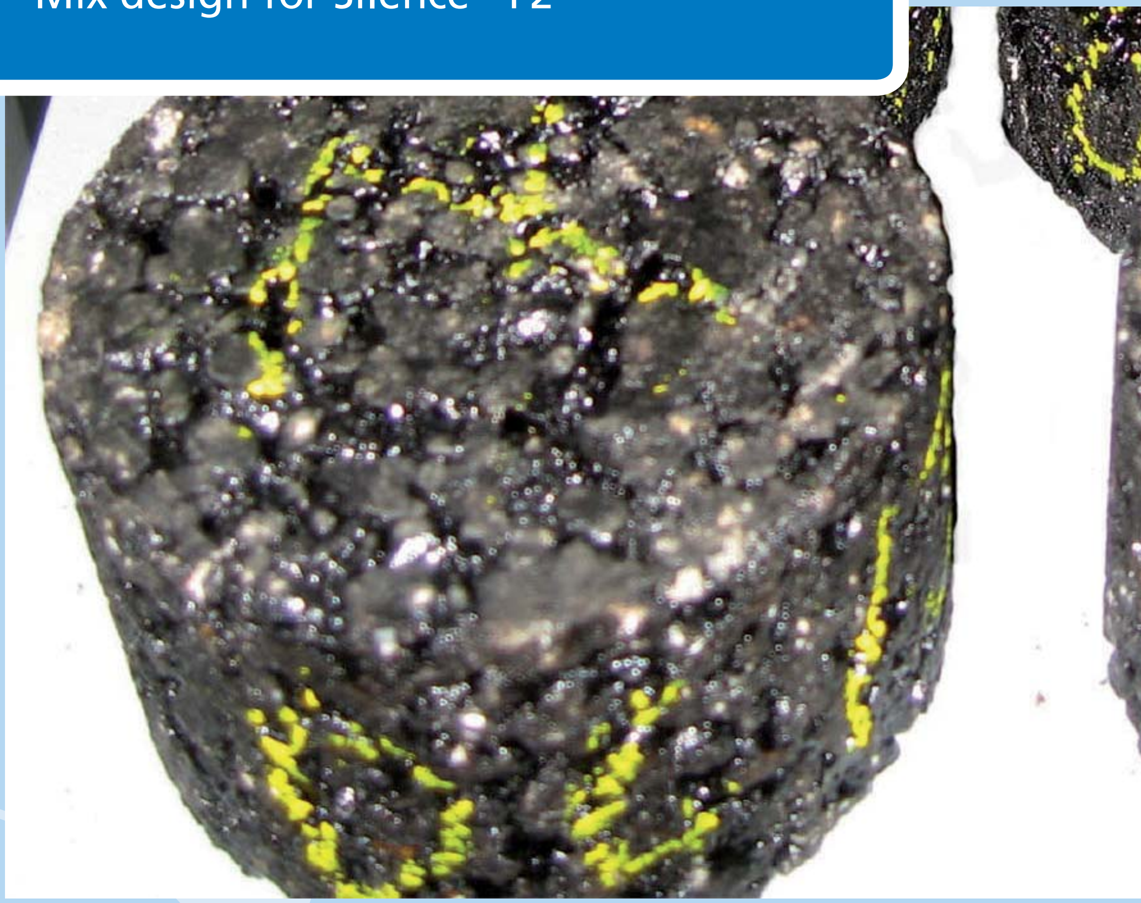
Noise reducing SMA pavements

- Mix design for Silence - F2



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Technical note 39
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Road Directorate
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Noise reducing SMA pavements

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Contents

Preface

This technical note is produced by the Danish Road Institute/Road Directorate (DRI) as part of the work for Forum of European Highway Research Laboratories (FEHRL) in the EU project SILENCE [1] that was started in February 2005. The report is part of the work DRI carry out in Working Package WP F.2 “New production technologies for surfaces on urban main roads”. The following organisations take part in this WP F.2 working group:

- Danish Road Institute/Road Directorate (DRI)
- Transport Research Institute (VTI), Sweden.
- Federal Highway Research Institute, (BASt) Germany.
- Autostrada, Italy
- Skanska Contractors, Sweden.

It is the goal of this part of the SILENCE project to develop new noise reducing pavements for urban roads and test concepts for these. In the international working group which carries out the activities of WP F.2 it has been decided that DRI shall specially focus on the development of noise reducing thin SMA pavements [2]. Technical note 39 is on mix design for noise reducing SMA pavements to be acoustically tested at a special drum facility at BASt. After the testing in the drum the mix design will be adjusted according to the test results and full scale test sections will be established on an urban road in Copenhagen in 2007 in cooperation with the Municipality of Copenhagen.

In order to carry out the Danish part of the project DRI has established a special Danish project group with the following members:

- Michael Rasmussen, Pavement Laboratory, Municipality of Copenhagen.
- Lars Ladehof, Colas Contractors.
- Bjarne Bo Jensen, Colas Contractors.
- Jørn Raaberg, Danish Road Institute/Road Directorate.
- Erik Nielsen, Danish Road Institute/Road Directorate.
- Sigurd Thomsen, Danish Road Institute/Road Directorate.
- Hans Bendtsen, Danish Road Institute/Road Directorate.

Colas Contractors has been selected by the Municipality of Copenhagen to take part in the construction of the test sections in full scale. To start and plan the work the project group has had two meetings in the spring of 2006 and two members of the DRI staff has participated at a meeting at BAST in Cologne. Besides this test samples have been produced and analysed at the laboratories of DRI and Colas in Denmark.

The report is produced by:
- Senior Researcher Jørn Raaberg, DRI
- Senior Researcher Erik Nielsen, DRI
- Senior Researcher Hans Bendtsen, DRI

Road Directorate/Danish Road Institute
Hedehusene, Denmark, September 2006

Forord

Dette eksterne notat er udarbejdet af Vejteknisk Institut/Vejdirektoratet (VI) som en del af arbejdet for Forum of European Highway Research Laboratories (FEHRL) i EU-projektet SILENCE [1], som blev startet i februar 2005. Rapporten er del af the arbejde, som VI udfører i Arbejdspakke WP F.2 ”New production technologies for surfaces on urban main roads”. De følgende organisationer deltager i denne arbejdspakke WP F.2:

- Vejteknisk Institut/Vejdirektoratet (VI)
- Transport Research Institute (VTI), Sverige.
- Federal Highway Research Institute, (BASt) Tyskland.
- Autostrada, Italien
- Skanska Contractors, Sverige.

Det er målet med denne del af SILENCE projektet at udvikle nye støjreducerende belægninger for bygader og teste konceptet for disse. I den internationale arbejdsgruppe, som udfører aktiviteterne i WP F.2, er det besluttet, at VI især skal fokusere på udviklingen af tynde SMA belægninger [2]. Eksternt notat 39 omhandler mix design for støjreducerende SMA belægninger, som skal afprøves akustisk i et specielt tromleudstyr hos BASt. Efter afprøvning i udstyret vil mix design blive justeret i henhold til resultaterne, og fuld skala demonstrations strækninger vil blive udført i 2007 på en bygade i København i samarbejde med Københavns Kommune.

For at udføre den danske del af projektet har VI oprettet en speciel dansk projektgruppe med følgende medlemmer:

- Michael Rasmussen, Vej og Park, Københavns Kommune.
- Lars Ladehof, Colas Danmark A/S.
- Bjarne Bo Jensen, Colas Danmark A/S.
- Jørn Raaberg, Vejteknisk Institut/Vejdirektoratet.
- Erik Nielsen, Vejteknisk Institut/Vejdirektoratet.
- Sigurd Thomsen, Vejteknisk Institut/Vejdirektoratet.
- Hans Bendtsen, Vejteknisk Institut/Vejdirektoratet.

Colas Danmark A/S er udvalgt af Københavns Kommune til at deltage i udførelsen af fuld skala demonstrationsstrækningerne. Til opstart og planlægning af arbejdet har projektgruppen afholdt to møder i foråret 2006, og to medlemmer fra VI har deltaget i et møde hos BASt ved Køln. Herudover er prøveblandinger blevet produceret og analyseret i laboratorierne hos VI og Colas Danmark A/S.

Rapporten er udarbejdet af:

- Seniorforsker Jørn Raaberg, VI
- Seniorforsker Erik Nielsen, VI
- Seniorforsker Hans Bendtsen, VI

Vejdirektoratet/Vejteknisk Institut
Hedehusene, Danmark september 2006

1. Introduction

Working package WP F3.2 in the SILENCE project is dealing with new production technologies for surfaces on urban main roads. The task is an integrated part of work package F3 about improved systems for maintenance of quieter road surfaces [1]. In WP F3.2 new pavement concepts will be developed and tested in full scale on urban roads in different European cities [7]. In WP F3.5 the Federal Highway Research Institute, (BASt) in Germany will perform acoustical tests in a special drum facility (se Figure 1) of samples produced under laboratory conditions of different promising pavements. The tests will be performed in a way where the pavement will be rotated and a tyre will roll on the pavement generating tyre-road noise.

The pavements to be tested shall be applied to some special moulds which will be mounted in the drum tester (see Figure 2). Noise measurements will be performed at measurement positions close to the test tyre (equivalent to the CPX method microphone positions) and at a distance of 7,5 meters (equivalent to the SPB method microphone position).

Figure 1. The BASt drum facility.


Figure 2. Mould to be filled with pavements to be tested.

At a joint workshop of the work packages F1, F2 and F5, which took place at the Federal Highway Research Institute (BASt) on March 9th 2006 [2], it was decided which pavement types to be further developed and optimized for noise reduction before they will be tested in the BASt drum facility in the second part of 2006. An important part of the work of DRI in working package F2 is based on results from a workshop to suggest mix design for pavements to be tested in the BASt drum. In this report suggestions for pavement mix design are presented in chapter 4.

After the acoustical test at BASt the pavement mix design might be adjusted and optimised further in order to improve the noise reduction. The improved mix design will be used to construct up to 6 test sections on an urban road in Copenhagen in springtime 2007. “Kastrupvej” in the municipality of Copenhagen has for the present been selected as the test road. Some months after the construction full scale SPB noise measurements will be performed together with measurements of texture and skid resistance. A “before” SPB noise measurement will be performed on the existing old pavement on the test road prior to paving the noise reducing surface layer.

At the March workshop at BASt it was decided that the Danish part of the experiment shall focus on optimising and developing thin noise reducing road surfaces. It was also decided to use the Stone Mastic Asphalt (SMA) concept as the background for all the pavements to be included in this part of the experiment.

The noise optimisation will basically be done by:

- Using small maximum aggregate size (4, 6 and 8 mm) in order to achieve an even and smooth pavement surface that can reduce noise generated from vibrations in the tyre.
- Using a high built in air void in order to achieve a very open surface structure that can reduce noise generated from air pumping.
- Using a small proportion of oversized aggregate in order to increase the openness of the surface structure
- Using as cubic an aggregate as possibly in order to achieve an even and smooth pavement surface that can reduce noise generated from vibrations in the tyre.

In order to optimize the mix design Marshall samples have been produced in the laboratory of DRI and Colas Contractors and laboratory tests have been performed (see chapter 3). From the test results the mixes to be tested have been selected on the strategy of trying to achieve a balance between long time structural durability and a good noise reduction.

2. Mix design

2.1 Back ground for mix design in Denmark

The normal practise that has developed over the years of road building in Denmark and is embedded in the Danish Road Standards, is that the mix design is the responsibility of the asphalt contractor. The specified mix composition shall – after optimisation using the Marshall method - then fall within the categories of the framework of the given asphalt families like Asphalt Concrete (dense or open graded types), Stone Mastic Asphalt, Soft Asphalt, Porous Asphalt etc. in order to show what design criteria and level of control will be appropriate.

In the recent development of noise reducing thin surface layers it has been important that the asphalt contractor in his mix design is not limited by the framework for asphalt families which have been established over the years without addressing the noise reducing capability of the mix. The Road Standards in Denmark are voluntary and not restrictive/mandatory standards which allow for the freedom for new developments in mix design to be contracted and tested without causing disturbance in the way public contracts are drawn up between road administrations and asphalt contractors.

Mix design of noise reducing pavements and especially of thin surface layers has gained momentum in the last three years in Denmark. The road sector is still in the experimental stage of development of these mixes but the first steps have been taken in order to make a proper nomenclature for these products, both among the products themselves but also in relation to the traditional known mix types in the presently approved Road Standards. It is foreseen that within 3-4 years a formal introduction of these noise reducing thin surface layers in the Danish Road Standards will take place.

A mix design is developed by the asphalt contractor who will draw up a product specification for the asphalt material. This stage and contracting according to this specification can easily take place during the winter period. When the production at the asphalt plant takes place the asphalt contractor is allowed to adjust his former specification if slight changes in raw material or other things have occurred.
The contract and the following control will then be performed in accordance with this “renewed” asphalt plant produced mix specification because it is this material rather than the “old” laboratory specified material that is going to be paved.

2.2 Strategy behind proposed mix compositions

DRI has over a period of several years followed three Danish test sections of two layer porous asphalt in urban area both from an acoustical and technical point of view (the Øster Søgade Experiment [3]). Some of the lessons learned are that clogging is a phenomenon that you must take into account and that cleaning operation is expensive and can at best only give a partly restoration of the initial acoustic properties.

For these reasons amongst others the focus in mix design of noise reducing surface layers has changed towards thin surface layers which might have a slightly less noise reducing capability than two layer porous asphalts, but a better durability, so the long term acoustical benefit will be positive.

The thin layer surface layers have been the hot item in Denmark in several recently performed projects like:

- Thirteen test sections on urban roads in Copenhagen, Århus and Randers (in connection to the SILVIA project in 2004 [4]).
- Six test sections on motor highway M10 south of Copenhagen [5] (on a maintenance contract close to Solrød in 2004).
- Up to 11 test sections on a 80-90 km/h highway, near Herning planned for Summer 2006 [6].

In all cases a reference section of dense graded asphalt concrete AB 11 is used.

These tests have been developed in collaborating between the road authorities and asphalt contractors which also is the case in the present situation of development of mix compositions for the Drum Facility at BASt. These thin layer asphalts will also be paved this year at some test sections on the island of Amager in the Copenhagen area.

The direction of development of these noise reducing solutions has been greatly influenced by the fact that the desire to reduce traffic noise is naturally linked to high volume roads which again calls for surface layers that have excellent resistance to permanent deformation and shearing effects from turning vehicles and good friction. For these reasons the stone mastic asphalt has been an obvious choice as starting point.

In the mix design variations that have been tried there is a trend towards the smallest possible maximum aggregate size without endangering stability and friction of the mix. A balance has to be obtained, but the experience is that maximum aggregate sizes of 6 and even 4 mm could be used.

But the direction of development is a one-way street. It can state what asphalt family has been your inspiration or starting point. But when examining the specification of a mix design for a material with a maximum aggregate size of 4 mm or 6 mm and large voids in the surface it is difficult to detect if the origin of asphalt family has been stone mastic asphalt, open graded asphalt concrete or even porous asphalt. Of course the mix design and the characteristic properties of the mix in question has to be evaluated in its own right, but in these times of European standardisation a desire to classify or characterise propriety of company specific products the link to the origin is in many cases wanted as a guideline.

The line of development of the present Danish mix composition has been stone mastic asphalt.

The proposed mixes have also been made up of aggregates coming from different sources. There exists in Denmark a hypothesis that the acoustical properties will benefit from as cubical an aggregate as possible and the spatial properties are normally linked to some extent to the mineralogy and also to the type of crusher. To test this hypothesis several different aggregates could have been tested, but with the limitation of five mix compositions and the practicality of production of samples for the Drum Facility at BASt which has to be produced locally the aggregate types have been limited to two natural aggregates: a granite from a quarry in Sweden called Karlshamn and a Labradorite from a quarry in Norway The Labradorite is very bright in colour and has been added because of a demand for a certain light reflection from the pavement surface in the Danish specifications.

2.3 Danish nomenclature

As earlier mentioned concerning noise reducing thin asphalt surface layers neither the mixes nor the nomenclature are standardised but a rough outline of the nomenclature is developing.

Few technical fields are subjected to greater confusion than abbreviations for asphalt materials in international projects involving acousticians and asphalt technologists. To avoid the confusion when several laboratories transfer and transform data from one laboratory to another and further into the international scene it has been decided to use the Danish designations for the five proposed mixed. The evolving Danish nomenclature is explained here for the reader to better understand the background or origin of the used abbreviations and mix names.

An abbreviation is used in Denmark as a general term describing these thin asphalt layers with noise reducing capability. SRS (Støj Reducerende Slidlag) covers noise reducing wearing courses in a direct translation into English.

The line of development of the mixes is originating from stone mastic asphalt, which in Danish is called "Skærvemastiks" (which is a direct translation from the German origin "Splittmastixasphalte". The abbreviation is SMA in all three languages.)

SMA is used in the Danish Roads Standards for the already standardised stone mastics asphalts. In order to distinguish the SRS mixes of SMA origin that might or might not fall outside the approved frame work it is becoming customary to add LN to the abbreviation of the mix. Even though LN is the abbreviation for the English term Low Noise it is used as such in Denmark.

The marketing people have very early understood that the smaller the better with respect to maximum aggregate size and noise reducing capability. On the other hand small numbers trigger the anxiety among asphalt technologists with respect to permanent deformation and friction. In addition the minute changes in grading curves is not easily described by the traditional nomenclature for maximum aggregate size where a surface layer mix is either 4, 6, 8, 11 or 16 mm. To overcome these difficulties an addition to the abbreviation has developed as either P or + ; like in SMA 6P or SMA 6+. The interpretation is in this example indicating that the mix in question is predominantly a SMA 6 mix but with minor addition of some oversized particles in the next fraction to give larger voids in the surface and to satisfy asphalt technologists' wish for sufficient friction.

Figure 3 shows the general outline of the different grading curves in the report.

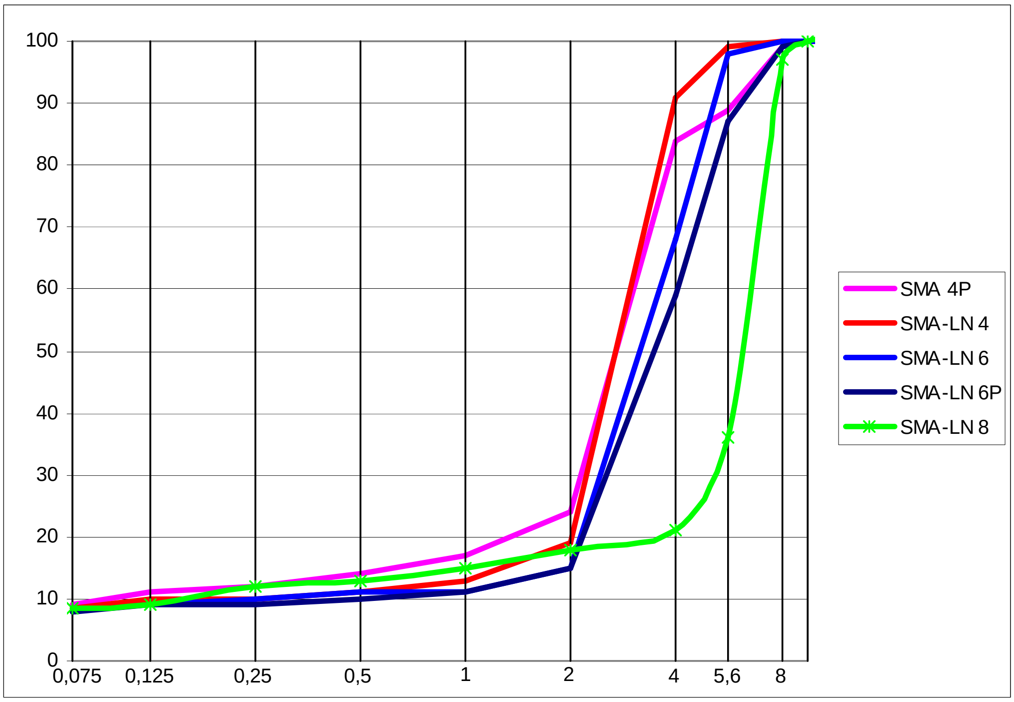

Figure 3: Gradation curves of proposed mix designs for noise reducing surface layers.

2.4 Mix design in practise

2.4.1 Mix design set up

After discussion of general outline of the grading curves for the five mixes in the Danish project group two of the members, Colas Danmark and Danish Road Institute, took on the task to optimise the binder content with respective three and two mixes to each laboratory in order to obtain a division of labour.

It was decided to start with a target binder content of 7,3 % binder and then vary the amount of binder in steps of 0,4 % either upwards or downwards until at maximum five mix compositions for each grading curve had established the optimum binder content with respect to volumetric composition and ability to retain the high binder content on the aggregate skeleton.

For the mix design and the test in the BASt Drum Facility a standard 50/70 binder will be used, as this grade is common in Germany. For the test sections later to be paved in the Copenhagen area a polymer modified bitumen with a high SBS content will be used. The Danish project group has evaluated that this difference in binder will not influence the compactability and the acoustical properties of the five mixes which is the main focus of the study. By using a standard 50/70 paving grade binder it will help in the evaluation of the sensitivity to binder run-off of the mixes during mixing, transport and laying.

2.4.2 Test methods and equipment

The production of the mix variants at the two laboratories has used two different kinds of procedure, which both are described in EN 12697-35 Laboratory mixing and which have shown in the past to produce a homogeneous asphalt mix on laboratory scale. While Colas Danmark has mixed the material by hand, Danish Road Institute has used a twin axle laboratory mixer from Strabag, Germany (Figure 4), which has been run according to a set up (mixer speed, temperature and mixing time) that resembles an asphalt batch plant which is the dominant plant type in Denmark.

Figure 4. Strabag laboratory mixer at Danish Road Institutte.

The loose asphalt mix has been compacted to cylindrical Marshall specimens (height approx. 63 mm and diameter approx. 101 mm) in accordance with the general out line of EN 12697-30 Specimen preparation, impact compaction (Figure 5a).

At Danish Road Institute the optimum mixes of SMA-LN 6 and SMA-LN 8 have been compacted in a gyratory compactor (Figure 5b) using the equipment described in EN 12697-31 Specimen preparation, gyratory compactor. The cylindrical samples (Figure 5c and 5d) with a diameter of 150 mm and a height of approx. 115 mm is compacted with 50 gyrations and are considered used for a laboratory test for assessing noise reducing capability.

The grading curves of the mixes have been determined by EN 12697-2 Determination of particle size distribution following either EN 12697-39 Binder content by ignition or extraction described in EN 12697-1 Soluble binder content.

Figure 5a. Marshall compaction equipment in its noise reducing cupboard at Danish Road Institute.

Figure 5b. Troxler Gyratory Compactor at Danish road Institute.

Figure 5c. Gyratory compacted specimen of SMA –LN 6.

Figure 5d. Gyratory compacted specimen of SMA –LN 8.

Volumetric properties of the mixes have been calculated using following input values:

- EN 12697-6 Determination of bulk density of bituminous specimens (procedure d, bulk density by dimension)
- EN 12697-8 Determination of air voids content of bituminous specimens
- EN 1097-6 Determination of particle density and water absorption (using the whole grading curve, e.g. including the filler)
- An assumed binder density of 102 Mg/m3

2.4.3 Results of optimised mix design

Based on the sieving curves of the raw materials Colas Danmark A/S had in agreement with the project group designed five different mixes. As described earlier the aggregates from which these mixes are produced are Karlshamn and Labradorite. On all the five mixes the first mix were made with a bitumen content of 73 weight percent. The air voids content in these initial mixes lead to some minor changes for three of the mix designs to obtain the expected air voids. In appendix A the results of all the mix designs are shown. On the meeting on the 23rd of June the working group decided which bitumen content should be use in the different mixes. These decisions can be seen in chapter 4.1.

3. Recommendations

3.1 Mix composition

Table 1 shows the optimised mix composition of the aggregate which can be summed to 100 %.

The given binder content stated in Table 1 is the binder content that shall be found after analysis of the produced mix e.g. aggregate + binder equals 100 %.

Table 1. Composition of the five Danish optimised SMA mixes.

Component designation	**Mix designation**				
	SMA 4P	**SMA-LN 4**	**SMA-LN 6**	**SMA-LN 6P**	**SMA-LN 8**
0/2 Crushed rock	8,35	-	-	-	6,27
2/4 Karlshamn	70,45	75,70	-	-	-
2/5 Karlshamn	-	-	76,53	59,86	-
5/8 Karlshamn	-	-	-	15,42	73,53
2/5 Labradorite	-	15,50	15,67	15,42	-
5/8 Labradorite	13,90	-	-	-	13,90
Limestone filler	5,50	7,00	6,00	7,50	4,50
Portland Cement	1,50	1,50	1,50	1,50	1,50
Cellulose fibres	0,30	0,30	0,30	0,30	0,30
Sum	100	100	100	100	100
Binder content (by analysis)	6,50	6,90	6,90	6,50	6,50

3.2 Practical suggestions and advice

The Danish project group understands that for obvious reasons the height of the different segments to be placed in the BASt Drum Facility must be the same and therequirement is 50 mm [7]. The segments are 1000 mm long and the radius of thedrum is 2748 mm.

The Danish project group has evaluated different options concerning sample preparation for the BASt Drum facility and have the following suggestions or recommendations:

- With the present knowledge of the influence of the spatial arrangement of the aggregates on the noise reducing capability of a mix we support the point of producing the samples for the Drum Facility with the same aggregates that were used in the mix design. We believe we are looking for small variations that might influence the acoustic properties. To transfer a developed mix design and grading curve for mixes with that low maximum aggregate size to be produced elsewhere with aggregates coming from other sources and crushers may be a too crude an approximation.

- It should be possible to produce plane samples of the five Danish mixes and to let them deform to fit the curvature of the segments by a combination of gravity and a slight temperature raise above ambient temperature due to the rather fat nature of the mixes.
- For the two mixes with 4 mm maximum aggregate size (SMA 4P and SMA-LN 4) the Danish project group fears that the risk of extensive permanent deformation due to a unfavourable maximum aggregate size to sample height ratio is too high if the sample is produced solely of the surface layer material mentioned. In this case it is suggested to make a stable bituminous bound base or binder course on which the surface layer can be paved.

4. References

[1] The SILENCE homepage: http://www.silence-ip.org/

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[5] Test of thin layers on a highway. Danish Road Institute – Road Directorate. Technical note 35, 2006.

[6] Noise reducing thin layers – Promissing concepts. Danish Road Institute – Road Directorate. Technical note 36, 2006.

[7] Prototype mixes for testing. SILENCE deliverable F.D5, Oliver Ripke, Hans Bendtsen, Jørn Raaberg, Erik Nielsen and Ulf Sandberg.

Appendix A

Results from the final mix designs

SMA 4P			
Bitumen content	**6,5**	6,9	7,3
Marshall			
Density (Volumetric), g/cm^3	**2,12**	2,18	2,20
Air voids	**13,0**	9,9	8,4
Voids filled with bitumen (VFB)	**51**	60	65
Voids in mineral aggregate (VMA)	**26,5**	24,7	24,2

SMA-LN 4				
Bitumen content	6,5	**6,9**	7,3	7,7
Marshall				
Density (Volumetric), g/cm^3	2,02	**1,99**	2,03	2,09
Air voids	16,8	**17,3**	15,5	12,4
Voids filled with bitumen (VFB)	43	**44**	48	56
Voids in mineral aggregate (VMA)	29,6	**30,7**	30,0	28,2

SMA-LN 6				
Bitumen content	6,14	6,45	**6,91**	7,62
Marshall				
Density (Volumetric), g/cm^3	2,051	2,047	**2,079**	2,119
Air voids	15,6	15,4	**13,5**	10,9
Voids filled with bitumen (VFB)	44	46	**51**	59
Voids in mineral aggregate (VMA)	27,9	28,3	**27,5**	26,7

The mixes with "white background" and "bold font" are the chosen SMA mixes.

SMA 6P			
Bitumen content	**6,5**	6,9	7,3
Marshall			
Density (Volumetric), g/cm^3	**2,04**	2,05	2,09
Air voids	**16,1**	15,3	13,1
Voids filled with bitumen (VFB)	**45**	48	53
Voids in mineral aggregate (VMA)	**29,1**	29,3	28,0

SMA-LN 8				
Bitumen content	6,05	**6,52**	6,76	6,87
Marshall				
Density (Volumetric), g/cm^3	2,152	**2,153**	2,155	2,179
Air voids	11,2	**11,1**	10,7	9,5
Voids filled with bitumen (VFB)	53	**56**	57	61
Voids in mineral aggregate (VMA)	24,1	**24,8**	24,9	24,2

The mixes with "white background" and "bold font" are the chosen SMA mixes.

Grading curve for the five mixes.

Sieve size, mm	SMA 4P	SMA-LN 4	SMA-LN 6	SMA 6P	SMA-LN 8
11,2	100	100	100	100	100
9,5	100	100	100	100	100
8	98	100	100	98	96
5,6	89	100	99	86	51
4	84	89	76	60	28
2	26	19	19	21	18
1	18	14	14	17	15
0,5	15	13	13	15	14
0,25	13	12	12	14	12
0,125	11	10	11	12	11
0,063	8,6	8,5	9,2	9,2	8,7

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