Quality assessment of polymer modified bitumen - performance related test methods and field performance

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ABSTRACT

As a part of a research and development project conducted by the Norwegian Public Roads Administration, an investigation was conducted on the quality of Polymer Modified Bitumen (PMBs).
Norwegian PMB grades are typically soft penetration grades with a high content of elastomeric polymer. Both softening point and elastic recovery are high, keeping good low temperature properties.
A follow-up on PMB samples taken from road sections with PMB modified asphalt concrete included testing of RTFO-aged PMBs. Traditional test methods were used together with Dynamic Shear Rheometer testing: involving Complex Modulus and Multiple Stress Creep Recovery Test (MSCRT). A special effort was made to gain insight into the MSCRT, including how to do the testing and the criteria to be used in future requirements.
The condition of the Norwegian Public Road net is measured annually with a mobile laser profile scanner. Rutting data from selected sites were linked to PMB test data from corresponding control samples. Data from road sections and laboratory tests were compared to find any correlation between field and laboratory data.

Keywords: Modified Binders, Performance based standards, Permanent Deformation, Rheology

1. INTRODUCTION

The Norwegian Public Road Administration (NPRA) manages 55.000 km national and county road network in Norway. The use of polymer modified bitumen (PMB) in asphalt pavements has increased from less than 1 % in 2005 to 10 % in 2010. Nearly 15 % of the asphalt produced in 2015 contained polymer modified bitumen.

Test sections with polymer modified asphalt concrete from 2002, performed well, and motivated increased use of PMB [1]. This project delivered documentation on binders, aggregates and different mix formulations. The rutting of the trial sections was monitored with a mobile pavement profile scanner. Field data were stored in the NPRA Pavement Management System (PMS). After nine years in service, mixes with same formulation showed 40 % less rutting with PMB than mixes with 70/100 bitumen.

The causes of rutting on Norwegian roads are wear and tear from studded tyres in winter, plastic deformation in summer and low bearing capacity (on the low volume road net). In the last ten years, the traffic volume has increased significantly. The impact from increased tyre pressure of heavy vehicles has become larger. The use of studded tyres has decreased, and less aggressive studs are used today. In the largest cities, rutting due to deformation is on the same level as asphalt wear from studded tyres.

The product standard for PMBs, NS-EN 14023, was implemented in Norway in 2008. Today there are several PMB products on the market. Compared to 2002, the PMB grading is changed and new products are available.

PMB types used in Norway are typically made of a soft bitumen grade (e.g. 120 to 250 penetration) with an thermoplastic elastomer (SBS-type). High softening point and high elastic recovery is specified. Countries tend to use harder PMB grades, with lower penetration and softening point, when plastic deformation is the main problem.

In the European Standards Committee CEN TC 336, there is ongoing work to develop Performance Related Specifications. Some new test methods from American standards (ASTM and FHWA) are adapted and transformed into EN standards. These test methods are not utilized in the current PMB specification. However, member states are encouraged on a voluntary base to evaluate these test methods for future use, as a base for new requirements.

The NPRA binder laboratory is testing PMBs sampled from the quality control of asphalt paving jobs. The PMB samples are traceable to the job site by their contract number. In this way, the test results can be linked to the performance of the corresponding road section.

The rutting resistance of polymer modified asphalt mixes is normally validated with the wheel-tracking test (EN 12697-22). With more than ten PMB products on the market, and at least four relevant asphalt mixes, this was not possible in this project. An alternative way to assess the effect on rutting, is to collect and compare rut depth data from the PMS. The objective was to verify that PMB-containing asphalt wearing courses had better rutting resistance and longer service life than non-modified asphalt wearing courses.

To ensure optimum requirements in the asphalt contracts, better characterizing PMBs is needed. Due to the extra cost of PMBs, it is important to verify good performance and value for money.

In the NPRA research program ”Durable roads” one of the activities was to establish new and better test methods for PMBs, and to propose future PMB requirements.

The aim of the PMB activity was to:
- assess the PMB types used in Norway with traditional and new test methods
- establish DSR-methods such as G* and MSCRT for high service temperature properties
- recommend suitable test methods and test conditions
- assess the benefit of using PMB on a number of road sections by comparison of rut depth development of the new and the old asphalt wearing course.

2. LABORATORY TESTING OF POLYMER MODIFIED BITUMEN

Test data were from the quality control of PMB samples in the period 2009 to 2012. These samples also supplied material for RTFOT and further testing as shown in table 1.

Table 1: Test methods used in the laboratory work

Test method	Standard	Fresh sample	RTFOT hardened @ 163°C
Penetration @ 25 °C	EN 1426	x	n.t. *)
Softening point	EN 1427	x	x
Cohesion, Force ductility @ 10 °C	EN 13589	x	n.t.
Elastic recovery @ 10 °C	EN 13398	x	n.t.
Storage stability, 72 h @ 180 °C Difference in Softening point	EN 13399 EN 1427	x	n.t.
Dynamic Shear Rheometer (DSR), Complex shear modulus @ 40 °C, 60 °C and 70 °C	EN 14770	n.t.	x
Multiple Stress Creep and Recovery Test (MSCRT) @ 60 °C $J_{nr\ 3,2\ kPa}$, % $J_{nr\text{-}diff}$, % $R_{3,2\ kPa}$	prEN 16659	n.t.	x

*) not tested

In this study, we concentrated on the high temperature properties. The reason for this is that the PMBs are mainly used to enhance rutting resistance (reduce plastic deformation). Low temperature cracking is not a significant problem on the major part of the road net. Besides, no new methods were available for assessing low temperature cracking.

2.1 Experiences with conventional test methods

The quality control of PMBs revealed some issues with the softening point results:

- quite a few PMBs had softening point (SP) close to or above 80 °C, therefore testing in both water and glycerol was required. This causes extra work
- the drop in SP in the storage stability test (e.g. a 10 °C drop in SP) - in both top and bottom part. The current specification has no limit for drop in SP in this test
- some PMB samples had a much higher SP than specified (e.g. 20 °C above minimum limit). There is no maximum limit for the SP of a PMB grade in EN 14023. The same product can be marketed as at least two different grades (e.g. 65/105-60 or 65/105-80), which makes it difficult to compare PMB products on their grade designation.

Both drop and boost in SP in the storage stability test were found. Drop in SP does not necessarily lead to poor performance, but deviating results create doubts and discussions on the quality of the PMB and asphalt pavement.

In the literature, it is well known that there is poor correlation between softening point and performance. Already in 1985, Kolb and Paulmann [2] stated (our English translation): " *It is not possible to assess permanent deformation of polymer modified asphalt by the binders softening point, due to the different elastic and viscous properties under practical stress and strain conditions*".

The BitVal project [3] also concluded that the softening point was not suitable to indicate permanent deformation for PMB asphalt mixtures.

Better test methods are available today to indicate high temperature properties. Testing with a Dynamic Shear Rheometer (DSR) is the most rational choice.

2.2 Complex Modulus and Multiple Stress Creep Recovery Test (MSCRT)

The MSCR test was implemented in USA with the AASHTO MP19-10 and M 332 specifications [4, 5, 6]. A good correlation betweeen J_{nr} parameter (non-recoverable creep compliance) and full scale testing of rutting in the Accelerated Loading Facility (ALF) was found. Also in Europe, good correlation is found between the J_{nr} parameter and rutting in laboratory testing [7, 8].

The Superpave PG specification prescribes that testing of complex shear modulus shall be within the Linear Viscoelastic (LVE) range. However, severe rutting causes a high strain in the asphalt pavement that is beyond the LVE range [9, 10]. Since G*/sin δ of PMBs did not correlate well with rutting in laboratory and full scale testing, a supplementary test, MSCR, were introduced to specify rutting resistance of both modified and unmodified bitumen.

MSCR testing is carried out at high binder strain values, far outside the LVE range. In the MSCR test procedure, the non-recoverable compliance (J_{nr}), the stress-sensitivity parameter ($J_{nr\text{-}diff}$) and the elastic recovery (% R) are determined in the same test run. The stress-sensitivity parameter ($J_{nr\text{-}diff}$) is the percent difference in non-recoverable creep compliance between applied stress of 0,100 kPa and 3,200 kPa.

In our study the Anton Paar Smartpave DSR was used for G*/sin δ and MSCR testing on RTFO-hardened PMB samples. The test methods were EN 14770 and prEN 16659 (2013).

3. Road sections investigated

A list of road sections considered suitable to the study, were set up. Representative PMB-samples of the sections were tested. Since there were no reference road sections established, the performance of the new asphalt with PMB was compared with that of the asphalt laid before for each road section.

Most of the new PMB asphalts were asphalt concrete (AC), but also a few sections with stone mastic asphalt (SMA). In the old asphalt (AC or SMA), 70/100 bitumen was used. The PMBs are specified in the NPRA road manual N200 “Road construction” and in the individual contracts.

The mobile Road Profile Scanner provided the rut depth data, see figure 1. The NPRA road net is measured annually with this equipment. The data are stored in the National Road Data Bank, for use in the Pavement Management System.

Figure 1: NPRA’s mobile road profile scanner for measurement of rutting

Table 1 lists the PMB types and corresponding road sections. The climate classes for the road sections according to the Superpave PG binder specification are also given. Most of the sites have maximum design temperature 52 °C to 54 °C, and from the PG-specification, the binder should be a PG 58. A 70/100 bitumen normally corresponds to a PG 58.

Only one of the test sections is located in a very cold area, with minimum air temperature below -40 °C. This road section experienced low temperature cracking (transverse cracking) in cold winters. Using PMB in this area should give less low temperature cracking, fatigue cracking and less deformation.

Test section	PMB grade	Length of road section	Old wearing course	Year	New wearing course	Year	AADT 2015 [1)]	Increase in AADT [2)]	Climate class [3)] max / min
1	75/130-65	440 m	SMA11	2001	SMA11	2009	11.400	22 %	52 / -28
2	65/105-80	2000 m	SMA16	2004	AC16	2009	32.000	-6 %	54 / -22
3	70/120-60	500 m	AC11	2004	AC11	2009	17.700	32 %	52 / -28
4	75/130-65	480 m	SMA11	2006	AC11	2009	7498	-4 %	52 / -28
5	75/130-65	500 m	AC11	2006	AC16	2009	16.600	13 %	52 / -28
6	75/130-65	500 m	AC16	1999	AC16	2010	6360	67 %	46 / -16
7	40/100-75	500 m	AC11	2002	AC11	2010	7100	48 %	53 / -10
8	65/105-80	500 m	SMA11	2006	AC11	2010	9600	4 %	54 / -22
9	40/100-75	261 m	AC11	2002	AC11	2010	8000	-4 %	52 / -28
10	90/150-75	500 m	AC11	1995	AC11	2011	3000	11 %	47 / -33
11	70/120-80	500 m	AC11	2007	AC11	2011	4154	9 %	52 / -28
12	75/130-65	500 m	SMA11	1999	AC11	2011	5456	20 %	52 / -28
13	65/105-80	232 m	SMA11	2007	SMA11	2011	22.000	32 %	53 / -22
14	65/105-80	500 m	SMA16	1994	AC16	2012	7640	43 %	52 / -28

Table 1: Road sections and PMB grades in this study

[1)] Traffic volume, Annual Average Daily Traffic
[2)] Increase in AADT from placement year of old pavement to year of new pavement
[3)] According to Superpave criteria. Calculated maximum and minimum pavement design temperature from meteorological data

4. RESULTS AND DISCUSSION

4.1 Laboratory testing

Table 2 shows the results of the binder testing with current specification test methods.

Four of the fresh PMB samples had too low SP according to their grade. Six RTFOT residues had too low SP. Eight samples had more than 2 °C drop in SP after RTFOT. The storage stability test showed a similar trend: four samples had too low SP according to their grade.

The elastic recovery @ 10 °C for all PMBs complied with the specified minimum limits of 50 % or 75 %.

Table 2: Binder testing with test methods from EN 14023

Test section	PMB grade	Pene-tration 1/10 mm	Soften-ing point, °C	Storage stability SP, °C top	bottom	diff	SP after RTFOT, °C SP	SP-diff	Elastic recovery %	Force ductility 10 °C J/cm²
1	75/130-65	90	51,8	53,6	53,6	0,0	58,2	6,4	79	0,76
2	65/105-80	86	73,4	72,4	74,8	-2,4	61,0	-12,4	89	1,41
3	70/120-60	112	68,2	69,8	70,8	-1,0	68,5	0,3	97	1,17
4	75/130-65	96	62,4	68,8	70,0	-1,2	56,0	-6,4	90	0,97
5	75/130-65	87	71,8	55,8	56,8	-1,0	57,2	-14,6	89	1,00
6	75/130-65	98	72,2	69,8	69,8	0,0	72,0	-0,2	81	2,81
7	40/100-75	55	> 83,0	81,4	80,8	-0,6	83,5	no value	66	1,10
8	65/105-80	67	> 97,0	96	95,5	-0,5	80,0	-17,0	85	2,63
9	40/100-75	72	94,0	79,5	79,5	0,0	82,0	-12,0	81	1,94
10	90/150-75	120	93,0	88,0	91	3,0	88,0	-5,0	90	0,88
11	70/120-80	111	86,0	86	84	-2,0	80,0	-6,0	98	0,95
12	75/130-65	97	72,6	69,6	69,6	0,0	70,6	-2,0	82	2,77
13	65/105-80	75	62,6	56,2	55,2	-1,0	67,0	4,4	79	1,46
14	65/105-80	73	94,0	89,5	91	1,5	79,2	-14,8	84	1,98

Four of the samples had lower force ductility cohesion less than specified in EN 14023 (≥ 2,0 J/cm²). Figure 2 shows an example of three PMBs with different types of force/elongation-curves.

Figure 2: Force ductility @ 10 °C curves of three types of PMBs: stress sensitive (pmb 7), soft PMB-grade (pmb 10) and typical curve (pmb 9)

Table 3 shows the results from DSR testing of RTFOT-hardened samples. The Superpave PG high temperature (when G*/sin δ = 2,2 kPa) was calculated from G*/sin δ values at 60 and 70 °C.

Table 3: Testing of RTFOT-hardened PMB samples with the Dynamic Shear Rheometer

Test section	PMB grade	G*/sin δ @			MSCRT @ 60 °C			Temperature G*/sin δ is 2,2 kPa, °C
		40 °C	60 °C	70 °C	$J_{nr\ 3,2\ kPa}$	% $J_{nr\ diff}$	% $R_{3,2\ kPa}$	
1	75/130-65	95	7,6	2,6	0,70	31	30	72
2	65/105-80	92	8,8	3,3	0,36	25	53	74
3	70/120-60	50	5,3	2,2	0,65	60	52	70
4	75/130-65	75	6,2	2,9	1,25	29	13	74
5	75/130-65	90	7,4	2,5	0,83	29	23	71
6	75/130-65	70	6,9	2,9	0,08	-9	90	73
7	40/100-75	239	19,5	8,8	0,28	200	43	87
8	65/105-80	298	20,0	8,6	0,09	31	74	86
9	40/100-75	237	16,3	4,9	0,48	12	88	77
10	90/150-75	93	7,2	2,4	0,29	74	69	71
11	70/120-80	57	5,4	2,0	0,18	42	86	69
12	75/130-65	80	7,2	2,9	0,10	-10	88	73
13	65/105-80	192	14,0	4,3	0,29	15	44	76
14	65/105-80	173	14,5	5,0	0,11	46	75	78

All calculated PG high temperatures were above the highest climate class (PG 58) of the road sections in table 1.

In AASHTO M 332 [6], DSR-testing is at the climate class temperature, which is designated as the average seven-day maximum pavement temperature. Maximum measured pavement temperature in Norway is approximately 60 °C. The AASHTO M 332 specification for J_{nr} includes classes based on expected traffic level (ESALs) and traffic loading rate (normal speed - slow speed - standing traffic). The corresponding four J_{nr} based traffic classes are shown in table 4.

Table 4: Supplementary grading from AASHTO M-332, based on traffic level and traffic rate

Traffic	Grading	Traffic level, ESALs	Traffic load rate	J_{nr} -limit
Standard	S-grade	< 10 million	> 70 km/h	≤ 4,5 kPa^{-1}
Heavy	H-grade	10-30 million	20 – 70 km/h	≤ 2,0 kPa^{-1}
Very heavy	V-grade	> 30 million	< 20 km/h	≤ 1,0 kPa^{-1}
Extremely heavy	E-grade	> 30 million	standing < 20 km/h	≤ 0,5 kPa^{-1}

For all classes the stress-sensitivity parameter ($J_{nr\text{-}diff}$) shall be maximum 75 %.

Our data show that 10 out of 14 PMB samples satisfy the E-grade, 13 satisfy the V-grade and all satisfy the H-grade. One PMB (sample 7) did not satisfy the FHWA stress-sensitivity requirement. The high temperature PG of this sample is the highest of the tested PMBs. At this time, no performance problem is reported on the corresponding road section.

AASHTO M 332 includes recommended requirements for elastic recovery (% R) from MSCRT. Three samples (no. 1, 4, and 5) fell below these limits, and are “failing % recovery” according to M 332. However, these three PMBs had satisfying elastic recovery at 10 °C, according to Norwegian PMB specifications.

4.2 Rutting data of road sections

The results from field measurements of rut depth are given in table 5. The 90/10-value (90-percentile) is the rut depth value of which 10 percent of the data have higher values.

The initial rutting was deducted before calculating the annual rutting. Initial rutting is associated with paving and compaction operations, and the time before the traffic is allowed on the new pavement.

Table 5: Development of rutting (annual rutting rate) of new PMB-asphalts compared to previous asphalts (90 percentile values).

Test section	Previous asphalt	Year	Rutting rate (90/10) mm/year	New asphalt	PMB	Year	Rutting rate (90/10) mm/year
1	SMA11	2001	1,9	SMA11	75/130-65	2009	0,9
2	SMA16	2004	4,7	AC16	40/100-75	2009	1,5
3	AC11	2004	4,6	AC11	65/105-80	2009	4,4
4	SMA11	1995	4,0	AC11	70/120-60	2009 *)	2,1
5	AC11	2006	6,7	AC16	75/130-65	2009	2,6
6	AC16	1999	2,6	AC16	75/130-65	2010	2,4
7	AC11	2002	2,5	AC11	75/130-65	2010	1,9
8	SMA11	2006	4,3	AC11	40/100-75	2010	0,6
9	AC11	2002	2,8	AC11	65/105-80	2010	1,8
10	AC11	1995	1,3	AC11	40/100-75	2011	1,0
11	AC11	2007	4,5	AC11	90/150-75	2011	1,4
12	SMA11	1999	2,3	AC11	70/120-80	2011	1,7
13	SMA11	2007	4,3	SMA11	75/130-65	2011	0,2
14	SMA16	1994	0,9	AC16	65/105-80	2012	1,0

*) 2013 measurement

Figure 3 shows the annual rutting rate of the corresponding old and new asphalts. A significant improvement in rutting rate is found for most of the sections. The rutting data were not corrected for eventual increased traffic load on the new asphalts. The rutting rate values of the test sections will be more certain after more years in service.

Increased traffic load may explain why four of the sections did not experience reduced rutting. With higher traffic loading and higher speed, the wear and tear from studded tyres have larger effect on the rutting.

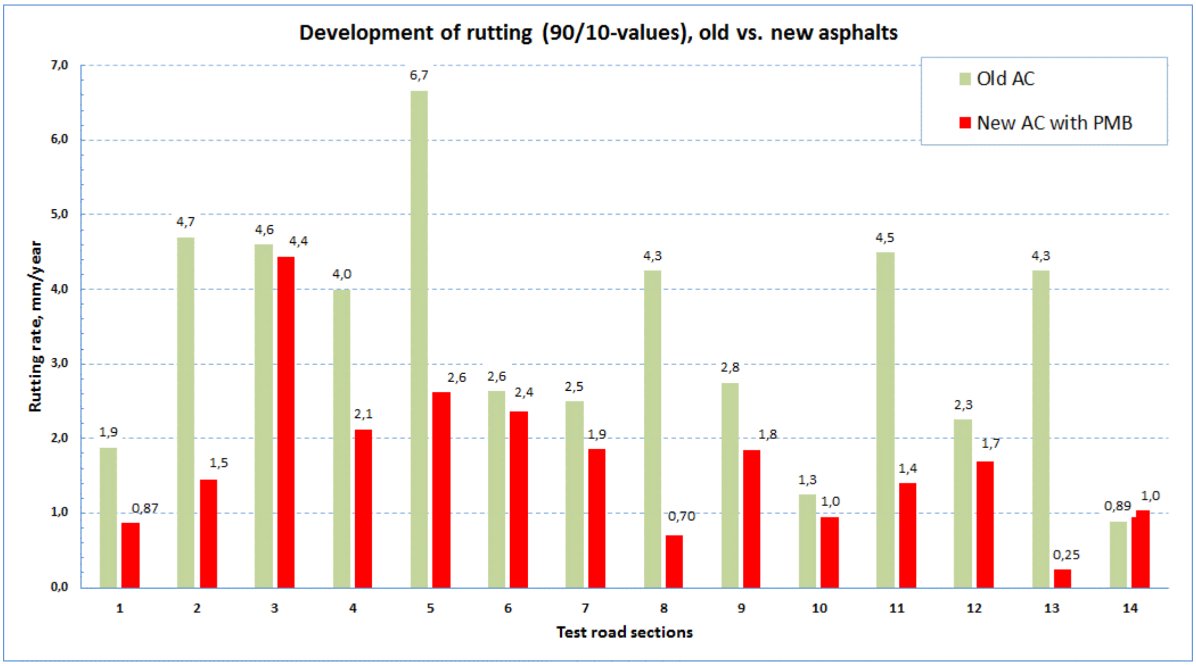

Figure 3: Development of rutting (rutting rate) on test sections after 3 to 6 years in service.

Figure 4 shows the rutting rate of the test sections versus Jnr-value. Modest correlation was found between rutting rate and Jnr-value. This is not surprising, since the road sections have different traffic loads and have different asphalt mixes. Wear and tear from studded tyres causes rutting, and deformation of the base course is another possible cause.

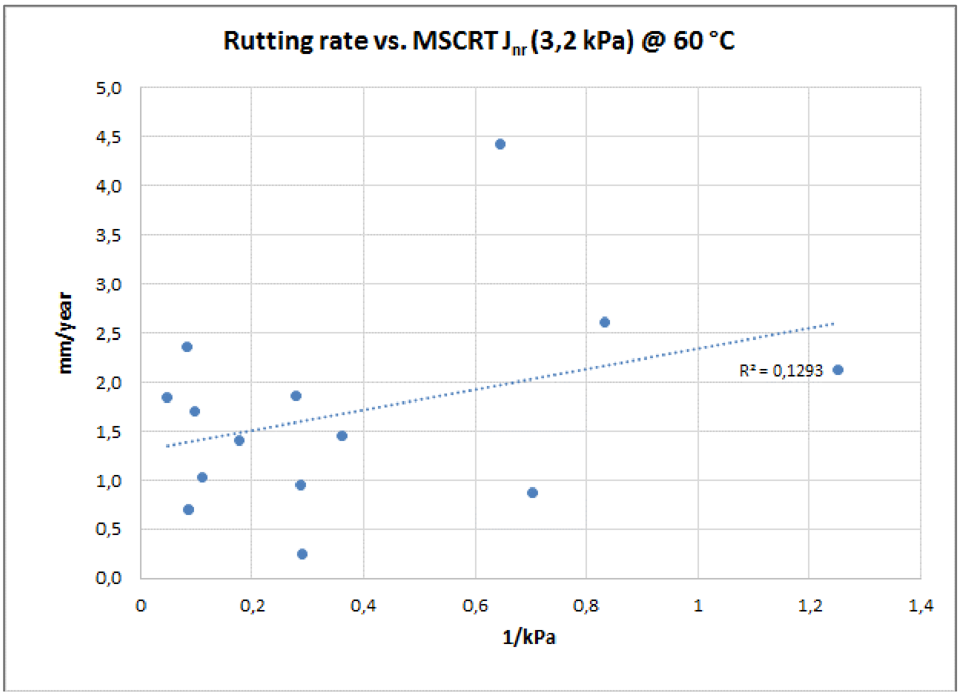

Figure 4: Rutting rate versus Jnr on corresponding asphalts and PMBs

4.3 Discussion
Between the test methods, excellent correlation was found only between G*/sin δ @ 60 °C and G*/sin δ @ 70 °C (R= 0,95) – as expected. Fair correlation was found between force ductility cohesion @ 10 °C and Jnr (R= -0,63).

Modest correlations were found between rutting rate and three laboratory methods: Jnr @ 60 °C (R= 0,36), G*/sin δ @ 40 °C (R= -0,45) and G*/sin δ @ 60 °C (R= -0,42).

Modest correlation was found between penetration of original binder and rutting rate (R= 0,34). The other test methods showed poor correlation with the rutting rate.

The softening point values appeared to have limited value. There is a clear trend for drop in SP after RTFOT. To compensate for this, PMBs may be produced with a much higher SP than required in the grade. This is not an ideal situation for the supplier, contractor or road holder.

The force versus elongation curve in the force ductility test revealed that one PMB had a deviant curve. This PMB also failed on the stress sensitivity parameter $J_{nr\text{-}diff}$. A wax modifier was added to this PMB, leading to a high SP and a high G*/sin δ value.

The MSCR testing detected one stress sensitive PMB and one PMB close to the $J_{nr\text{-}diff}$ limit. Figure 2 shows the force ductility curves of these two PMBs, together with one with a “normal” curve shape.

The curve shape in the force ductility test is not interpreted in the test standard, and is only informative. For the time being, there is a “to be reported” requirement on force ductility cohesion in the Norwegian PMB specifications. The cohesion classes @ 10 °C in EN 14023 do not fit well with the PMBs used in Norway. An extra cohesion class (≥ 1,0 J/cm^2) could be introduced in the standard. Alternatively, the existing cohesion classes @ 5 °C could be used.

Although the J_{nr} –value did not correlate as well with rutting rate as expected, we believe it is the best parameter to use to control deformation rutting. Requirements on both G* (or G*/sin δ) and J_{nr} @ 60 °C should be used.

Most of the PMBs in this survey were classified as E-grades according to AASHTO M 332. One of the E-grades was optimized for excellent low-temperature flexibility, and not for high-temperature stability.

Suitable PMBs for extremely high traffic loadings, such as bus stations, heavy trafficked roundabouts and crossroads, were not assesed in this study. Further laboratory testing, e.g. with wheel-tracking on asphalt mixes with different PMBs, may clarify test methods and requirements.

5. CONCLUSIONS

Most of the selected PMB asphalt sections showed reduced rutting. According to the policy of using the asphalt wearing course that give best “value for money”, PMB is justified as a better choice than bitumen for most of the test sections.

The binder testing showed that for at least six PMBs, softening point requirements in the current specification might lead to dispute. So far, there is no specific deformation problem on these road sections.

According to the new specification, AASHTO M 332, all of the PMBs in this survey pass the J_{nr}-criteria. There were 10 E-grades, 13 V-grades and 14 H-grades.

One PMB failed on the stress sensitivity parameter Jnr-diff. This PMB also had a deviating force ductility curve.

DSR test methods seem to be the best choice for use in performance related binder specifications. Requirements based on complex modulus and MSCRT Jnr parameter should replace the softening point requirements.

Current EN 14023 is not working satisfactory for PMBs in Norway. High and low temperature requirements may be different from those used in warmer climates. In the coming PRS specifications, PMB requirements should cover regional climate and traffic conditions in a better way.

The MSCRT procedure should be further developed, e.g. to improve reproducibility. In further studies, stress sensitivity and its relation to asphalt pavement performance should be studied on different modified bitumens, e.g. with wheel-tracking testing on asphalt mixes.

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