ASPHALT CONCRETE TEST SECTIONS CONTAINING BITUMEN OF DIFFERENT ORIGINS

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ABSTRACT

From 2010, Sweden will adapt to the new harmonized European bitumen specification (EN-12591:2009). The Swedish so-called A-deviation concerning higher requirements for dynamic viscosity at 60 °C will disappear, and this change will probably lead to a wider range of bitumen of various crude oil origins.
For investigating the impact of the change, the former Swedish Road Administration initiated this project in 2008 by inviting different bitumen suppliers to participate in a large scale project where bitumen 70/100 was purchased according to the new European specification for penetration grade bitumen.
For each bitumen type, 500 tones of asphalt mixture were produced and placed on a road.
Bitumen and asphalt mixture samples were taken out during production for comparative testing in the laboratory. In addition, core samples were taken from the road and analyzed.
Performed laboratory tests cover the different relevant functional properties believed to be of significant importance for an asphalt pavement, for instance wear resistance, durability, low temperature performance and deformation.
In some cases, the bitumen shows conflicting results depending on which functional property was selected for testing.
It was concluded in the study that the re-heating of asphalt mixture in oven before the production of slabs had a strong hardening effect on the binder, although different for each binder.

The new European specification for penetration grade bitumen will be more demanding on contractors and their experience of bitumen. Particularly as most constructions in the future will be procured using functional requirements for the asphalt concrete pavement.

Keywords: Asphalt mix performance, bitumen from different origins, pavement durability, field test

1. INTRODUCTION

As from 2010, new European standard specifications for bitumen and bituminous binders (EN 12591:2009) are in use. Consequently, new bitumen products (for road asphalt), with possibly lower dynamic viscosity at 60°C, have been introduced on the Swedish market due to the removal of the Swedish A-deviation in the standard.

A pilot study was performed by the Swedish Road Administration for bitumen of paving grade 160/220 during 2006 – 2007, indicating big differences between bitumens of different origin. Although the bitumens fulfilled all requirements according to specification, asphalt mixtures containing these bitumens were found to perform differently. The largest differences between bitumens were shown for rutting, using the Hamburg wheel-tracking machine with test slabs submerged in water. This method, however, under dry conditions, is part of the new European material specifications for bituminous mixtures (EN 13108). Large differences in dynamic creep testing, according to former specifications used in Sweden, were shown as well. The asphalt mixtures tested were divided into different classes of rutting and resistance to deformation, respectively. The ranking, however, was not the same. Consequently, bitumen origin made a difference but the two methods used for showing it did not give comparable results.

For further investigation concerning the impact of bitumen origin on asphalt properties, a joint large scale project was started by the Swedish asphalt industry and the Road Administration. Based on experience from the pilot project, new binders of different origin have been compared. Properties of binders as well as asphalt mixtures have been thoroughly investigated using a number of testing methods available within this project (not all European standards). By trying to isolate effects due to differences in mixture composition and specimen preparation, binder effects have become more evident.

This paper presents results from the joint large scale project involving different bitumens of the same penetration grade.

2. EXPERIMENTAL

2.1 Bitumens and mastic mixtures

Totally seven different bitumens of penetration grade 70/100 from different bitumen suppliers in Europe were used for the studies. The binders were tested and compared to requirements for paving grade 70/100 according to EN 12591:2009.

Binder samples were taken during asphalt mixture production for reference samples. In addition to bitumen hardening during asphalt production and manufacturing of asphalt slabs, three different tests for simulating ageing of asphalt mixtures in the laboratory were performed. After ageing, the binders were recovered and tested for penetration, softening point and viscosity. Cores from the road were taken, extracted and analyzed as well. Ageing procedures are described in [1].

Methods used for binder analysis were standard testing according to EN 12591. Dynamic mechanical analysis (DMA), chemical characterization and testing according to Superpave were also performed but are not presented in this paper.

In addition, a set of nine pure mastic specimens was produced for each binder, using the 0-2 mm aggregate fraction. The vändskak method (under development) was used for determining the wear resistance of mastic. In this test, specimens are saturated with water under pressure and are then weighed and placed in a metal pipe partly filled with water. Pipe and test specimen are rotated 3600 revolutions for two hours in the equipment, making the specimens falling back and forth between top and bottom of the pipe. After the process, the test specimens are weighed once more. The amount of material being worn off is expressed in percentage of the initial weight, and reported as the wear value.

2.2 Stone mastic asphalt mixtures and test methods

Stone mastic asphalt mixtures (ABS 16) were produced at an asphalt plant using seven different bitumens of penetration grade 70/100 from different bitumen suppliers in Europe. The mixtures were placed on road Rv 49 between Mariesjö-Ingelstorp (approximately 500 tonnes of each product, using 90 kg/m^2). Test sections were coded, from bitumen 1 to bitumen 7. Mixture material for preparing slabs in the laboratory was taken from production at the plant. The production temperature was about 160-165°C. The stone mastic asphalt recipe was developed in a previous study, including evaluation of each bitumen product using laboratory prepared mixtures. Marshall void contents from the pre-study were used to adjust binder contents in the large scale asphalt mixture production. In connection with specimen preparation at the production laboratory as well as during production at the asphalt plant, each asphalt mixture was checked against the recipe (binder content, aggregate size distribution and void content).

All asphalt mixture samples were taken during production at the asphalt plant. Composition was checked and compared to mix design recipe in connection with sample preparation as well as sampling. Only minor variations in particle size distribution and binder content were found. The target air void content according to recipe was 2.5 % by volume for all bitumen variants used and the binder content was between 6,1 and 6,4 % by weight. Target sieve curve is shown below.

Sieve size (mm)	0,063	0,125	0,25	0,5	1	2	4	5,6	8	11,2	16
Passing %	9	12	14	16	18	23	26	30	39	60	96

Stone mastic asphalt slabs were manufactured using the so-called plate compactor equipment. In a first round, 44 slabs were compacted. In order to increase the effect of binder impact on the structural strength of test specimens, a lower degree of compaction to the target of 5 % void content was used for all slabs.

During the project, it was found that dynamic creep stability test results were very high at lower degrees of compaction, and it was therefore difficult to compare between the different binders. It was suspected that compaction of ABS 16 to a thickness of 80 mm, in order to get 60 mm test specimens, did not give representative specimens. To confirm these suspicions, it was decided to repeat wheel-track testing as well as creep stability testing on a new set of slabs. This time, stone mastic asphalt slabs for dynamic creep testing were manufactured in the same way as the slabs used for wheel-track testing, that is by compaction to 50 mm thickness. Test specimens were then sawn to a thickness of 30 mm and combined in pairs to a total thickness of 60 mm as specified in the test method.

The compaction temperature was between 155 and 160 ºC. Heating of 20-25 kg samples was performed in an oven for approximately 8-9 hours. The compaction needed for target density varied between asphalt mixtures.

Methods used for testing mixture properties were:
- Hamburg wheel-tracking test (EN 12697-22), dry and in water
- Dynamic creep stability test (FAS-468)
- Stiffness modulus test (EN 12697-26)
- Water sensitivity test, ITSR (FAS-455)
- Prall test (FAS-471)
- Tensile stress restrained specimen test ,TSRST (AASHTO TP10)

Stiffness modulus testing was performed at 10 ºC before and after ageing, before and after freeze thaw conditioning and on cores after 1 year in the road. Water sensitivity was tested before and after freeze/thaw conditioning. The methods are described in [1].

3. RESULTS

3.1 Bitumens and mastic mixtures

Standard tests
Binder samples taken in connection with producing the asphalt mixtures were analyzed twice for penetration value and softening point, respectively, once in binder testing according to standard (Table 1), and the next time when evaluating ageing performance.

The different bitumens come from different crude oils. Standard analysis shows that all seven binders fall within the European standard for bitumen 70/100, except for bitumen 5, due to lower kinematic viscosity at 135 °C. Furthermore, bitumen 4 and 5 do not fulfill the previous Swedish specification concerning dynamic viscosity at 60 °C, but fall very well within the European specification.

Table 1: Binder testing according to standard

Characteristic	Req. EN 12591:2009	Bitumen						
		1	**2**	**3**	**4**	**5**	**6**	**7**
Penetration (1/10mm)	70 - 100	71	83	83	72	83	80	84
Softening point (°C)	43 - 51	47	46	46	46	46	47	46
Kinematic visc., 135°C (mm²/s)	≥230	357	386	367	336	192	465	366
Dynamic visc., 60°C (Pa s)	≥90	150	137	174	112	105	172	171
Solubility (%)	≥99.0	100.0	99.8	100.0	99.8	99.5	100.0	100.0
Fraass breaking point (°C)	≤-10	-16	-19	-18	-19	-18	-20	-19
Flash point (°C)	≥230	352	346	320	356	326	340	284
Change of mass, RTFOT (%)	≤±0.8	0.1	0.0	-0.2	0.1	0.0	0.0	-0.1
Retained pen., RTFOT (%)	≥46	65	67	67	64	48	64	61
Softening point, RTFOT (°C)	≥45	51	52	52	51	52	52	51
Increased soft. point, RTFOT (°C)	≤9	4	5	5	5	6	5	5
Density (kg/m^3)	-	1019	1015	1019	1012	1028	1022	1023

Bitumen hardening
For all binders, the change in softening point after asphalt mixture production at the asphalt plant is between 1 and 4 ºC, and approved according to Swedish requirements (< 6 °C).

The results for recovered bitumen of cores after one year of traffic show that the change in softening point is largely on the same level as the change due to asphalt mixture production in the asphalt plant. Consequently, no significant hardening of the binder has occurred after one year on the road.

A number of procedures leading to hardening of the binder were used in connection with production of test specimens in the laboratory and conditioning. Results show that the binders were largely affected. The manufacturing of slabs involved long heating time and hardening of the binder. For the first produced set of slabs, the asphalt mixture had to be heated for about 5-6 hours in order to reach the correct manufacturing temperature. Also binder recovered from specimens prepared for stiffness modulus analysis, including osmotic conditioning, showed significant hardening. Most of the hardening was due to heating of the mixture in connection with production of the slabs. The different bitumen types were more or less affected. Bitumen 3 and 6 were affected the most. For the second set of slabs, the asphalt mixture was stored in 20-25 kg buckets and had to be heated for about 9 hours in order to reach the correct manufacturing temperature of 160 ºC. Significant binder hardening occurred, in spite of bucket lids being used.

Figure 1 shows how viscosity at 60 °C changed in the different hardening processes, indicating that the bitumens are affected in various large scale. The largest differences are obtained during oven heating in the laboratory.

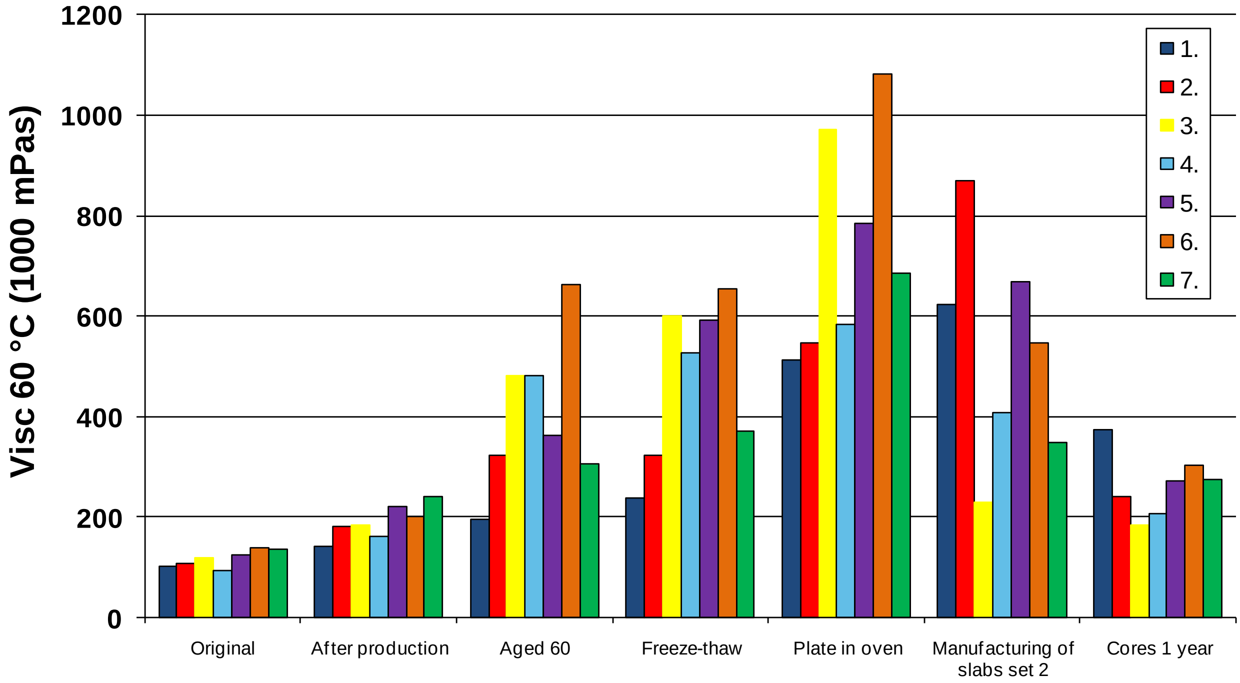

Figure 1: Comparison of Brookfield viscosity at 60 °C in the different bitumen hardening processes

Wear of mastic mixtures in vändskak

The mastic mixture samples containing bitumen 1, 2 and 6, respectively, showed higher wear values compared to the rest of the samples. This was confirmed by both laboratories used. However, the results were not on the same level (systematic difference), indicating insufficient reproducibility for the method still being under development. Results are shown in Table 2.

Adding cement showed positive but varying effect for all mixtures, more for the mixtures containing bitumen 5, 6 and 7, respectively, than for the rest of the mixtures.

Table 2: Results after wear in vändskak

Bitumen	Mastic/Lab. A	Mastic/Lab. B	Mastic + cement/Lab. B
	Wear (weight-%)	Wear (weight-%)	Wear (weight-%)
1	16.3	26.5	25.4
2	15.0	23.7	20.8
3	12.1	14.3	13.5
4	11.8	16.1	14.6
5	13.2	17.7	10.7
6	15.3	23.8	14.1
7	12.3	15.7	11.0

3.2 Stone mastic asphalt mixtures

Wheel-tracking

Totally four slabs for each bitumen quality were tested at 50 °C under dry and wet conditions, respectively. The test was completed for all the mixtures (10 000 cycles).

The total rut depth under dry conditions varied from 3.6 mm (for the mixture containing bitumen 5) to 6.2 mm (for the mixture containing bitumen 1). The void content varied between 2.3 and 3.7 vol-%. Under wet conditions, the total rut depth varied from 6.6 mm (for the mixture containing bitumen 5) to 14.7 mm (for the mixture containing bitumen 1 and

7, respectively). The void content varied between 2.3 and 3.8 vol-%. There was no indication of higher void content giving more rutting.

According to EN 13108-5:2006, the mixtures containing bitumen 5 and 6, respectively, are classified as $WTS_{AIR\ 0,15}$ concerning deformation progress (WTS = wheel-tracking slope), while the mixtures containing bitumen 2, 3, 4 and 7 are classified as $WTS_{AIR\ 0,30}$, meaning the class below $WTS_{AIR\ 0,15}$. The mixture containing bitumen 1 is classified as $WTS_{AIR\ 0,40}$. Concerning proportional rut depth (PRD), the mixtures containing bitumen 2-7, respectively, fulfill requirements for $PRD_{AIR\ 1,0}$, while the mixture containing bitumen 1 belongs to the lower class $PRD_{AIR\ 1,5}$.

The ranking based on rut depth is almost the same for both conditions, although wheel-tracking in water showed bigger differences between mixtures. Rut depth results after wheel-tracking for both conditions are shown in Figure 2.

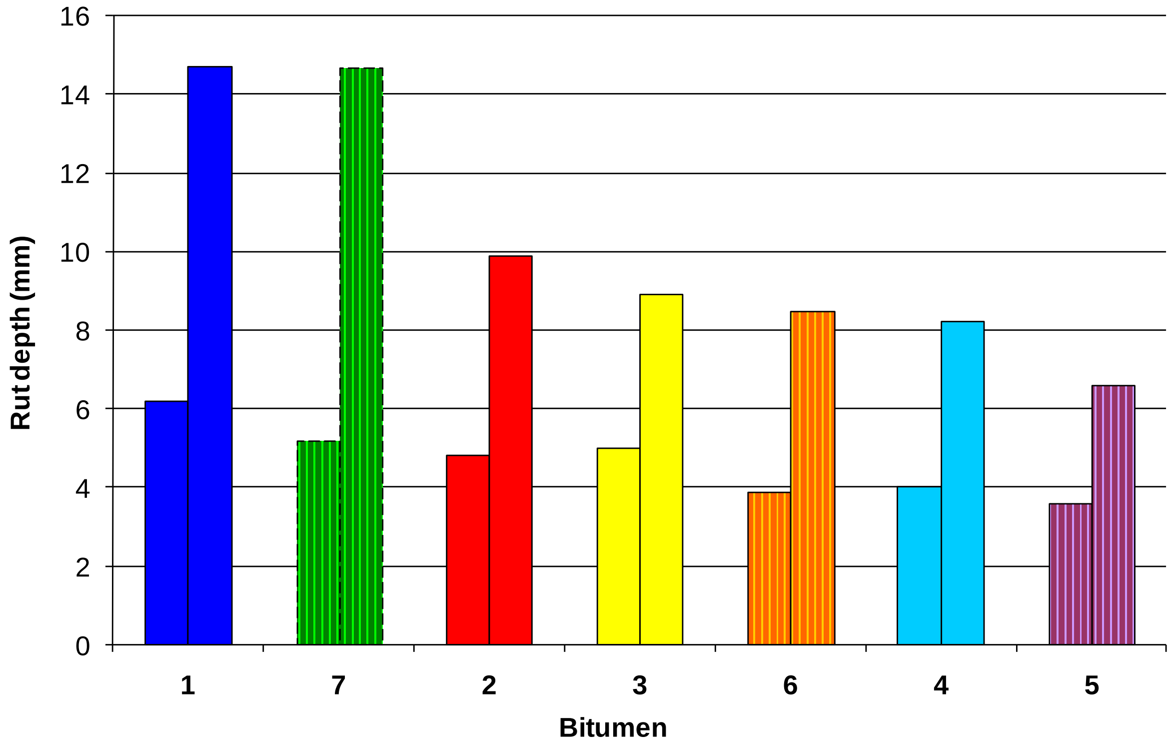

Figure 2: Rut depth after wheel-tracking, dry and in water

Dynamic creep stability

In dynamic creep stability testing, air void contents varied within each test series, depending on where drilling was performed on the slab. The slabs were compacted to 80 mm thickness and test specimens were then cut to a 60 mm thickness. The variation of results is shown in Figure 3.

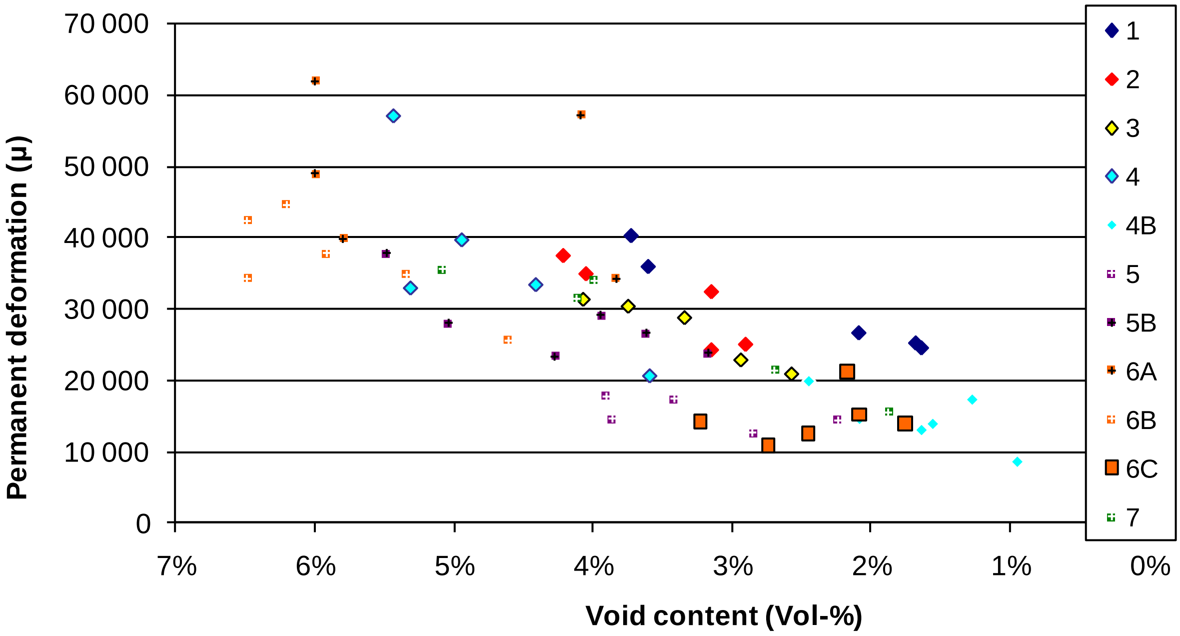

Figure 3: Effect of compaction on the total deformation

The dynamic creep stability test obviously is strongly affected by asphalt mixture composition and compaction of the mix. Additional sets of specimens were therefore prepared for three of the mixtures, trying to minimize small differences in compaction. It is important to keep in mind that compaction of the different mixtures was carried out at the same temperature. The viscosity of the binder may therefore have had a certain effect on compaction. Furthermore, the test slabs containing bitumen 4B and 6C, respectively, were deliberately compacted to a higher degree corresponding to the air void content interval 1-3 vol-%.

As all pavements seemed to be highly dependent on the degree of compaction, it was decided to expand the study with an additional set of slabs. This time, the asphalt mixture slabs were manufactured with a thickness of 50 mm, meaning that dynamic creep testing was performed on specimens of 2*30 mm thickness. Furthermore, the slabs were compacted to the highest possible degree, i.e. low void content and less impact from degree of compaction.

For this set of slabs, creep stability values were between 14 600 and 18 600 microstrain for all mixtures, and void content between 0.8 and 2.2 vol-%. Results are shown in Figure 4, including standard deviation values, showing no significant difference between series.

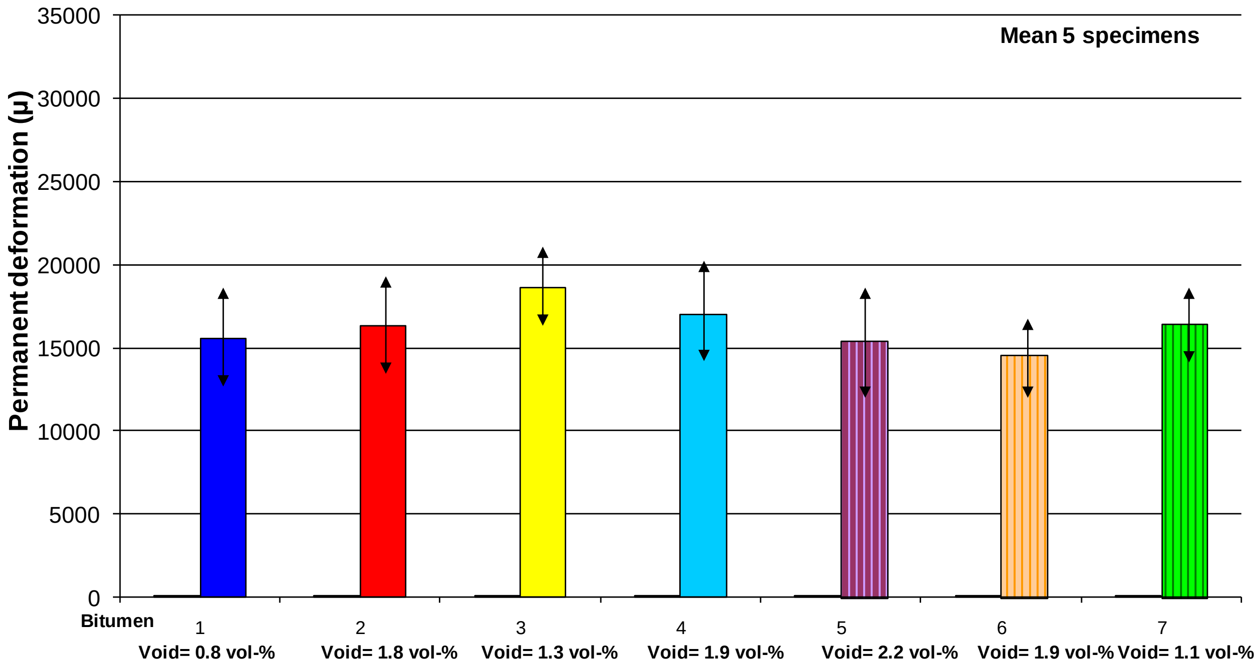

Figure 4: Effect of compaction on the total deformation

Stiffness modulus
Certain differences in stiffness modulus level at 10 ºC between the mixtures were shown, but there was little or no effect from air void content. Neither laboratory ageing at 60 °C for 50 days nor freeze/thaw conditioning showed any considerable effect on the stiffness modulus. However, after laboratory ageing at 60 °C for 50 days, the stiffness modulus level for the mixtures containing bitumen 1, 4 and 5, respectively, was about 2 500 MPa higher than for the rest of the mixtures (see Figure 5).

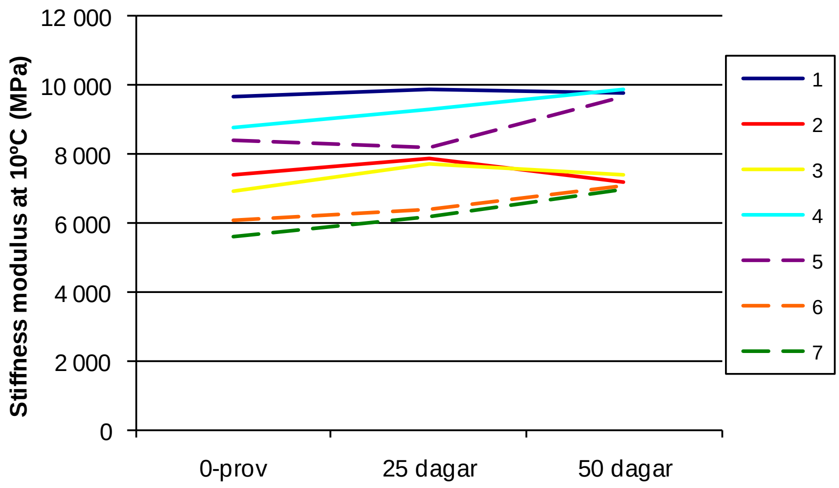

Figure 5: Stiffness at 10 after laboratory ageing at 60°C

Six cores were drilled out from each mixture type on the road and stiffness modulus was determined, directly as well as after ITSR conditioning for 7 days. The conditioning only had a marginal decreasing effect on stiffness modulus values for all mixtures. In line with laboratory made specimens, the stiffness modulus level for mixtures containing binder 1, 4 and 5, respectively, was higher than for the rest of the mixtures. Stiffness modulus for cores after 1 year in the road is shown in Figure 6.

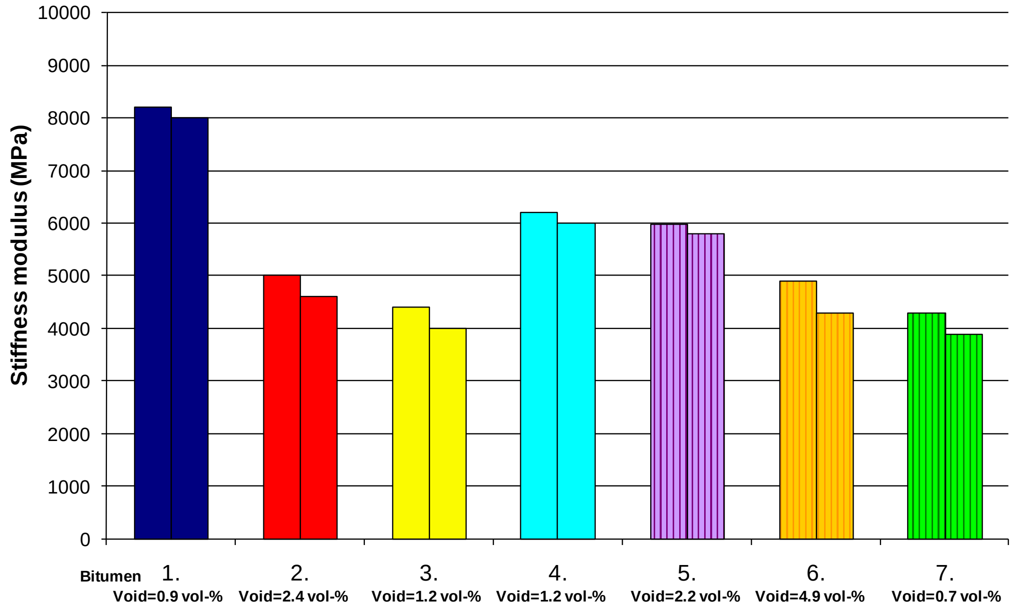

Figure 6: Stiffness modulus for cores after one year in the road

Water sensitivity (ITSR)

A somewhat higher void content was aimed at in the production of test specimens for water sensitivity testing, and most specimens were between 3 and 4 vol-%. None of the seven tested mixtures showed low ITSR values (high water sensitivity). The variation in tensile strength between mixtures may be linked to binder stiffness as well the addition of cement additive and small differences in compaction and composition. The special freeze/thaw conditioning used for half of the specimens showed, in this case, no decisive effect compared to the conventional testing procedure for water sensitivity.

Ranking of the different types of bitumen according to ITSR is different from that of the rolling bottle test (see next section). The ITSR method takes into account the total mixture, while in the rolling bottle test only adhesion between quartz aggregate fraction and binder is involved.

Water sensitivity results at 10 ºC after winter conditioning are shown in Figure 7.

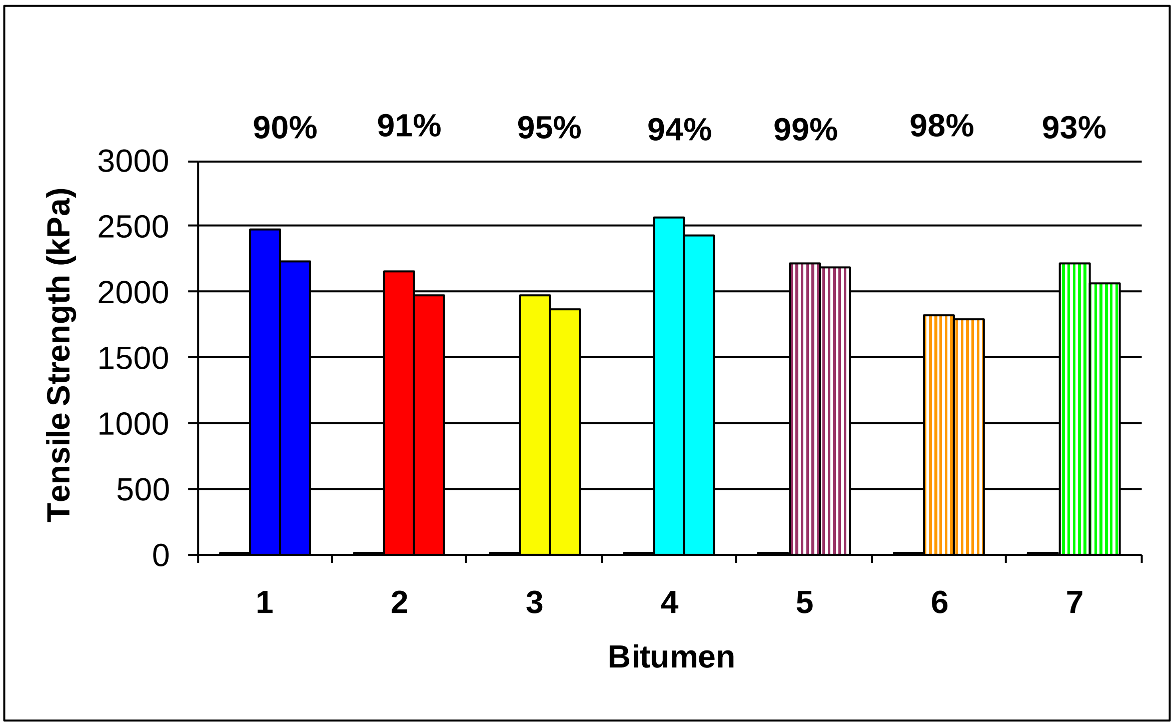

Figure 7: **Water sensitivity after winter conditioning**

Adhesion (the rolling bottle method)
All binders showed 0 % of bitumen coverage on the aggregate after 24 hours. Adding cement as adhesion agent showed little effect, except in combination with bitumen 3 and 7, respectively (about 60 % bitumen coverage).

Wear after abrasion (Prall)
All seven binders showed similar abrasion values (17-21cm^3) for cores from the road as well as for specimens from slabs produced in the laboratory. Any differences in bulk density did in this case not significantly affect the test results, see Figure 8. The quartz aggregate used in the mixtures (> 4 mm) is known to be very wear resistant.

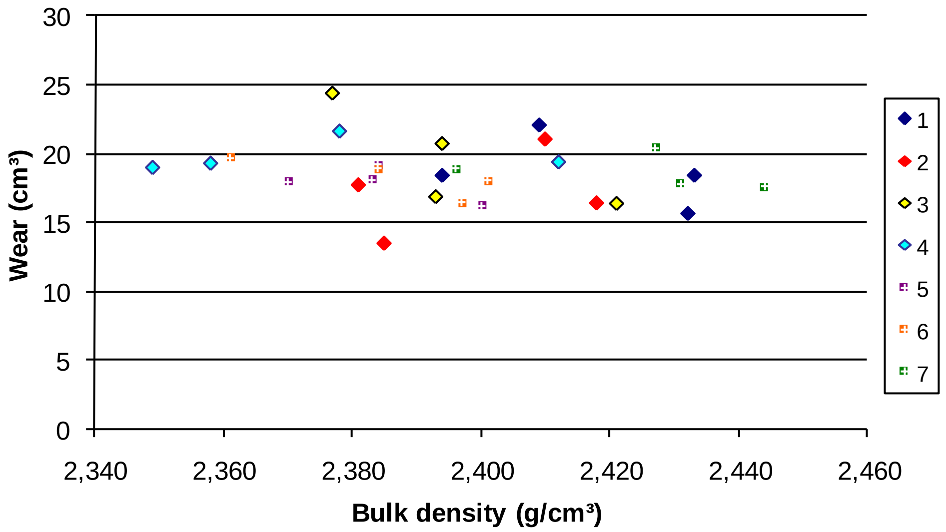

Figure 8: **Effect of bulk density on wear**

Low temperature performance (TSRST)
Two beams (35 mm*35 mm*250 mm) were sawn from each slab/binder for TSRST. The beams were all stored for the same amount of time before testing. Examples of test results from the TSRST are illustrated in Figure 9.

The results show fracture temperatures around -21 to -25 ºC. Comparing the lowest fracture temperature for each binder, the beams containing binder 1, 4 or 5 fail at an earlier stage. Also higher stiffness modulus has been registered for these binders.

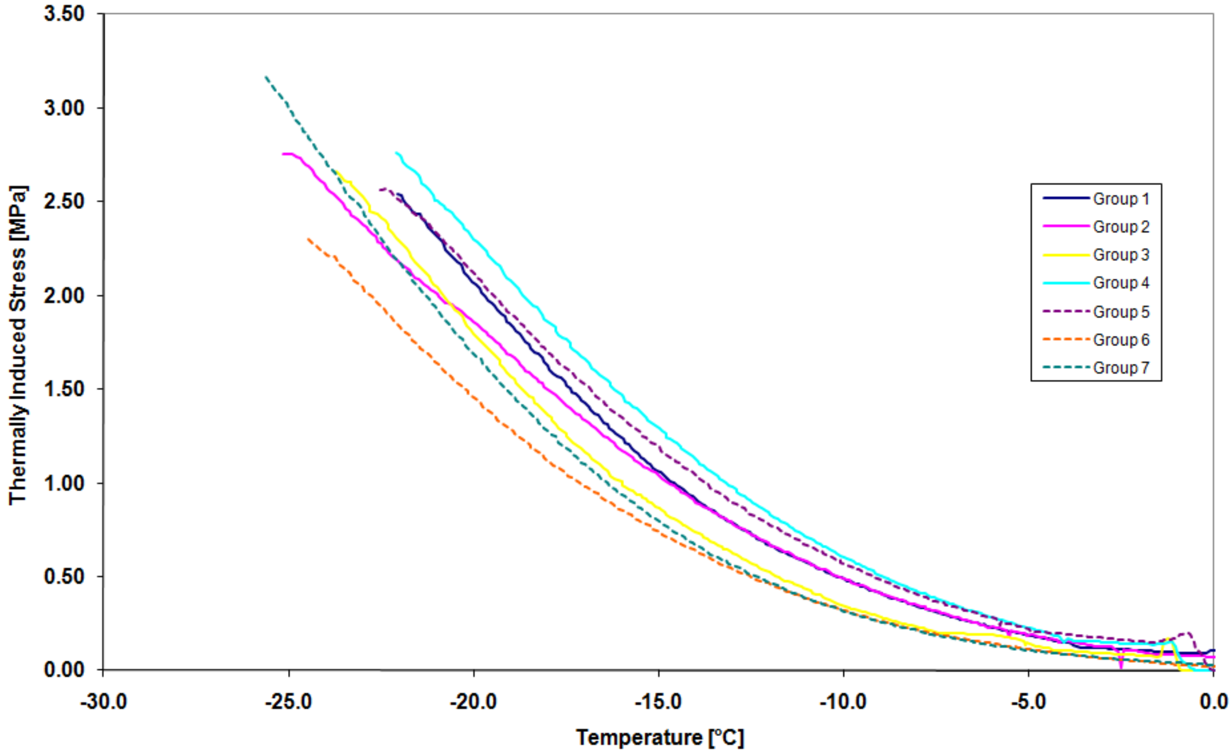

Figure 9: **TSRST response**

4. DISCUSSION AND CONCLUSIONS

Except for one bitumen (bitumen 5), all bitumens fall within the new European norm (EN 12591:2009) for penetration grade bitumen. Only kinematic viscosity at 135°C was not within the specification for bitumen 5.

The change in softening point due to hardening, in the asphalt plant and after one year of traffic on the road, was found to be between 2 and 5 °C, depending on bitumen. Bitumen 1 hardened the most.

Heating of asphalt mixture in connection with the production of slabs definitely had a hardening effect on the binder, although different for each binder.

Bitumen 4 and 5 did not fall within the previous European version of EN 12591 used in Sweden until 2009. However, deformation investigations performed in the study show that these two bitumens performed the best according to both wheel-tracking test results at +50 °C and dynamic creep testing at +40 °C. Low temperature performance according to TSRST was slightly worse for these two bitumens. As could be expected, the stiffness modulus was also higher.

Water sensitivity according to ITSR showed similar results for all bitumens tested, before as well as after winter conditioning. According to the rolling bottle test, using quartz and binders, bitumen 3 and 7 showed the best results in combination with cement. Without adhesion agent, all bitumens showed 0 % of bitumen coverage.

Wear resistance according to Prall was similar for all bitumens tested.

Ranking of binders
This study covers a wide range of properties believed to be of importance for the performance of stone mastic asphalt pavements in the field. Depending on the property under investigation, presented results show a certain variation in functional performance for the different binders. None of the bitumens performs consistently best or worst. This applies to the tests, which in a meaningful way can scale the measured properties for one of the bitumens as better or worse compared to another. In this study, it is assumed to be applicable for the following tests:

- Wear according to vändskak (with/without cement)
- Adhesion according to the rolling bottle method (with/without cement)
- Water sensitivity, ITSR (freeze-thaw conditioning)
- Wear according to Prall, (laboratory made specimens, field specimens)
- Deformation according to wheel-tracking (dry, wet)
- Dynamic creep

Based on testing listed above, the binders have been ranked with respect to function, meaning that 1 is the best. Figure 10 gives an overview of this ranking of binders.

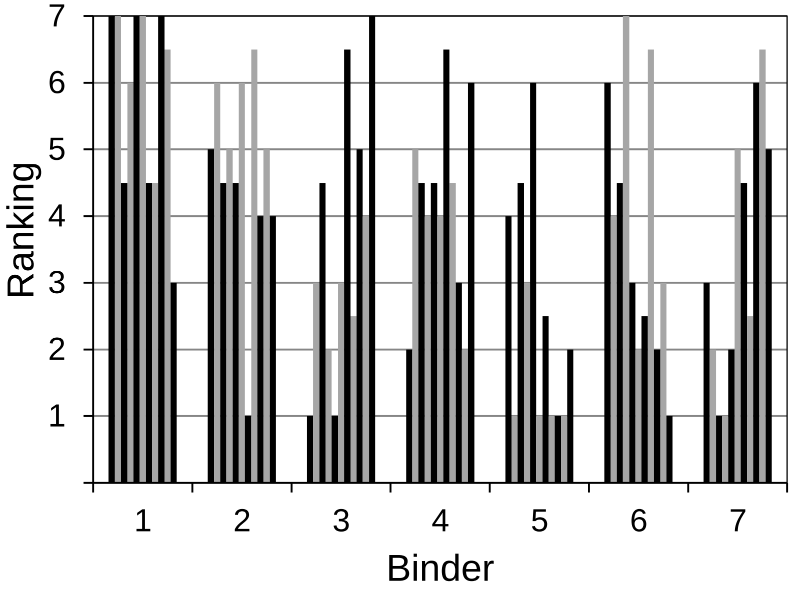

Figure 10: Ranking of binders based on the different tests

As shown in the figure, the variation for each of the binders is considerable. In spite of that, certain patterns emerge. For instance, binder 5 often gets a high ranking while binder 1 often is ranked as one of the worse. Statistical significance for the mean ranking of the binders can be analyzed using a so-called Friedman test (significance level $\alpha = 0.05$). The mean ranking for the different binders are shown in Figure 11.

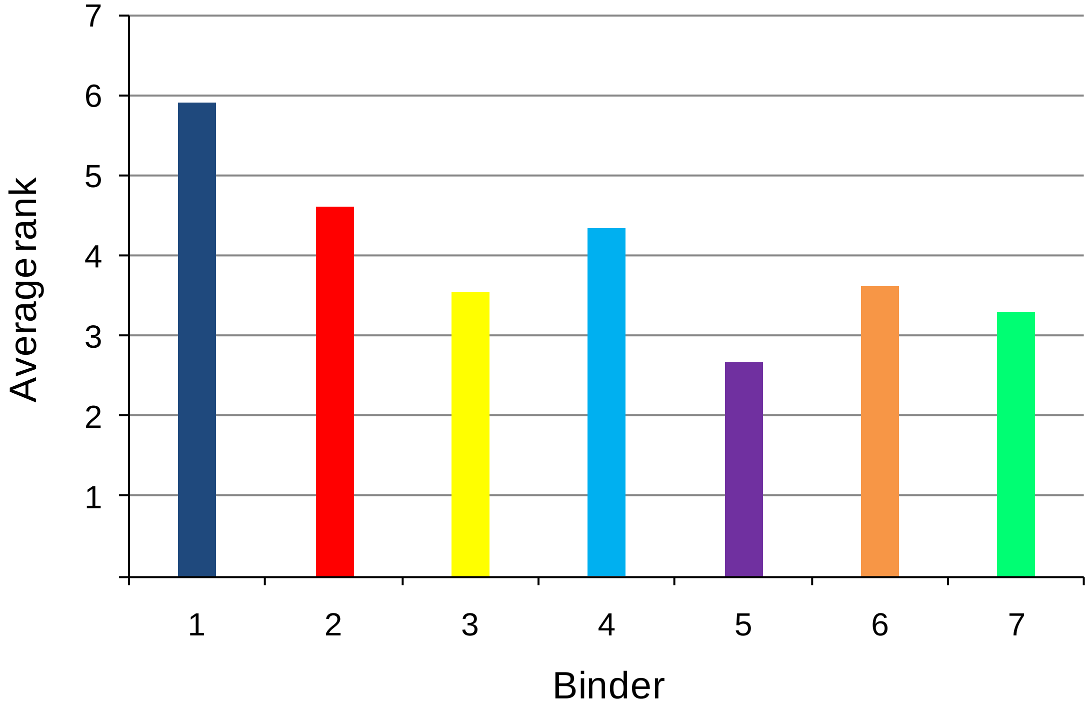

Figure 11: Mean ranking for the different binders

Among the tested binders in Figure 11, binder 5 gets the highest ranking and binder 1 the lowest. The Friedman ranking test shows significant differences between the binders used ($p = 0.02$). To examine which ranking differences are statistically significant, a so-called Conover test was performed. The main conclusion from that test is that the ranking for binder 1 is significantly lower than for all other binders, except binder 2. Furthermore, the ranking of binder 5 is higher than for binder 1, 2 and 4. Most other differences can be explained by sampling errors. However, it should be pointed out that the statistical results are valid only for the measurements carried out in this particular study. The Friedman ranking test is not affected by the measured size discrepancies, meaning that the difference between two binders may in practice be negligible, which is not shown in the ranking. In addition, there is no weighting of the individual measurements, but all measurements are assigned the same level of significance.

In conclusion, these studies show that there are certain differences between different binders of the same quality (70/100). For the future, contractors as well as clients will have to work actively from a functional thinking point of view in the production and development of good quality asphalt pavements.

5. REFERENCES

[1] Asphalt concrete test sections containing bitumen of different origins, Olsson K., Krona N., Nordgren T., SBUF report Id 12091, 2010