated in field trials.

5. Acknowledgements

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