LONG-TERM PERFORMANCE OF ASPHALT SURFACINGS CONTAINING POLYMER MODIFIED BINDERS

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ABSTRACT

This paper reports on a field and laboratory study conducted to evaluate the performance of asphalt surfacings containing a polymer modified binder. Seven test sections were laid in southern Norway in 2002 to study the field performance of asphalt surfacings containing a polymer modified binder in comparison to surfacings containing conventional binder. The test sections were laid on the same road and the same area, which meant the sections were exposed to the same traffic and climatic conditions. The study involved two surfacing mixture types; an asphalt concrete (AC) and a stone mastic asphalt (SMA). The surfacing mixtures were tested both at the time of construction as well as afterwards in the laboratory with focus on resistance to deformation and wear. The field performance of the pavements was monitored with yearly measurement of rutting and roughness development. This paper provides the findings of the study and conclusions regarding the effect of modified binders on development of rutting in the field as well as the relationship between laboratory test results and field performance.

Keywords: Asfalt surfacings, polymer modified binders, rutting, field performance

1. INTRODUCTION

Rutting caused by both pavement wear due to the use of studded tires in winter times and deformation in pavement layers is the major distress mechanism that triggers maintenance on Norwegian pavements. The problem of pavement wear due to studded tires has been extensively studied in the 1970s and 80s because of the high road maintenance costs and health issues (dust pollution) associated with the pavement wear. As a result of this work several measures were introduced to reduce the wear including the use of large and hard stone materials in the asphalt, development of light-weight, so-called environmental studs, development of stud-free winter tires and introduction of fee for using studded tires in some urban centers. In combination, these measures have led to a substantial reduction in pavement wear. Despite this reduction, wheel-path rutting remains to be the major distress on the pavements. As a result there is a growing interest in Norway in the use of polymer modified bitumen in asphalt pavements in an attempt to increase the resistance of the pavements to rutting.

The purpose of modifying bituminous binders with polymers has been to reduce the temperature susceptibility of the binders and thereby produce asphalt mixture with better resistance to cracking and to permanent deformation (rutting). The polymers used in modification of bituminous binders can be categorized into three major groups: thermoplastic elastomers, plastomers and reactive polymers. Of these three categories it is the thermoplastic elastomers that are commonly used for modification of binders for road construction purposes. Elastomers improve the elastic properties of the binders. Modification of binders with elastomers increases the binder's capacity for elastic recovery after loading and unloading over a wider temperature span. The most commonly used elastomer for bitumen modification is the SBS (styrene-butadiene-styrene) co-polymer. In Norway SBS modified binders have been used in nearly all of the pavements containing modified binders. Plastomers and reactive polymers, on the contrary, impart high rigidity to the binders and strongly reduce deformation under load.

The beneficial effects of polymer modification on the performance of asphalt materials with regard to rutting and fatigue cracking have been reported by many researchers. Yildirim [1] published review of research that has been conducted on polymer modified binders in the last three decades. The vast majority of the research work reviewed indicated that pavements with polymer modification exhibited greater resistance to rutting and thermal cracking, and decreased fatigue damage and stripping. It has been reported that polymer modified binders have successfully been used at intersections of busy streets, airports, vehicle weigh stations, and race tracks [1]. Several other authors including Bouldin and Collins [2], Udin [3] and Lu [4] have reported significant improvement in properties of asphalt mixtures containing modified binders as compared to those containing unmodified binders. However, most of these studies are based on laboratory test results and not on the long- term performance of asphalt mixtures containing modified binders in the field.

Few studies have been conducted to evaluate the effect of polymer modification on the resistance of asphalt mixtures to wear due to the use of studded tires. Saba et al [5] reported the result of a laboratory study in which asphalt mortars containing various polymer modified binders were tested for their resistance to wear. The result showed that the mortars containing modified binders have much better resistance to wear compared to those containing unmodified binders. The result also showed that the resistance to wear is correlated to the binders' elastic recovery; the higher the elastic recovery the better is the resistance. Similar results were earlier reported by Rønnes [6].

Jacobson [7] reported an extensive study conducted in Sweden on wear resistance of bituminous mixes. The study involved testing of asphalt pavements slabs produced in the laboratory and inserted in real road pavements as well as testing of those slabs in VTI's pavement testing machine (an accelerated pavement testing device). Some of the slabs were produced using polymer modified binders although little information was given on the type and content of the polymer. The results showed that, for stone mastic asphalt mixes, the polymer modified binder had no appreciable effect on the wear resistance. However, for dense graded asphalt concrete, the result was different; the wear was 20 – 40% less for sections containing modified binders than the reference section containing the conventional 85 pen binder.

Uthus [8] reported the results of a field research conducted in the city of Trondheim, Norway. The research work included constructing and monitoring test sections containing polymer modified binder (styrelf) and a reference section. Based on field measurements after two winters, the author concluded that the sections containing polymer modified binder had better resistance to wear than the reference section.

This paper reports on results of a field test conducted from 2001 – 2009 to study the effect of a polymer modified binder used in surfacing mixtures on the development of rutting. Details of the test sections and the materials tested as well as the results obtained are described in the following sections.

2. TEST SECTIONS

Seven test sections were laid on highway E18 in southern Norway in September 2001. The purpose of building the test sections was to investigate:

- The effect of a polymer modified binder on the development of rutting.
- The effect of aggregate mechanical properties used in the asphalt surfacing on the development of rutting.
- If the use of polymer modified binders can compensate for relatively low quality aggregate materials.

The test sections were built adjacent to each other on the same subgrade material and were subjected to the same traffic and climatic loading. The sections were laid on the outer lane of a four- lane (two-way) highway. The ADT at the time of opening in 2001 was 16 560 vehicles with 14% heavy vehicles. Figure 1 shows the pavement structure for the test sections.

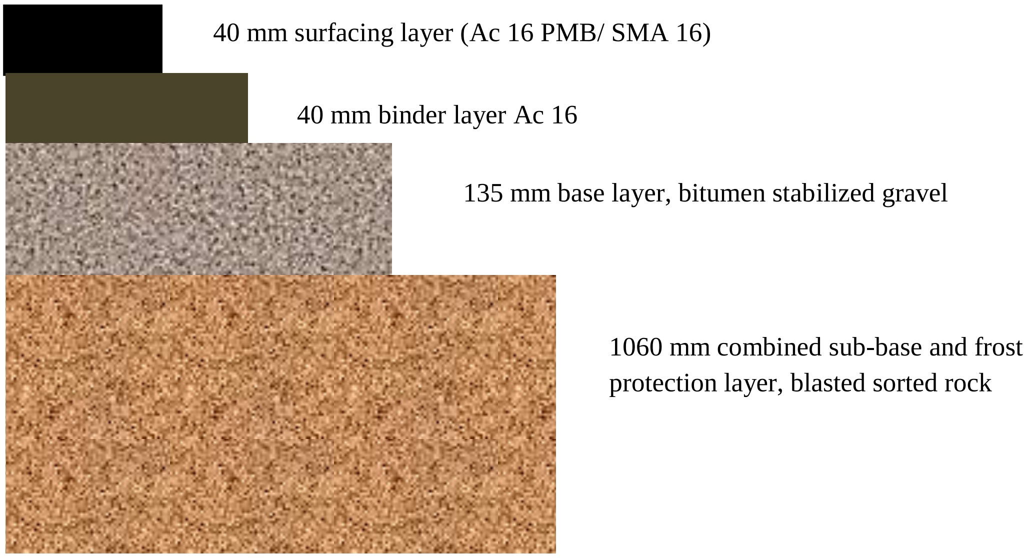

Figure 1: Pavement structure for the test sections

The test sections were monitored with measurement of rutting and roughness every year and were inspected several times to see if other distresses, such as cracking developed. Surfacing material types and lengths for each test section are given in table 1.

Table 1: Details of the test sections

Test section	Length (m)	Surfacing type	Binder type	Binder content (%)	Aggregate type
1	140	Asphalt concrete, Ac 16	PMB 60	5.4	1
2	142	Asphalt concrete, Ac 16	PMB 60	5.5	2
3	202	Asphalt concrete, Ac 16	PMB 60	5.5	3
4	177	Asphalt concrete, Ac 16	PMB 60	5.7	4
5	190	Stone mastic asphalt, SMA 16	pen70/100	5.9	1
6	184	Stone mastic asphalt, SMA 16	pen70/100	6.3	4
7	142	Asphalt concrete, Ac 16	pen70/100	5.3	1

Sections 1 and 7 had the same recipe but with different binder; section 1 had a polymer modified binder while section 7 had a conventional binder. The results from these two sections are therefore directly comparable to see the effect of the modified binder. Sections 2 – 4 had also the same recipe as section 1 but with different aggregate materials. These sections were used to see if the use of polymer modified binder can compensate for low quality aggregates, as well as to see the effect of aggregate materials on the development of rutting. Sections 5 and 6 had the same recipe (SMA 16) with the same binder but different aggregate materials. Some material properties of the aggregates and binders are shown in tables 2 and 3.

Table 2: Aggregate properties

Aggregate type	Los Angeles abrasion value (EN 1097-2)	Nordic abrasion value (EN 1097 – 9)	Polished stone value (EN 1097 – 8)
1	15.4	9.5	45
2	32.5	17.1	47
3	13.4	7.1	50
4	13.4	3.4	46

Table 3: Binder properties

Binder	Penetration	Softening point(^{o}C)	Fraas breaking point (^{o}C)	Elastic recovery (%) at 10^{o}C
PmB 60/120-60	60 - 120	$\geq$ 60	$<$ - 15	$\geq$ 60
Pen 70/100	75	46		

3. MATERIAL TESTING

Core samples were taken from the test sections both at the time of construction and afterwards. The samples were tested in the laboratory to determine their properties with regard to permanent deformation and wear resistance. Deformation properties were tested using wheel-tracking test (EN 12697 - 22) and Nottingham Asphalt Tester, NAT (EN 12697 – 25). The resistance to studded tire wear was tested using the Prall test (EN 12697 – 16). Figure 1 shows the results of wheel- track testing of the core samples taken from the road at the time of construction. This testing provided initial ranking of the mixtures based on their deformation properties. It showed that test section 2, which had a low quality aggregate, had the least resistance to permanent deformation, indicating the use of polymer modified binder would not compensate for low quality aggregates. As can be seen from figure 2 the wheel tracking rates for the mixtures containing the modified binder (with exception of section 2) is lower than the mixture containing unmodified binder (section 7) indicating an improved resistance to permanent deformation due to the use of the modified binder.

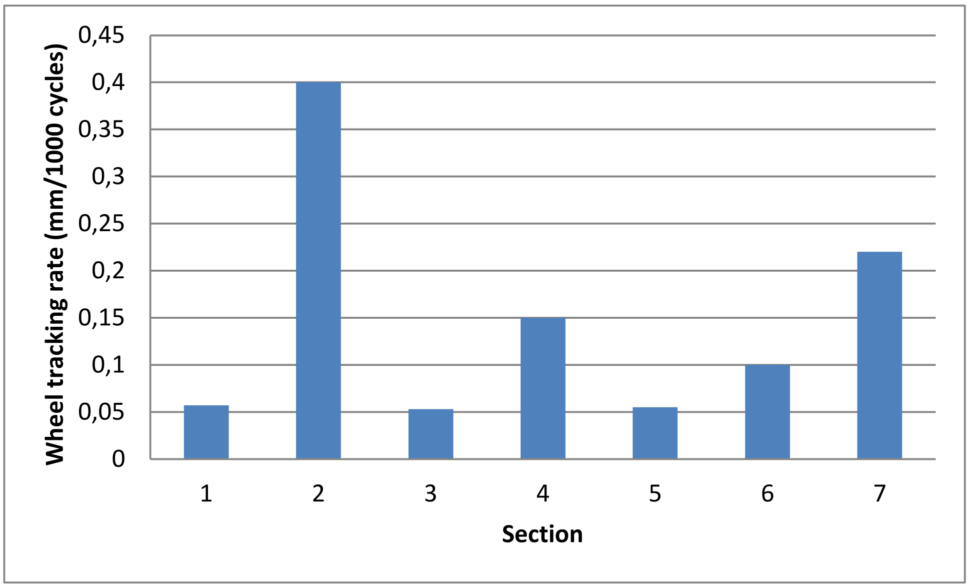

Figure 2: Results of deformation testing in the wheel track on field core samples [9].

In 2008 a new set of core samples were taken from the test sections and tested in the laboratory to evaluate the deformation and wear resistance properties of the surfacing material. Figures 3 and 4 show results of deformation testing in NAT and wheel-track respectively, while figure 5 shows results from the Prall testing.

It can be seen from figures 3 and 4 that section 2 has the least resistance to deformation, confirming earlier test results. However the two tests provide different ranking of the mixtures/sections. Based on testing in the NAT, section 3 would be ranked as the best but testing in the wheel-track shows virtually the same level of resistance to deformation for sections 3, 4, and 5 and indicates that section 1 is the most resistant. Results of wear testing, given in figure 5, show that section 2 has the least resistance to studded tire wear and section 4 has the best resistance. The wear testing provides a different ranking compared to the deformation testing. A summary of rankings obtained from these tests in comparison to field measurements is provided in section 6 of this paper.

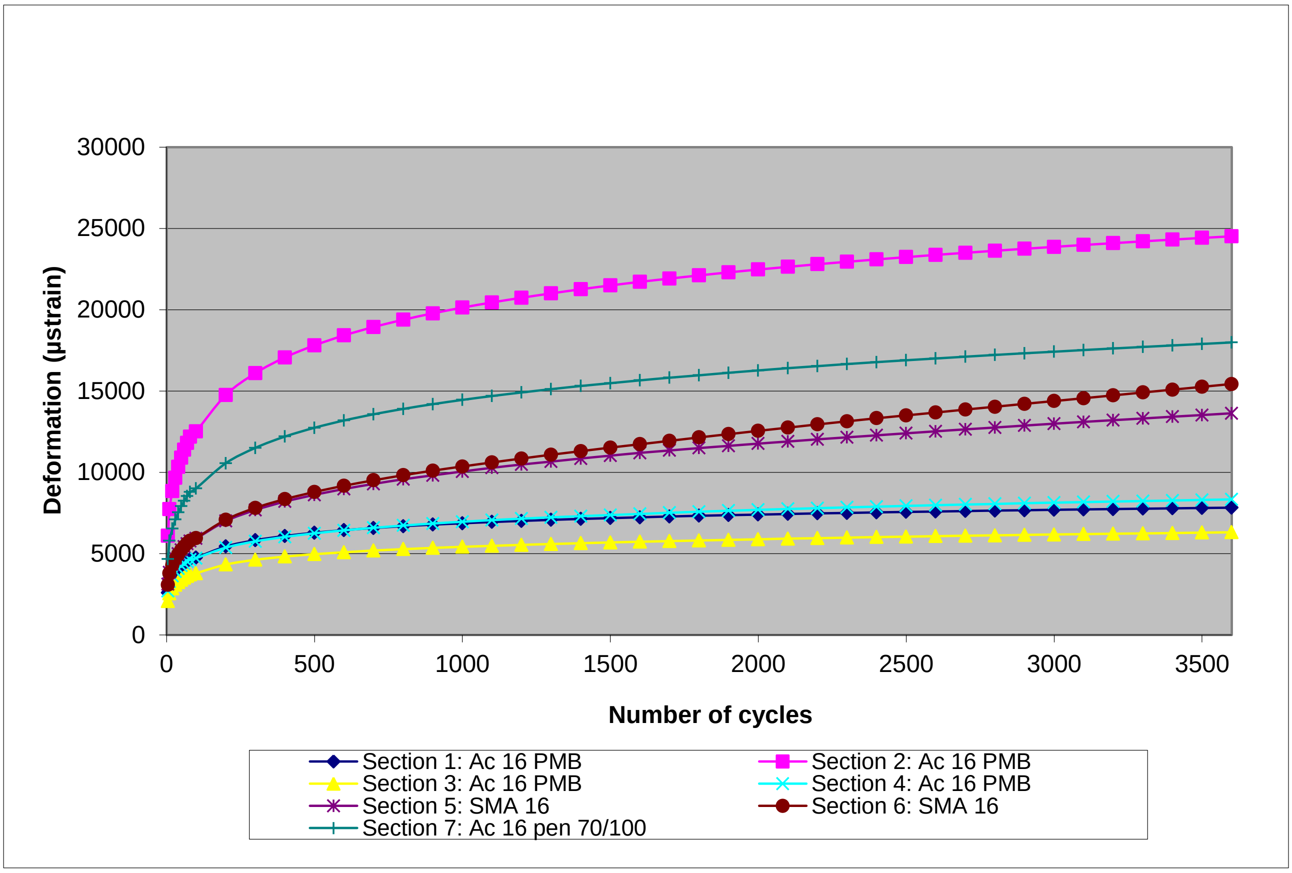

Figure 3: Results of deformation testing in NAT

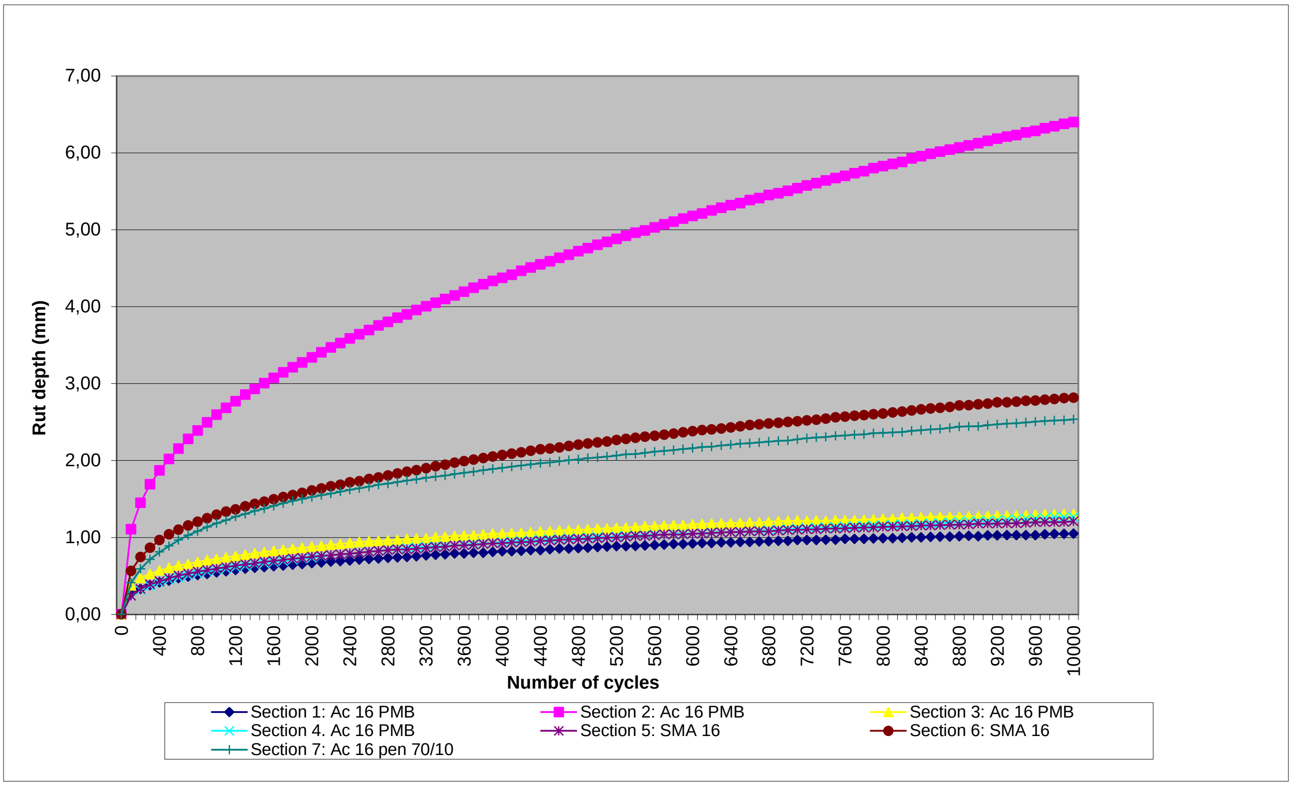

Figure 4: Results of deformation testing in the Wheel-track

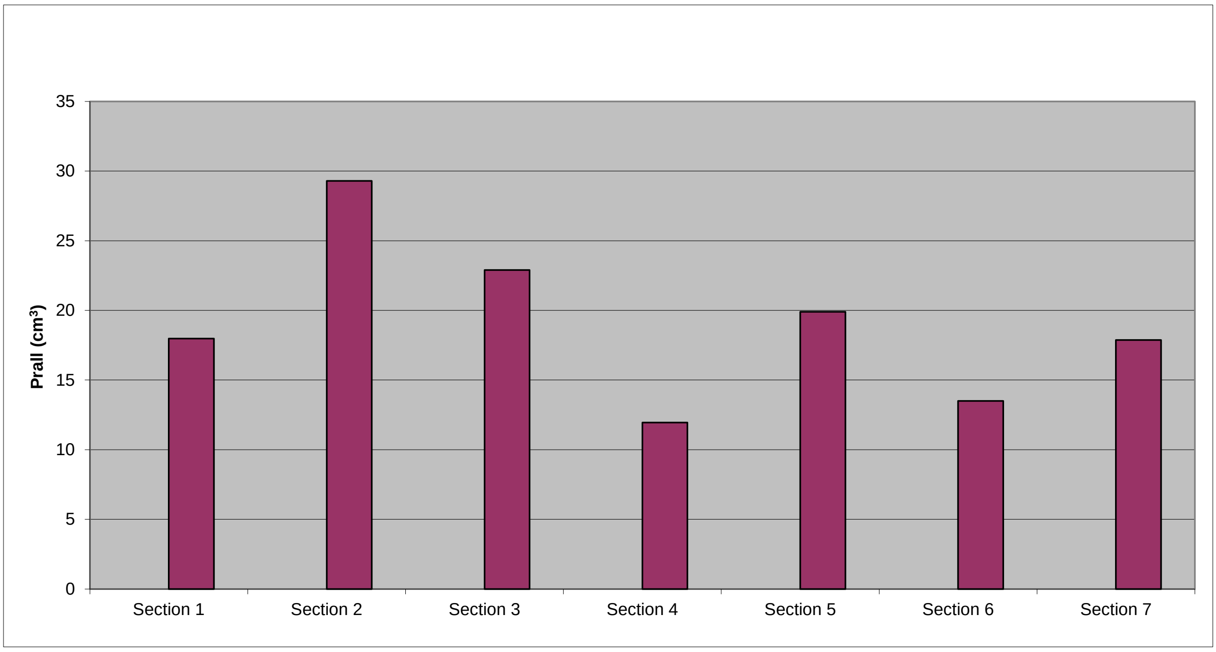

Figure 5: Results of the wear resistance test (Prall)

4. FIELD MONITORING

The condition of the test sections was monitored with yearly measurement of rutting, roughness and texture. In addition several manual inspections were conducted to monitor development of other distress types. None of the sections developed surface defects other than roughness and rutting with exception of few points where inhomogeneity has led to aggregate loss.

The measurements of rutting, roughness, and texture were conducted using instrumented vehicles of the Norwegian Public Roads Administration. The measurement from year 2002 – 2008 was conducted using an ultra-sound based measuring system. This system measures using 17 ultra-sound sensors mounted on two beams with a distance of 12.5 cm between the sensors. The equipment is capable of measuring over a width of 2.00 meters. The system therefore measures rutting in one wheel path at a time. In 2008 the Norwegian Public Roads Administration introduced a new measuring system, which is based on laser technology, known as Via Pavement Profile Scanner (ViaPPS). The new system has a vehicle mounted rotating laser, which is capable making 140 rotations per second and scanning the cross-sectional profiles at about every 16cm while driving at 80 km/hr. This system is capable of measuring over the full width of a lane (4 meters) with a resolution of about 550 points which corresponds to about 6 – 7 mm distance between the measuring points. The new system therefore provides more accurate data than the old system.

The measurements are typically conducted just after the end of the winter season. Pictures of the old ultra-sound based system and that of the new pavement profile scanner are shown in figures 6 and 7, respectively.

Figure 6: Ultra-sound based pavement monitoring system

Figure 7: Pavement profile scanner (Via PPS)

5. FIELD PERFORMANCE

The performance of the test sections was evaluated based on field measured data. In this section the results of the rutting measurement are presented. Figure 8 shows the measured rutting for the test sections. The rut depth values plotted in the figure are the 90-percentile values of measured rut depths for each section. The 90-percentile rut depth values are used in Norwegian pavement management system (PMS) and maintenance standards to determine the need and timing for overlays. As can be seen from figure 8, section 2 had the largest measured rut depth, which is in agreement with laboratory test results. This section had a relatively low quality aggregates in surfacing and the result shows that although the use of polymer modified binder may have increased the service life of the surfacing for this section, it may not compensate for low quality aggregates.

Section 1 and section 7 have the same recipe apart from the binders, as mentioned earlier. One can therefore directly compare the field measured rutting for these two sections to see the effect of polymer modification. By comparing the 2009 rut depths for these sections (section 7 was overlaid in 2010) one can see that there is 40 % reduction in rut depth due to the use of modified binder after 8 years of service. This would mean a significant difference in service life of these two surfacings.

In general sections 1 and 4, both of which had an asphalt concrete surfacing with a modified binder performed better than the other sections. Thus asphalt concrete sections with modified binder performed better than SMA sections with the same aggregate quality but with conventional binder, sections 5 and 6 (based on the 2010 rut depth). Seen in light of previous experience, which shows that SMA mixtures generally have better wear resistance than asphalt concrete mixtures, the improvement obtained as a result of the use of modified binders is significant.

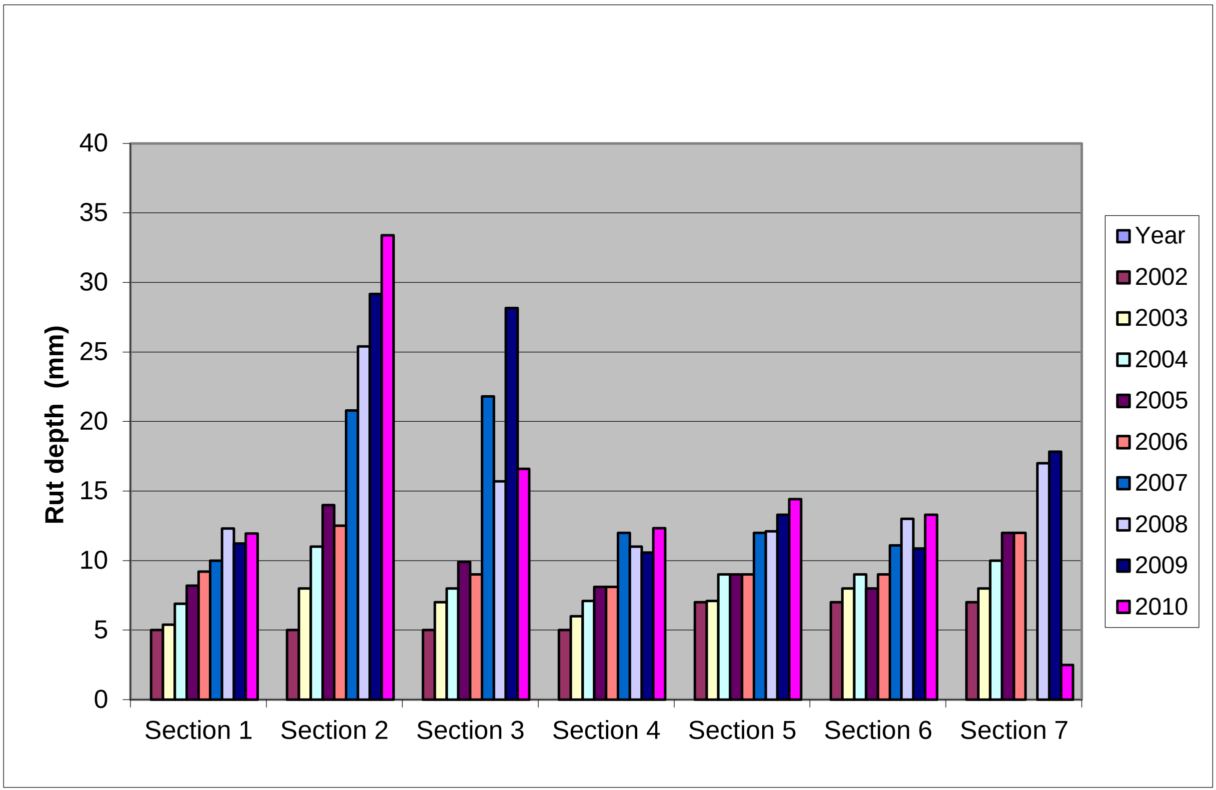

Figure 8: Measured rutting for the test sections

6. CORRELATION OF LABORATORY TEST RESULTS TO FIELD PERFORMANCE

The surfacing materials of the test sections were ranked based on laboratory test results as well as field performance. Table 4 summarizes the ranking. It can be seen that rankings based on laboratory tests do not agree well with ranking based on field performance with exception of the ranking based on the wear resistance test. This might be due to the fact that it is the studded tire wear and not the deformation that accounts for most of the measured rutting. Given that the thickness of the surfacing is only 4 cm, its contribution to the overall resistance to deformation of the pavement structure might not be that significant. However it is interesting to find that the use of polymer modified binder has such a significant effect on the resistance to wear. As can be seen from table 4, it is the ranking based on the results of the Prall test that agrees best with ranking based on field performance.

An attempt has been made to correlate the measured rut depth with the laboratory tests. Figures 9 – 11 show these correlations. As can be seen from figure 10, there is a reasonably good correlation between the wear test and the measured rutting. In contrast, there is relatively poor correlation between the proportional rut depth measured in wheel-track test and the field rutting (figure 9). The correlation between the Nordic abrasion value of the aggregates and the field rutting is also poor (figure 11).

Table 4: Ranking of the sections

Section	Rank based on wheel-track test at time of construction	Rank based on wheel-track test done in 2008	Rank based on NAT test done in 2008	Rank based on Prall test done in 2008	Rank based on field rutting (2009)
1	3	1	2	4	3
2	7	7	7	7	7
3	1	4	1	6	6
4	5	3	3	1	1
5	2	2	4	5	4
6	4	6	5	2	2
7	6	5	6	3	5

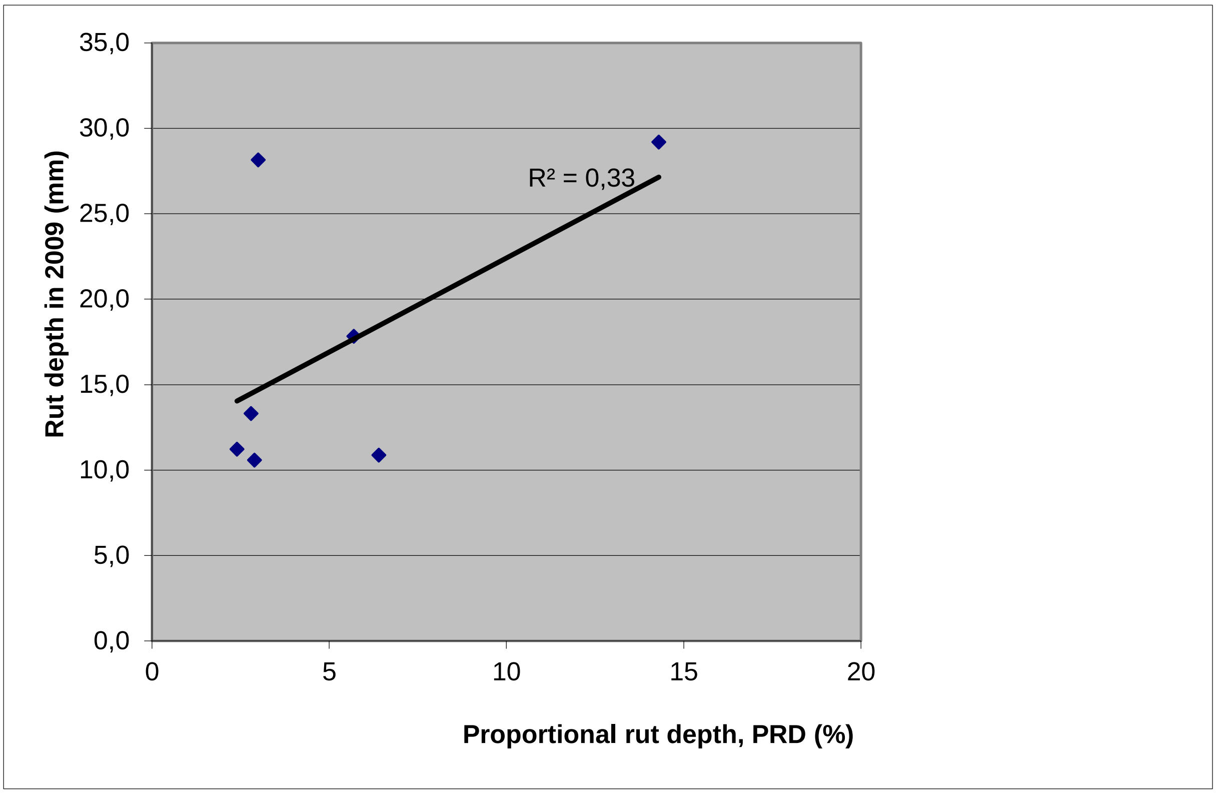

Figure 9: Correlation between rut depth measured in the field and proportional rut depth (wheel-tracking test)

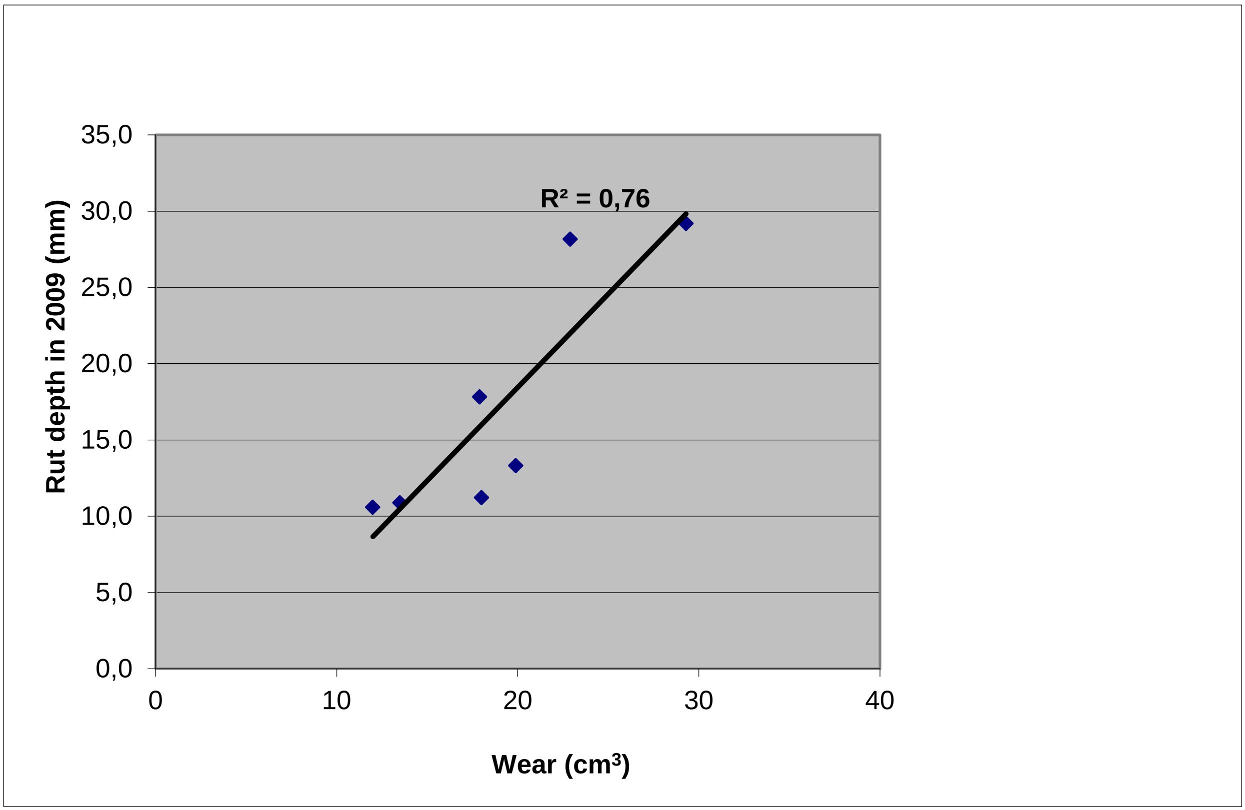

Figure 10: Correlation between rut depth measured in the field and laboratory wear (Prall test)

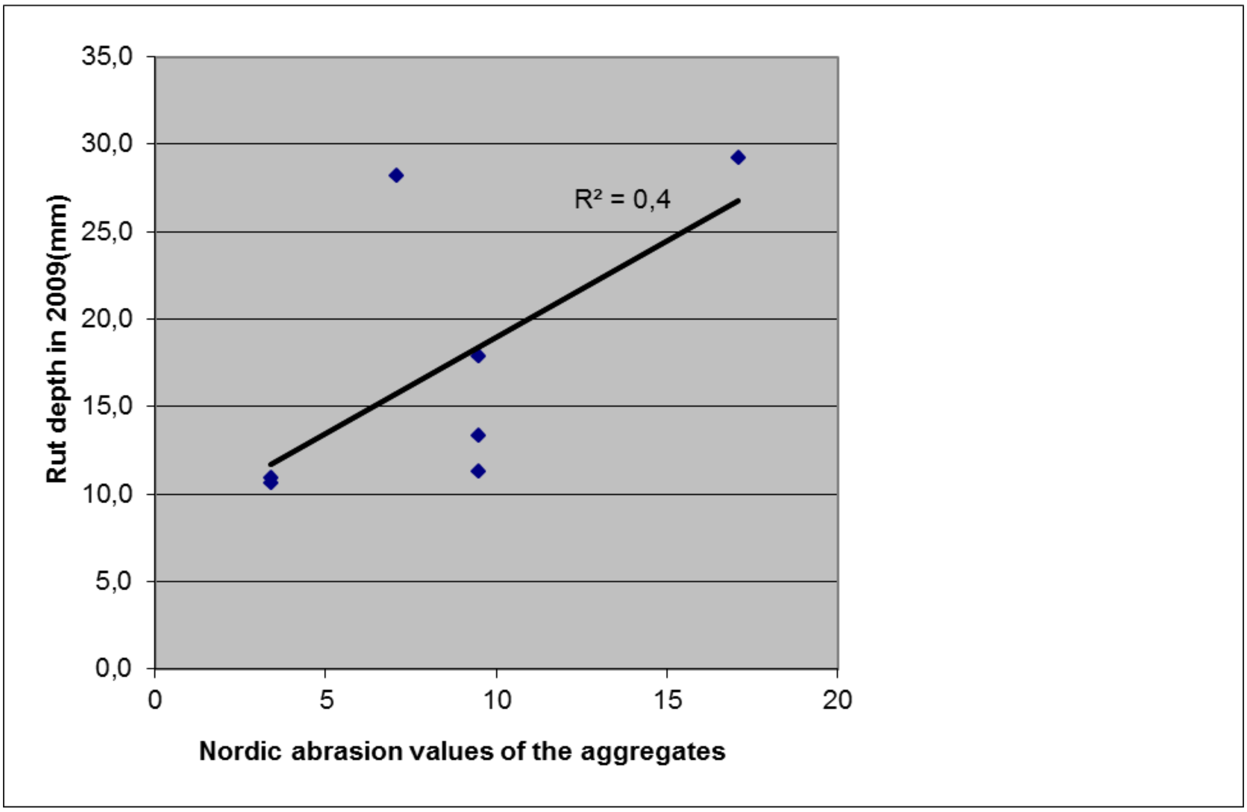

Figure 11: Correlation between rut depth measured in the field and the Nordic abrasion value of the aggregates

7. CONCLUSIONS

The field performance of some Norwegian asphalt surfacing materials containing a polymer modified binder is presented in this paper. The performance of seven test sections was monitored with yearly measurement of rutting and roughness. Regular manual inspections were also conducted to observe the development of other distresses. Based on the field measurements it can be concluded that asphalt surfacing containing the polymer modified binder had about 40% less rutting than the same asphalt surfacing mixture containing an unmodified pen70/ 100 binder. The use of the modified binder improved the performance of a surfacing material containing relatively low quality aggregates. However, it does appear that the binder modification cannot fully compensate for low quality aggregates. Asphalt concrete mixtures containing the modified binder performed slightly better than SMA mixtures containing unmodified binders. The test sections did not develop other distresses with exception of some aggregate loss resulting from apparent segregation at few points. Correlation of laboratory test results with field performance showed that it is only the wear test that has relatively good correlation with the measured rutting. This indicates that surface wear due to the use of studded tires accounts for most of the measured rutting for these test sections.

REFERENCES

[1] Polymer modified asphalt binders, Yildirim Y., Construction and building materials vol. 21, 2005.

[2] Influence of binder rheology on rut resistance of polymer modified and unmodified hot mix asphalt, Bouldin, M., G. & Collins, J. H., In Wardlaw, K.R. & Shuler, S. (editors), Polymer modified asphalt binders; ASTM STP 1108. Philadelphia: ASTM, 1992.

[3] Viscoelastic characterization of polymer modified asphalt binders for pavement applications, Uddin, W., Applied Rheology vol. 13, no.4: 191 – 199, 2003.

[4] Fundamental studies on styrene-butadiene-styrene polymer modified road bitumen, Lu, X., Licentiate thesis, Division of highway engineering, Royal Institute of Technology, Stockholm, 1996.

[5] Development of Wear Resistant Pavements Using Polymer Modified Binders, Saba, R. G., Bakløkk, L. J., Aksnes J., & Lerfald, B.O., Proceedings of the BCRRA conference, Illinois, USA, 2009

[6] Wear resistance of polymer modified asphalt, Rønnes, E., Masters thesis (in Norwegian), Norwegian University of Science and technology, Department of road and railway engineering. Trondheim,1989.

[7] Study of the wear resistance of bituminous mixes to studded tires – Tests with slabs of bituminous mixes inserted in roads and in the VTI's road simulator, Jacobson, T., VTI report no. 245, Swedish Road and Transport Research Institute, Linkoping, 1995.

[8] ELF test pavements 1987/1988, Uthus, N. S., SINTEF report STF61 F90001 (in Norwegian). Trondheim,1990.

[9] Aggregate quality and development of rutting in pavements: summary report (in Norwegian), Horvli, I. & Værnes E., SINTEF report SBF 53 A06013, 2006.