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Estimation of durability of new surface courses using accelerated load test and expert's opinions

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ABSTRACT: There is an increasing interest among road authorities in studying sustainability assessment of road infrastructure. The durability of the surface course is a critical factor in these calculations and must be carefully considered in the analysis. New types of asphalt mixes with the potential to improve the results in the sustainability assessment have no proven track record and are thus more likely not to be used until solid performance data is available. To bridge the gap and diminish the uncertainty about the durability of Green asphalt mixes for surface courses, a combination of laboratory tests and tests in a circular road simulator were performed. Eight mixes were tested in total, four stone mastic asphalt mixes and four porous asphalt mixes. Each group contained a reference mix with well-established performance. The mixes were characterized with dynamic IDT, complex shear modulus and water sensitivity using MiST (moisture induced stress test). Part of the loose mixes was oven aged at 85 °C simulate long term ageing. Plates of aged and virgin mixes were then tested in a circular road simulator in a program set up to check their sensitivity towards rutting, raveling, freeze-thaw cycles, polishing and fatigue. A combination of expert's opinion from academia and national road administrations together with the data from the tests were used to estimate the performance of the new Green mixes.

Keywords: Sustainability, durability, asphalt, service life

1 INTRODUCTION

National Road Authorities in Europe have an increasing interest in implementing sustainability assessment of roads. Service life is a critical parameter in any lifecycle calculation. The lifetime distributions for often used road surface mixes varies across Europe.

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Even within a country, the distribution varies with local conditions and with the type of road and traffic volume. New types of asphalt mixes with the potential to improve the results in the sustainability assessment have no proven track record and are thus more likely not to be used until solid performance data is available. To bridge the gap and diminish the uncertainty about the durability of new Green asphalt mixes for surface courses, a combination of laboratory tests and accelerated performance tests could be used.

In this study we have used stone mastic asphalt, SMA, and porous asphalt, PA, as reference materials since there is knowledge about their actual performance in different European countries. The reference SMA was compared to three SMA mixes with potentially higher durability and/or including high percentage of reclaimed asphalt (RA) potentially more sustainable asphalt mixes. The reference PA was compared to three PA with strong fibers or polymer modified binder.

2 MATERIALS AND METHODS

2.1 *Materials*

Four stone mastic asphalt were used in the study. SMA 16; SMA 11 10% RA; SMA 11 40% RA; SMA 8 60% RA

The reference mix was a SMA 16 70/100 with 6,2% binder. The mix was produced in a plant in Sweden. The aggregate was granite from Styvinge in Östergötland. 0.4% cellulose fibers and 0.3% Wetfix BE was added to the mix. Air voids in Marshall compacted specimens was 2.7%.

Two SMA 11 mixes were produced in plants in Denmark. The first mix was a SMA 11 40/60 with 5.8% binder. The aggregate was approximately 70% Hyperit, 20% Labradorit and 10% granite from the RA. 1.5% reactive filler and 1.25% limestone filler was used together with 0.35% Viatorp 66. The mix was produced in Hjallerup. Air voids in Marshall compacted specimens was 2.1 – 2.6%. The second mix was a SMA 11 with 40% RA in the mix. This was also produced in a plant.

The last SMA was a SMA 8 50/70 with 60% RA in the mix. It was produced in the lab. The RA collected from a plant was split into two fractions with a 4 mm sieve. A sieve and binder analysis were made of each fraction. The binder content in the fraction larger than 4 mm was 6.78% and had a penetration value of 18 x 10^{-1} mm and a softening point of 65,4 °C. For the other fraction, the binder content was 3.85% and the penetration value was 15 x 10^{-1} mm and a softening point of 68.6 °C.

The 50/70 binder added to produce the SMA 8 60% RA had a softening point of 51.0 °C. 33.4% of the aggregate in the mix were from the larger fraction of the RA and 26.5% of the aggregate in the mix were from the smaller fraction of RA. 54% of the binder in the final mix originated from the RA. To compensate/rejuvenate for the hardened binder in the RA, 0.53% of a VMA additive was used (8.7% of the total binder content) as described in the AllBack2Pave project (Wellner et al. 2015). 0.5% of cellulose fibres were used in the mix. The added aggregate was a granite from Skärlunda in Östergötland.

Four porous asphalt mix were used in the study they are designated: PA 16 or ZOAB+; PA 8 or Fibra 1; PA 8 Panacea or Fibra 3; PA 8 Aramid or Fibra 4.

The PA 16 70/100 with a binder content of 5.5% was produced in the laboratory based the mix detailed by Zhang (Zhang et al. 2018). All coarse granite aggregates 2–16 mm was washed and came from Skärlunda in Östergötland. Sand 0.063–2 mm came from Baskarp. Filler content (Wigro 60K) in the aggregate was 4.7%. 0.3% cellulose fibres were added to the mix.

The Fibra mixes were produced in a plant in Netherlands for the Fibra project (Slebi-Acevedo et al. 2020). Fibra 1 is the standard PA 8 mixture for two layers porous asphalt in the Netherlands. The binder is a SBS polymer modified bitumen. Fibra 3 is a PA 8 mixture made with 70/100 bitumen and panacea fibres. Fibra 4 is a PA 8 mixture made with 70/100 bitumen and aramid fibres.

2.2 *Methods*

It is widely thought that ageing of the binder in a pavement layer could have a detrimental effect on the performance of the mix in some. Extensive ageing makes bituminous binders hard and brittle. To what extent the progressive hardening of the binder is a limiting factor for a asphalt layer service life depends on the mix type and the structural properties of the road. To simulate the ageing and to be able to test the mixes in a hardened state we used oven ageing of the loose mixes to simulate the ageing that occurs during service. Oven ageing of loose mix has been used to simulate field ageing has been used in the past for example in (Mollenhauer et al. 2012, De la Roche et al. 2009). We followed these examples and aged loose mix in a tray at approximately 86 °C for seven and fourteen days. The temperature fluctuated in the oven between 84 and 88 °C. These aged mixes are called short- and long-term aged mixes, which should not be confused with the short-term ageing occurring at production of the mix or long-term ageing of binder using a pressure ageing vessel, PAV. The aged batches of the mixes were used together with the un-aged material in the accelerated test.

The binder recovery was performed according to EN 12697-3:2013+A1:2018. Dichloromethane was used as the solvent. During the first phase of the distillation, the oil bath temperature was 85 °C and the applied pressure was 85 kPa. During the second phase, the temperature was 150 °C and pressure was 2.0 kPa. No extra phase was needed for the binder recovery.

Furthermore, the obtained binders were tested for the complex shear modulus G* and phase angle δ in the linear viscoelastic region with a dynamic shear rheometer (DSR) according to EN 14770:2012. Temperature sweep was conducted at 10 rad/s with a 6 °C interval up to 82 °C. The plate-plate geometry of 25 mm diameter and 1 mm gap was used for the DSR measurement.

The cyclic indirect tensile test was conducted to characterize the stiffness of the asphalt mixtures. The test consists of applying a certain number of cyclic (sinusoidal) loading along the vertical diametral plane of a cylindrical specimen to achieve a constant peak tensile strain along the horizontal diametral plane perpendicular to the loading plane. The test was conducted according to the European standard EN 12697-26:2018 – Annex F. Laboratory compacted specimens having a dimeter of 100 mm and thickness of 40 mm were tested at three temperatures (-5, 10 and 20 °C) and 8 loading frequencies (16, 10, 5, 2, 1, 0.5, 0.1, 0.05 Hz).

The dynamic shear modulus test was conducted in accordance with the method and the equipment developed at VTI. According to this method, the two sides of a cylindrical asphalt specimen having diameter of 150 mm and thickness of ¼ of the sample diameter is glued to two steel plates using epoxy. The glued specimen is then mounted on the shear box device where one of the plates is rigidly fixed and the other is exposed to a vertical sinusoidal cyclic loading over a range of frequencies. Further details on the testing procedure can be found in (Said, et al. 2013). The dynamic shear testing is usually conducted at four temperatures: -5, 10, 30 and 50 °C, and eight loading frequencies: 16, 8, 4, 2, 1, 0.5, 0.1 and 0.05 Hz.

Accelerated load tests were performed in a circular road simulator, CRS. Asphalt plates were produced from fresh and aged mixes with a roller compactor and a steel frame with the dimensions 50 x 70 x 4 cm. Each plate was trimmed, i.e., two short ends of the plate were cut to create a trapezoidal shape, to make them fit into the track of the circular road simulator. After trimming the plates and fitting them into the track, joints were filled with mortar and the machine run for a few minutes at elevated temperature to push each plate firmly to the base.

The test in the CRS was divided in three phases:

1. 35 °C in dry conditions. 60 000 laps
2. ~ 0 °C. Seven freeze-thaw cycles in wet conditions. Each cycle started at -2 °C and gradually increased to 2 °C. 120 000 laps.
3. 30 °C in dry conditions with a soft base. Running until pavement failure. 2 000 laps.

In the final phase 3 the plates were released, and a 19 mm cellular rubber sheet were glued to the bottom of the plate and to the base and then fixed to the track. Joints were filled with mortar. Four tires, Cooper Discoverer S/T MAXX, LT 235/85 R16, was used in the for the test in the CRS. This tire type is typically used for SUV. The inflation pressure was 3,5 Bar. Each tyre was loaded with 450 kg.

The full records of the outcome of the laboratory tests can be found in the PavementLCM report (Kalman et al. 2021)

3 SERVICE LIFE OF REFERENCE MATERIAL

The service lives for reference mixes have been reported from different countries multiple times (Christensen et al. 2005, EAPA 2007, Briessinck et al. 2016). Comparing the results from the three studies indicates that there are large differences between the expected service life not only between countries but also between different surveys. A part of the differences in the results could be traced back to how the questions have been asked i.e., if the respondents are reporting the median actual service life or if it is the service life of the best performing roads. For example, Poland reports a service life of 10 years in the heavy traffic lane in the OECD study and 20 years in the PIARC study. Likewise, France reports a service life of 8 years in the heavy traffic lane and 16 years in the fast lane in the OECD study while in the PIARC study the expected service life is 12 years. Service life based on historical data should not be disputed numbers.

Based on historical records the service life distributions could be modelled using a Weibull distribution with increasing failure rate with time.

Historical survival data has two types of events, and each event has an event time. An event is a case if the time for end of life is observed. If rather the time at end of study is observed the subject is still alive, the event is known as censoring. Censored observations contain partial information about the survival time even though end of live is not observed. Survival analysis methods properly take care of both the complete information in the cases and the partial information in the censored observations. Having analytical expressions for the service lives facilitate the possibility to take into account the uncertainty in the lifetimes in life cycle analysis.

In Figure 1 the historical survival records of SMA pavements in Östergötland, Sweden laid from 1980 and onwards on roads with Annual Average Daily Traffic (AADT) volume between 12000 and 16000 is presented as a Kaplan-Meier curve together with the survival curve based on the estimated Weibull distribution. From the figure it can be concluded that the 10% of the SMA surface courses with the longest survival time lasted approximately twice as long as the 10% of the SMA surface courses with the shortest survival time.

4 DISTRESSES TRIGGERING PAVEMENT RESURFACING

Experts from Germany, Denmark, Lithuania, Sweden, Norway, and the Netherlands gave answers to questions which types of surface distress that are typical to causing resurfacing for low, medium, and high-volume roads. All experts except one answered

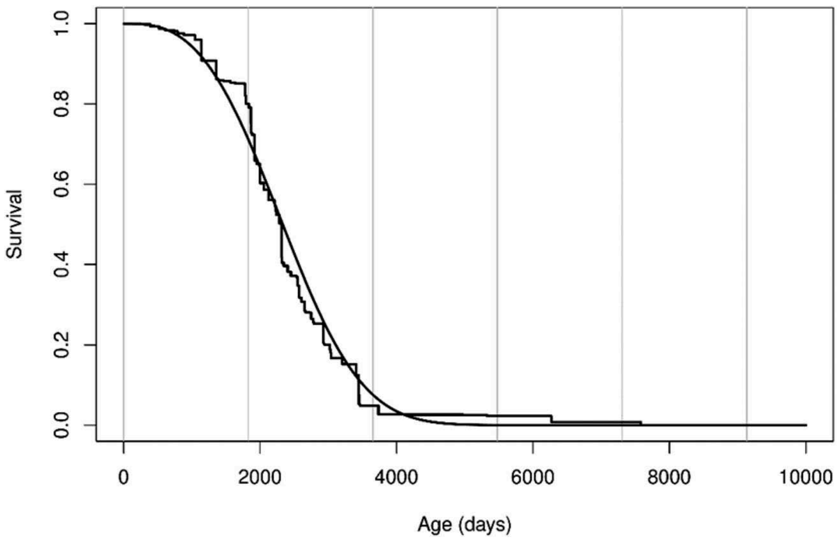

Figure 1. Survival function and the survival curve based on the estimated Weibull distribution for SMA pavements in the county Östergötland, Sweden for roads with AADT between 8000 and 12000.

that there are procedures or databases in their countries where the distresses, and possible other reasons for pavement maintenance operations, are detailed. The respondents were asked to classify each type of distress in terms of how likely it is that its presence triggered the decision to resurface a pavement with SMA or PA. The distresses the respondents could choose among were: Fretting (minor material loss); Ravelling (severe material loss); Rutting; Road wear; Low friction; Cracking (not specified); Transverse cracking; Longitudinal cracking; Edge cracking; Block cracking; Alligator cracking; Other.

The result of the survey regarding high-volume roads is presented in Table 1 for SMA16 or SMA11 and for PA16. Not all experts answered the questions for both types of reference mixes.

In the survey respondents were also asked to estimate how a change in traffic volume or other factors would eventually change the service life. A common assumption in structural road engineering is that the Palmgren-Miner linear damage hypothesis applies, which means that each single loading will contribute to the final failure of the road according to the damage each loading generates.

All experts agree that the service life will only change approximately by 10% (5-15%) if the traffic volume deceases by 25% for a high-volume road with annual average daily flow (AADF) of 8000. If the Palmgren-Miner linear damage hypothesis would apply, the service life would be inversely proportional to the traffic volume. A decrease in traffic volume by 25 % would then lead to an increase of the service life by 33% if the traffic would be the only factor responsible for the service life.

For roads with even higher traffic volume, ADDF of 16000, the experts have some disagreements in their estimates, but on the average the estimate on how a decrease in traffic volume by 25% would increase the service life is the same: approximately 10%.

For low volume roads with an AADF of 400, there is a shift in the estimates of how that would the increase the service life. In this case more experts estimate only a marginal effect (0-5%) on the service life.

From these answers it can be concluded that there are more factors influencing the service than the traffic volume. Factors that usually is mentioned as influencing service life are aging, wet conditions and wet freeze that cycles. Ageing could be caused by exposure to oxygen and UV radiation. The oxidation rate increases with temperature. It is sometimes postulated that pavements will be able to withstand the loadings of the traffic until the binder have reached a state where it is no longer flexible enough to endure the strains caused by the traffic.

Freeze thaw cycles in wet conditions could have an effect on the properties of asphalt concrete pavements. The experts differed among their estimates about the effect of decreasing the number of freeze thaw cycles in wet conditions. The experts from Norway and Sweden in most cases agree that the service life only increases marginally if number of freeze-thaw cycles decreases. The experts from Denmark and Germany agrees that the effect of freeze-thaw cycles on service life is higher. They estimate that the service life would increase more substantially (approximately 20%) if the number of freeze-thaw cycles decreases by half.

The estimated effect of decreasing the number of wet days by half is on average approximately 10% for high-volume roads although with some variations among the experts.

The number of wet days and the number of freeze-thaw a pavement is exposed to will increase with service life. Oxidative ageing will also increase with service life.

Since experts agrees that a decrease in traffic volume by 25% would only increase the expected service life for high volume roads by approximately 10% (5-15%), instead of 33% which would be expected if service life was only dependent on traffic, it can be concluded that other factors that influences the service life, such as ageing and exposure to wet conditions and freeze-thaw cycles have a substantial influence on the service life.

Table 1. Distress likely to trigger resurfacing of high-volume roads with for SMA16 (or SMA11, or SMA11 10%RA) or PA16. ++ indicates that the distress is likely cause for resurfacing operations. + indicates that the distress is somewhat likely cause for resurfacing operations.

	Denmark	Sweden 1	Sweden 2	Germany	Norway	Lithuania	Sweden 1	Sweden 2	Netherlands	Germany
Answers valid for	SMA11	SMA16	SMA16	SMA11	SMA16	SMA11	PA16	PA16	PA16	PA11
Fretting	++	++			+	++	++			
Ravelling	+	++			+	++	++		++	++
Rutting	+	++	++		++			++		
Road wear		++			+		++	++		
Low friction	+			++		++				
Cracking (not specified)		+		++		++				
Transverse cracking										
Longitudinal cracking		+			+	++				
Edge cracking					+	+				
Block cracking						+				
Alligator cracking		+				+				
Other						+			+	

If the estimates are correct, the calculated 33% increase in service life when traffic volume decrease by 25%, based on Miners' hypothesis would at the same time increase the number of exposures to wet conditions and freeze-thaw cycles by the same amount and ageing would also be increased. If the service life increases only by 10% when traffic volume decreases by 25%, the number of wet days and number of freeze-thaw cycles would only increase by 10 % which roughly could only explain less than 5% of the difference between the 33 % estimated by Miners' rule and 10% based on experience. From these considerations it is concluded that ageing probably is of major importance for limiting the service life.

5 ESTIMATES OF SERVICE LIFE OF NEW MIXES

To estimate the relative service life of the new asphalt mixtures compared to the reference mixes based on the results from the laboratory studies we must understand the context in which the new mixes is going to be used in, i.e. in which country and which type of road. We also need to have a picture of which type of distresses are common in that context. The latter information was collected in the questionnaire and presented in Table 1.

There are many different mechanisms which potentially and eventually put a limit on the service life of a surface course. Three main components for the degradation of the surface courses are ageing, climate and traffic. Ageing is usually a consequence of oxidation or UV light. Climate puts stress on the road surface through freeze-thaw cycles; presence of water; extreme temperatures and temperature cycles. Traffic induces stresses and strain on the surface course. The surface course is also a part of the road structure and thus protects to higher or lesser extent the other parts of the structure. If other layers in the structure fails, this will eventually have consequences for the surface course.

The results from the questionnaire clearly demonstrated that all three mechanisms, traffic, climate, and ageing are important for the service lives. Thus, any attempt to predict the service life of new mixes needs to address all three factors. To further complicate the situation there are probably positive and negative synergies between the different factors affecting the service life. E.g., ageing usually leads to a stiffening of the binder which in turn could be beneficial for preventing rutting (deformation) but could also be worsening the layer's resistance to withstand fatigue cracking or resist extreme low temperatures.

To summarize the outcome of the experimental studies the new mixes were classified as performing better or worse than the reference mix in each study using a scale with five levels. The compilations are presented in Table 2 and Table 3.

To make the estimations the service lives for the new mixes one needs to compare the relative performance of the new mixes considering the context. In the survey presented in Table 1, there were large differences between different countries regarding the typical distresses that triggers resurfacing. The following example for the situation in Denmark illustrate the procedure:

Typically, high-volume roads with SMA are resurfaced because of fretting/ravelling and to some extent due to rutting and low friction in Denmark. Since the test result regarding friction and ravelling were the same for the new SMA mixes compared to reference SMA, the only important difference between the mixes is their relative performance regarding rutting where the SMA11 10% RA performed better to much better, and the SMA8 60% RA performed worse (in the CRS study) or better (in the shear modulus test) than the reference SMA. The SMA8 60% RA did age considerably faster than the reference SMA. This could have an effect on the long-term durability of the mix.

Hence it is anticipated that SMA11 10% RA have a slightly longer (+5%) service life, that the SMA11 40% RA have the same service life, and that SMA8 60% have slightly lower service life (-10%), compared to the reference SMA. Since the average service life of SMAs on high-volume roads in Denmark is 14 years the estimated service lives of the SMA11 10% RA, SMA11 40% RA and SMA8 60% RA, are 15 years, 14 years and 12 years, respectively for high-volume roads.

Table 2. Relative performance of new SMA mixes compared to the reference SMA16 mix. The relative performance is indicated with - -, -, =, +, ++ where - - and - indicates much worse and worse, = indicates equal performance and + and ++ indicates better or much better performance.

	Test	SMA11 10% RA	SMA11 40% RA	SMA8 60% RA
Climate	Water sensitivity/MIST	=	=	=
Ageing	Short and long term oven ageing	+ +	+ +	- -
Traffic	ALT/CRS	= ravelling = rutting = cracking = friction	= ravelling - rutting = cracking = friction	= ravelling - rutting = cracking = friction
Traffic/ aging	ALT/CRS aged material	= ravelling = rutting + cracking = friction	= ravelling = rutting + cracking = friction	= ravelling = rutting - cracking = friction
Traffic/ climate	ALT/CRS Water sensitivity and freeze-thaw cycles	=	=	- aged material
Traffic	Stiffness modulus/road structure performance	+	=	-
Traffic	Shear modulus/rutting	+ +	=	+

Table 3. Relative performance of new PA mixes compared to the reference PA16 mix (ZOAB+). The relative performance is indicated as in Table 2.

	Test	ibra 1/PA8	Fibra 3/PA8 panacea	Fibra 4/PA8 aramid
Climate	Water sensitivity/MIST	=	=	=
Ageing	Short and long term oven ageing	=	- -	- -
Traffic	ALT/CRS	+ ravelling + rutting + cracking + friction	= ravelling = rutting = cracking + friction	= ravelling = rutting = cracking + friction
Traffic/ aging	ALT/CRS aged material	- - ravelling + rutting = cracking + friction	- - ravelling + rutting = cracking + friction	- - ravelling + rutting = cracking + friction
Traffic/ climate	ALT/CRS Water sensitivity and freeze-thaw cycles	=	=	=
Traffic	Stiffness modulus/road structure performance	-	=	=
Traffic	Shear modulus/rutting	/	+	+

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