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New innovative road surface designs as a mean for reducing sound emission from the tyre/road interface

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0 EXECUTIVE SUMMARY

0.1 OBJECTIVE OF THE DELIVERABLE

The objective of this deliverable is to summarize the work performed within SP3 on low noise road surfaces with an emphasis on presenting the new technology and innovative elements produced so far within the WP3.5.

For more detailed information on design and test methods we would like to refer to other deliverables e.g. D3.18 (strength calculations and grain size optimization of the poroelastic road surface), D3.26 (sound and vibration measurements for the poroelastic road surface) and D3.27 (recipe design and manufacturing of the poroelastic road surface) presented within this project.

0.2 THE POROELASTIC ROAD SURFACE – INNOVATIVE DESIGN STEPS TAKEN

The poroelastic road surface tested at Tagenevägen, Gothenburg during the fall of 2007 proved to give 6 dB(A) units of lower tyre/road noise compared to an adjacently and newly paved[1] SMA11. By increasing the void content from the current 15% up to 20-25 % we expect that the noise reduction effect would increase at least 2 dB(A) units (from 6 to 8 dB(A) units in total) for the new poroelastic road surface concept.

To achieve the reported results a number of innovative steps have been introduced. We will briefly mention some of them here.

- A calculation model for determination of strain and stress in a poroelastic road surface have been developed, which revealed that the binder must be a PMB (polymer modified bitumen) with an SBS content > 7% and that the size of the crumb rubber for normal asphalt mixes should be maximum 1 mm which is considerably smaller than what has previously been used (2-5 mm).
- A new impregnation technology for the crumb rubber has been applied that will prevents the rubber to absorb the binder. This could result in excess wear with a rapid deterioration of the surface as a result.
- New machine technology has for the first time been applied for impregnating and dissolving the impregnated crumb rubber on a larger industrial scale.

0.3 NON-POROUS ELASTIC ROAD SURFACES WITH CRUMB RUBBER.

From the tests of the poroelastic road surface performed at Tagenevägen Gothenburg it can be deduced that a dense and elastic surface (corresponding to a rubber content of 8%(w)) could give about 3 dB(A) units of noise reduction compared to a

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[1] The reference surface was paved about three weeks before the paving of the poroelastic test surface.

newly paved SMA11. This opens up the possibility to create a little less noise reducing surface but with the advantage that this lower noise reduction will remain stable over many years.

Tests will be performed in lab and on road for a dense elastic surface with a rubber contents in the range of 5-12 %.

0.4 ASPHALT LAYER WITH ELASTIC SUBLAYER.

A study of a new innovative road surface concept has been performed. The idea is to put an elastic sub layer beneath the dense upper asphalt layer.

A 40 mm thick dense asphalt layers on top of a 10 mm rubber mat were tested. Two types of asphalt layer as well as one test with mastic asphalt on two types of the 10 mm thick rubber mats were used.

The test samples were subject to wheel rutting tests. For the samples tested up to now, no one has passed the test with respect to cracking of the upper surface layer and delamination between the asphalt layer and the elastic sub layer.

Making the top layer more elastic at the same time as the elastic sub layer is made thinner and less elastic may provide a sample that would possibly pass the wheel rutting test.

1 BACKGROUND

Tyre/road noise is the dominating traffic noise source from about 30 km/h for passenger cars and for about 40 km/h for light and heavy trucks during constant speed.

Since about 25 % of the European population is exposed for equivalent sound levels exceeding 55 dB(A) outside their facades tyre/road noise could be claimed to be one of today’s most severe noise problem to solve.

Therefore it was decided that QCITY should comprise an attempt to produce new low noise concepts involving both tyres and road surface designs.

The objective of this deliverable is to summarize the work performed within SP3 on low noise road surfaces with an emphasis on particularly presenting the new technology and innovative elements produced so far within the WP3.5.

For more detailed information on design and test methods we would like to refer to other deliverables e.g. D3.18 (strength calculations and grain size optimization of the poroelastic road surface), D3.26 (sound and vibration measurements for the poroelastic road surface) and D3.27 (recipe design and manufacturing of the poroelastic road surface) also presented within this project.

2 THE POROELASTIC ROAD SURFACE – NEW TECHNOLOGY AND INNOVATIVE DESIGN STEPS

2.1 IMPREGNATION OF THE CRUMB RUBBER WITH BITUMEN EMULSION.

2.1.1 Impregnation/pre-treatment of the crumb rubber with bitumen emulsion to prevent it from absorbing the bitumen binder in the asphalt mix.

It has been found that rubber can absorb large quantities of bitumen. This process is very slow in normal outdoor temperatures, but will be clearly visible after some months. The amount of binder left "free" in the mix is then not enough to provide the necessary strength.

This means that if *dry* crumb rubber is blended into the asphalt mix the rubber will gradually suck up a substantial part of the binder. This means that the asphalt mix will contain too little binder to keep it together. The result will be a rapid wear of the road surface that will soon deteriorate.

By impregnating the crumb rubber with bitumen before blend it into the plant mixer this deteriorating effect can be prevented.

Mixing bitumen emulsion with crumb rubber was found to be the best method for impregnating or pre-treating the crumb rubber with bitumen. We have used a rather soft emulsion to an extent of 15-25 % of the total weight of the rubber/bitumen mix.

High bitumen content in the pre-treatment process has a disadvantage in the following process of adding the rubber/bitumen mix. This problem seems to have been solved by shredding with an ALU-loader (see Figure 1).

This means that the bitumen added to the rubber in the field test will be increased to about 17 % (i.e. the bitumen binder and bitumen absorbed by the crumb rubber by impregnation/pre-treatment will in total be 17 % of the total weight of the mix).

2.1.2 Machine technology applied for handling the bitumen impregnated crumb rubber on a larger industrial production scale.

In order to produce impregnated crumb rubber on a larger scale fitting the production of longer road sections of poroelastic road surfaces it was necessary also to adapt and develop machine technology for the purpose. Figure 1 - Figure 4 below show some of the machines and plants used for the impregnation process. The machines and plants used was already existing but have not until now been used for impregnating/pre-treating crumb rubber.

Figure 1. Cold mixing plant used for mixing the crumb rubber with 15 – 25%(weight) bitumen emulsion (the percent figures refer to the net weight of dry bitumen added the crumb rubber) . About two tons of rubber granulate 0-0.5 mm and 0.5-1 mm was pre-treated/impregnated using the plant shown above.

Figure 2. Shredder (type ALLU) used for disintegrating the impregnated crumb rubber.

Figure 3. Blocks of impregnated crumb rubber before the disintegration process before feeding the impregnated and pulverized crumb rubber to the plant mixer.

Figure 4. Disintegration of the bitumen impregnated/pre-treated crumb rubber to powder ready to be added in the plant mixer.

2.2 OPTIMIZING THE CRUMB RUBBER GRAIN SIZE.

By developing a FEM-model for calculation of the stress and strains in a poroelastic road surface it has been possible to optimize the grain size curve for the crumb rubber used in the poroelastic road surface.

Below in Figure 5 is presented the concept used when building the FEM-model. The stone material in the surface was represented by cubic stones of a size that was selected to the mean size of the main stone content used as aggregates. For a road surface with the main content of stones in the range of 4-8 mm, the FEM model consisted of cubic stones with the side 6 mm.

Load was applied to the model for resembling passenger cars and light trucks passing over the surface.

By studying this FEM –model and the calculated results in terms of stress and strain a number of interesting conclusions could be drawn:

- Polymer Modified Bitumen must be used as binder. And the content of SBS (Styrén Butadien-Styren) content must be high, at least 7% and preferably even somewhat higher.
- By using the "boundary condition" that the rubber grain size shall not be greater than the total binder film thickness in the cubic model we could draw the conclusion that substantially smaller grain size (maximum 1.0 - 1.5 mm rubber grain size) must be used compared to what has been used previously (2-5 mm rubber grain size).
- The rubber grain size shall have a fixed relationship to the size of the stones. This means that the smaller the stone in the aggregate/ballast, the smaller should the rubber grain size be.

The concept of analysing a rubberized asphalt surface with aid of a cubic stone FEM-model *is a new innovative analysis concept* that was found to move the technology further a great deal.

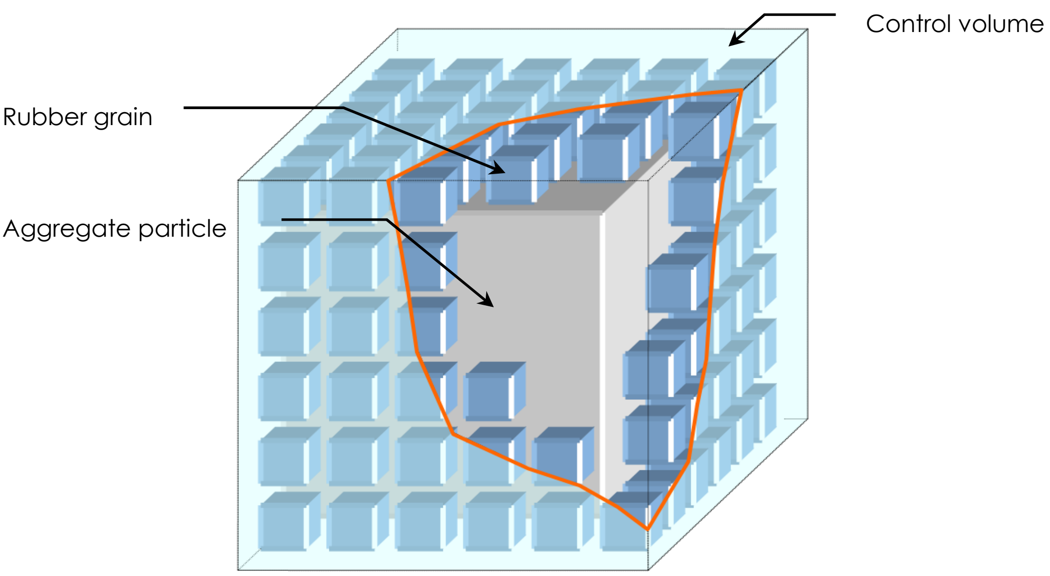

Figure 5. The conceptual sketch of how one aggregate particle is covered with bitumen binder and rubber grains. Here is shown a 5x5 matrix of rubber grains comprising a total number of 91 grains including edge and corner grains.

Figure 6 - Figure 8 below presents examples of calculated stress in the FEM- model and design charts for determination of the maximum rubber grain size to be used for a particular poroelastic (rubberized) road surface design.

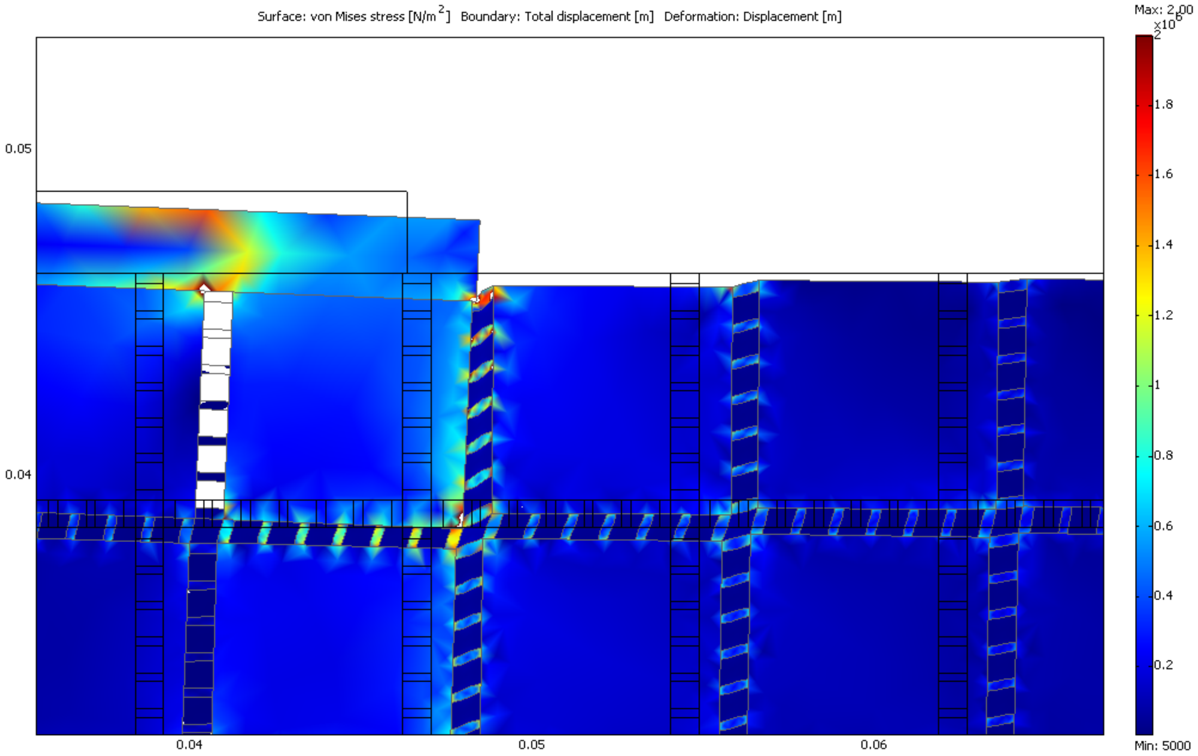

Figure 6. FEM calculated stress levels for 7 mm stones size in the cubic model. Both vertical and horizontal load is applied resembling a passenger car passages during braking.

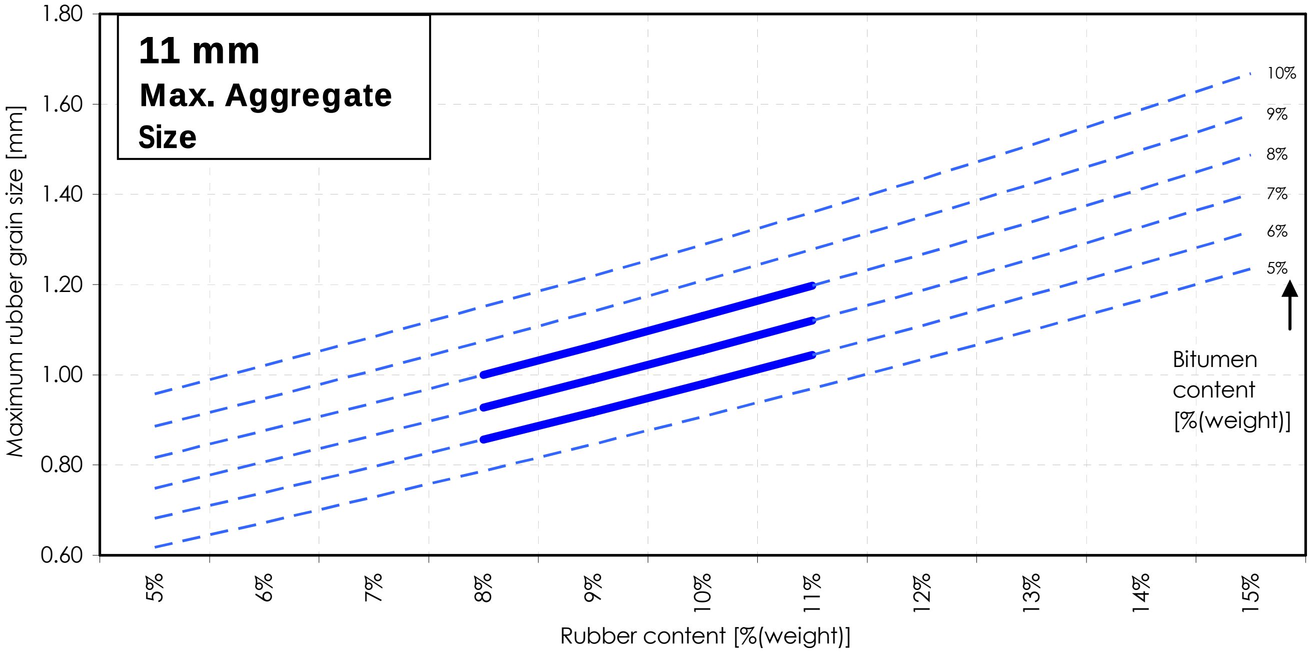

Figure 7. Design chart for determination of the maximum rubber grain size for a asphalt mix with 11 mm maximum stone size. Note that for 8 %(W) binder content and 8 %(W) crumb rubber content the max grain size should not exceed 1 mm.

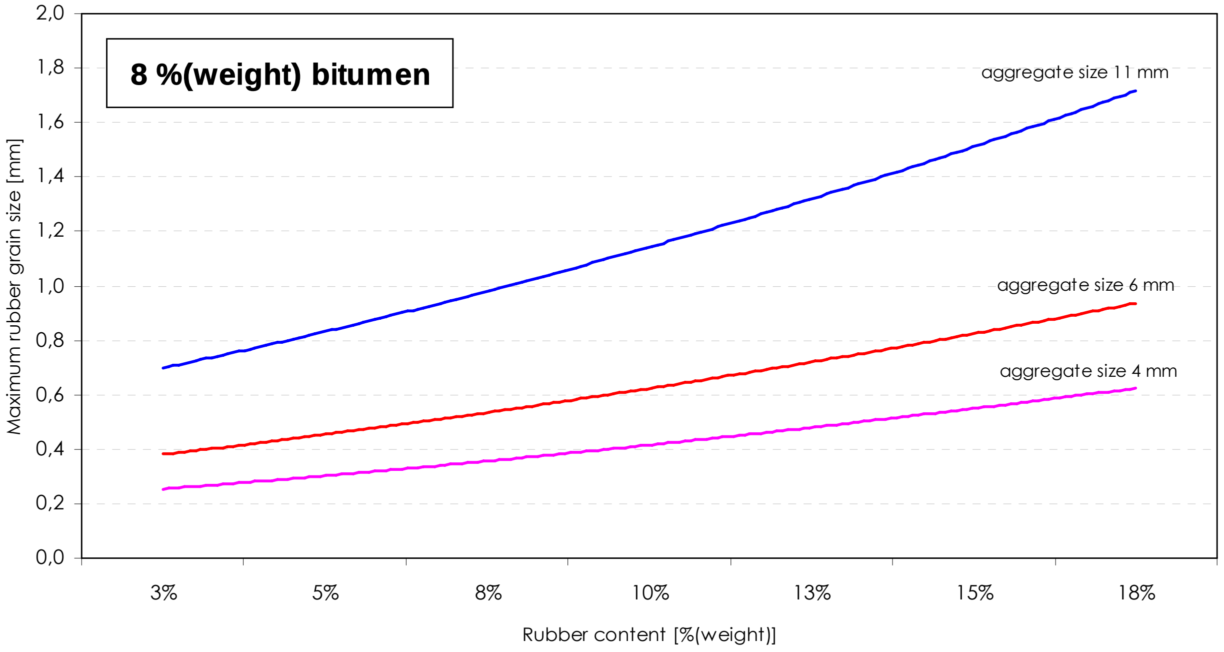

Figure 8. Design chart for determination of the maximum rubber grain size for a asphalt mix with 8 %(weight) bitumen binder.

2.3 TEST SECTION OF THE POROELASTIC ROAD SURFACE AND ACHIEVED TEST RESULTS.

2.3.1 Data for the test road surface.

In late September a test road of poroelastic surface was paved at Tagenevägen in Gothenburg (see Figure 9 below). The test section was 80 m long and contained of 8 %(W) rubber where 40 % of the added rubber was 0-0.5 mm and 60 % 0.5-1 mm. The aggregate had a maximum stone size of 8 mm.

Figure 9. The poroelastic road test section at Tagenevägen in Göteborg.

2.3.2 Test results for the poroelastic road surface.

The noise reduction compared to a newly paved SMA11 adjacent to the poroelastic road surface was found to be 6 dB(A) units in the speed range of 30 – 70 km/h, see Figure 10.

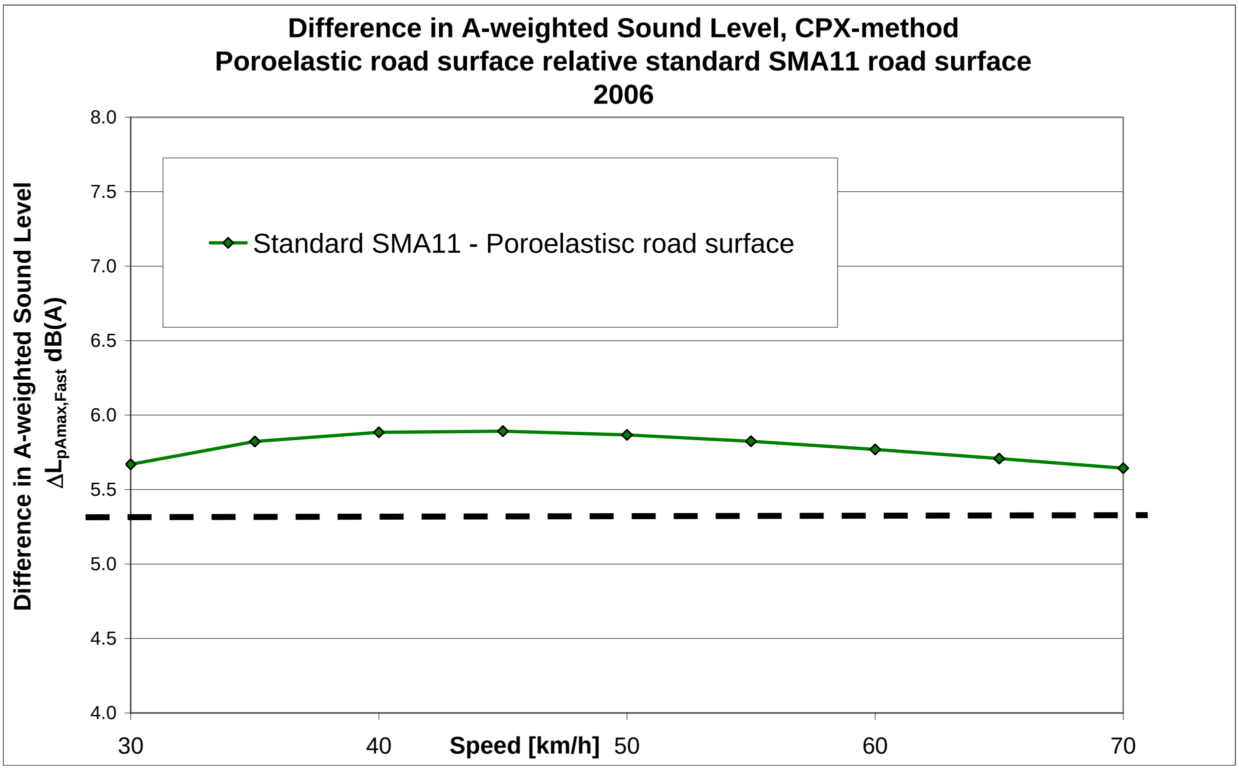

Figure 10. Difference in A-weighted Sound Level between the poroelastic road surface and the reference standard SMA11 road surface.
Note that the difference in sound level ΔLpA , as measured with aid of the CPX-method is almost constant throughout the speed range of 30 – 70 km/h.

As can be seen in Figure 11 below the reduction occur mainly in the frequency range above 800 Hz.

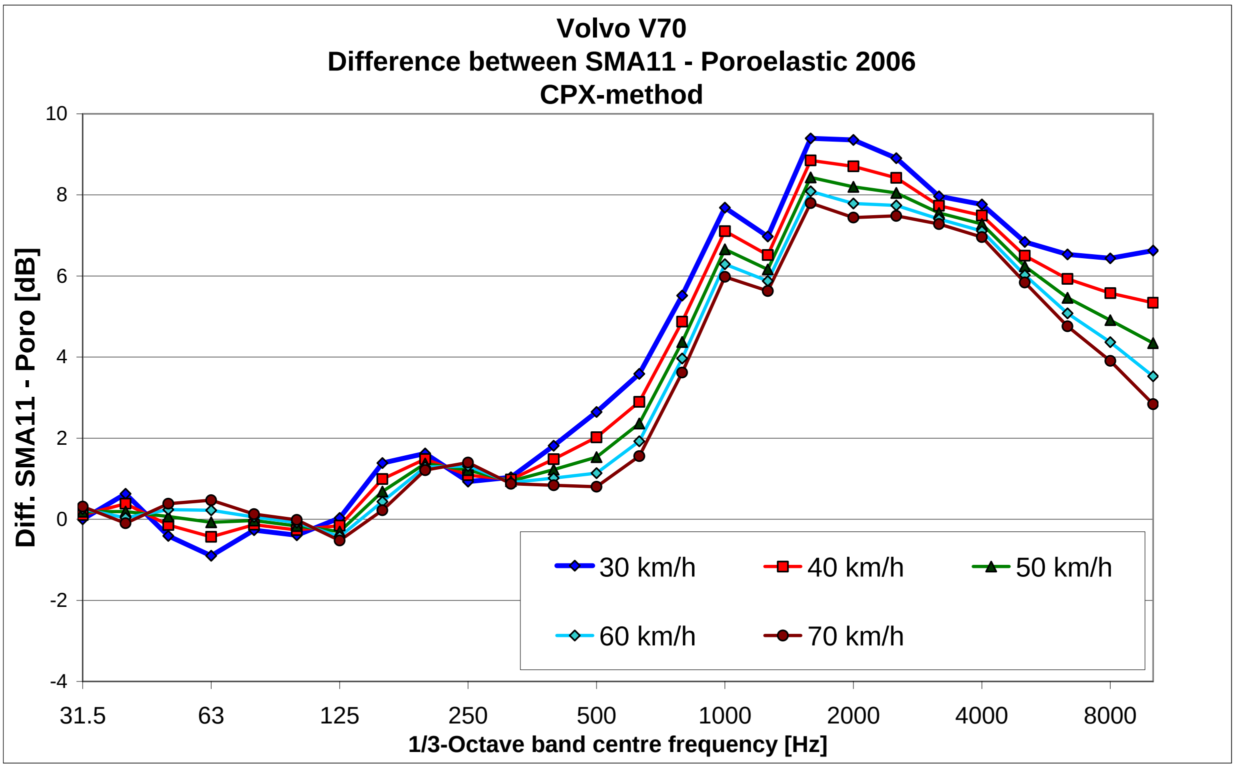

Figure 11. Difference in Sound Pressure Level (ref. SMA11 – Poroelastic) for the different evaluated velocities.

2.3.3 An estimation of how the found reduction is composed.

Table 1. An estimation of the different factors that are building up the total noise reduction found by the CPX and Pass-by tests.

Factors influencing the noise reduction for the poroelastic road surface (8 mm max stone size) compared to an SMA11 (11 mm max stone size)	**Estimated relative contribution dB(A)-units**
Reduced roughness when using 8 mm max stone size in the poroelastic surface compared to 11 mm in the reference surface	**1.5** dB(A) units
Reduced dynamic stiffness of the poroelastic road surface due to the 8 % (weight) crumb rubber in the mix.	**2.5** dB(A) units
Sound absorption, which was limited by the low void content (15%) of the poroelastic road surface compared to virtually no absorption for the reference surface	**1.5** dB(A) units
Other effects	**0.5** dB(A) units
Total noise reduction of the tested poroelastic road surface	**6.0 dB(A) units**

3 LOW NOISE DENSE ELASTIC ROAD SURFACES

3.1 INDICATIONS ON POSSIBLE NOISE REDUCTION

As indicated in Table 1 above even without the sound absorption effect due to the porosity or void content, the elasticity alone will cause a certain reduction in noise. The mechanisms is here e.g. reduced contact stiffness which will result in that the existing road surface roughness will result in smaller forces when the tyre is rolling over the surface. Another effect is that due to the generally smaller mechanical impedances of the road surface a certain amount of vibration energy will be drained from the tyre down to the road surface. Since it is the tyre that is the main sound radiation structure (very little sound radiation has been found from the road surface) this will result in less radiated sound.

As indicated in Table 1 above the sole noise reduction effect from the increased elasticity of the road surface would be about 3 dB(A) units for a rubber content of 8 %. Earlier studies with about 3 % rubber content (studies in late 1970:ies and early 1980:ies) indicate that about 1 dB(A) units of noise reduction was achieved.

An educated guess would therefore be that 3 % added crumb rubber to the mix will result in about 1 dB(A) unit of noise reduction. This means that a noise reduction effect according to the table below could be expected, assuming a thickness of 40 mm.

Table 2. Estimated noise reductions for a dense and elastic road surface for different amount of crumb rubber added to the mix.

Added crumb rubber to the asphalt mix	**Thickness 40 mm Estimated noise reduction in dB(A) units**
3 % rubber	1 dB(A) unit
6 % rubber	2 dB(A) units
9 % rubber	3 dB(A) units
12 % rubber	4 dB(A) units
15 % rubber	5 dB(A) units
18 % rubber	6 dB(A) units

3.2 INNOVATIVE ELEMENTS OF A DENSE ELASTIC ROAD SURFACE.

The earlier attempts to create a long lasting rubberized asphalt surface by adding 3 % dry rubber to the mix failed because the wear resistance became too poor. By the knowledge acquired in the QCITY project we now know that this depends on that the rubber will suck up or absorb part of the bitumen binder, resulting in that the aggregate particles loosen from the surface with an accelerated wear rate as a result.

The recently developed rubberized asphalt technology in the US has been successful with respect to the wear rate because the rubber is added to the hot bitumen during 20-40 min before pumping it to the plant mixer. This means that the rubber added to the mix is now saturated with bitumen and will not absorb the binder of the asphalt mix. The drawback of this method is that it limits the amount of crumb rubber to be 20 % of the total bitumen rubber mix. Since the binder content is typically 6 % (W) this means that the amount of crumb rubber is limited to 1-2 % of the weight of the total asphalt mix.

Due to the innovative step to impregnate the crumb rubber with bitumen emulsion the amount of crumb rubber to the mix can now be freely selected to any wanted number.

So instead of being limited to 1-3 % crumb rubber in the mix we are now able to freely choose the amount of crumb rubber in the mix to be e.g. 10 % or more. This opens up new possibilities to create interesting noise reducing road surface designs.

3.3 ADVANTAGES OF A DENSE ELASTIC ROAD SURFACE.

The advantages by creating a dense and elastic road surface could be summarised in these points:

- Since there are no pores that can be clogged with dirt the sound reduction caused by a dense and elastic road surface will be very stable in time. It can thus be expected that no decrease of the noise reduction effect would occur other than due to a possible increase of the surface roughness.
- The dense elastic road surface would be of particular interest in the low speed inner city applications where open graded sound absorbing surfaces with high void content cannot be used because of the clogging effect. At higher speeds open graded surfaces can be “cleaned” in the wheel tracks due to air flow in the surface. But at lower speeds 30-50 km/h there is no “cleaning” effect any more.

The drawbacks are

- the noise reduction is typically 3-5 dB(A) units lower (due to the absence of sound absorption) compared to what can be achieve from an poroelastic (open graded and elastic) surface.
- There is a certain risk that a dense elastic road surface will be more sensitive to the influence from tyre tread patterns. This means that poor tread pattern designs could give excessive noise generation on a smooth and elastic surface and thereby neutralize the reduction effect normally achieved by the elasticity.

3.4 FURTHER STUDIES ON THE DENSE-ELASTIC ROAD SURFACE.

NCC TRAF and ACL intend to test the concept of dense elastic road surfaces in the lab. After measurements on the lab samples it will be decided on the recipe to pave a test section in Gothenburg for sound testing.

4 ROAD SURFACE WITH ELASTIC SUBLAYER.

Heijmans and CDM tested a new concept which aimed at designing a dense and elastic noise reducing road surface.

The concept is to put a rubber mat underneath a regular asphalt pavement. In the current studies the elastic sub layer has been a CDM rubber mat of thickness 10 mm.

Standard solutions using porous asphalt concrete to reduce noise can't be used in an urban environment because of clogging of the pores in the surface. The speed of cars is too low to naturally clean the porous pavement.

An alternative is then to use a quiet road surface based on an elastic road foundation.

To assure a good solution it is important to execute wheel rutting test in order to check the durability.

4.1 PERFORMED TESTS OF THE ROAD SURFACE WITH ELASTIC SUBLAYER.

In order to see the possible effects from strain and stress in the harder top layer due to the elastic sub layer it was necessary to execute a wheel rutting test with the following test conditions:

- T = 35 °C
- Wheel pressure of 5kN
- Movement frequency: 1Hz
- Max. speed: 1,6 m/s
- Max. acceleration: 10 m/s²
- Slick tires 16x4ER
- Test ends after 100.000 cycle

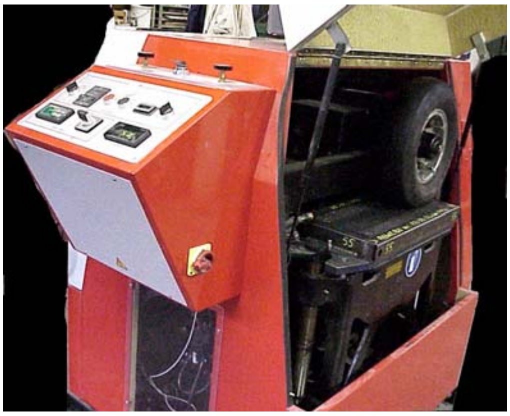

Figure 12. Wheel rutting test machine.

4.1.1 Test samples

Target of the test is to estimate the wear resistance of a compacted bituminous mixture

Tested samples:

Two different rubber mats where tested CDM43 and CDM45 both were 10 mm thick.

Two different asphalt top-layers where combined with the CDM43 and CDM45 rubber mats:

AB-4C: stone fraction 0 mm to 10 mm with bitumen B 50/70; 40 mm thick

SMA-C2: stone fraction 0mm to 10mm with polymer bitumen; 40 mm thick

2 x 4 samples are subjected to the effect of a charged wheel that moves back- and forwards with a given frequency at constant temperature.

The track depth is the constant height difference against the lips of the track.

Samples:

- 1cm CDM43 with 4cm AB-4C
- 1cm CDM45 with 4cm AB-4C
- 1cm CDM43 with 4cm SMA-C2
- 1cm CDM45 with 4cm SMA-C2

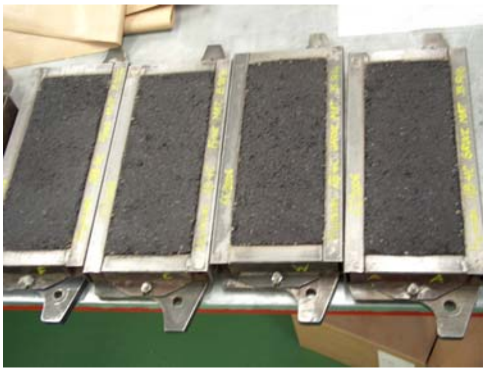

Figure 13. Test samples before rutting test.

4.1.2 Test results

4.1.1.2 Overlay with AB-4C 40 mm thick on top of CDM45 and CDM 43

We had to end the test after 10.000 cycles for the CDM 45 and after 30.000 cycles for the CDM43:

In both cases the tire was dancing on the pavement and resulting in cracking of the test plate. The fixing coat (between asphalt/rubber) broke and the asphalt came off, see Figure 14.

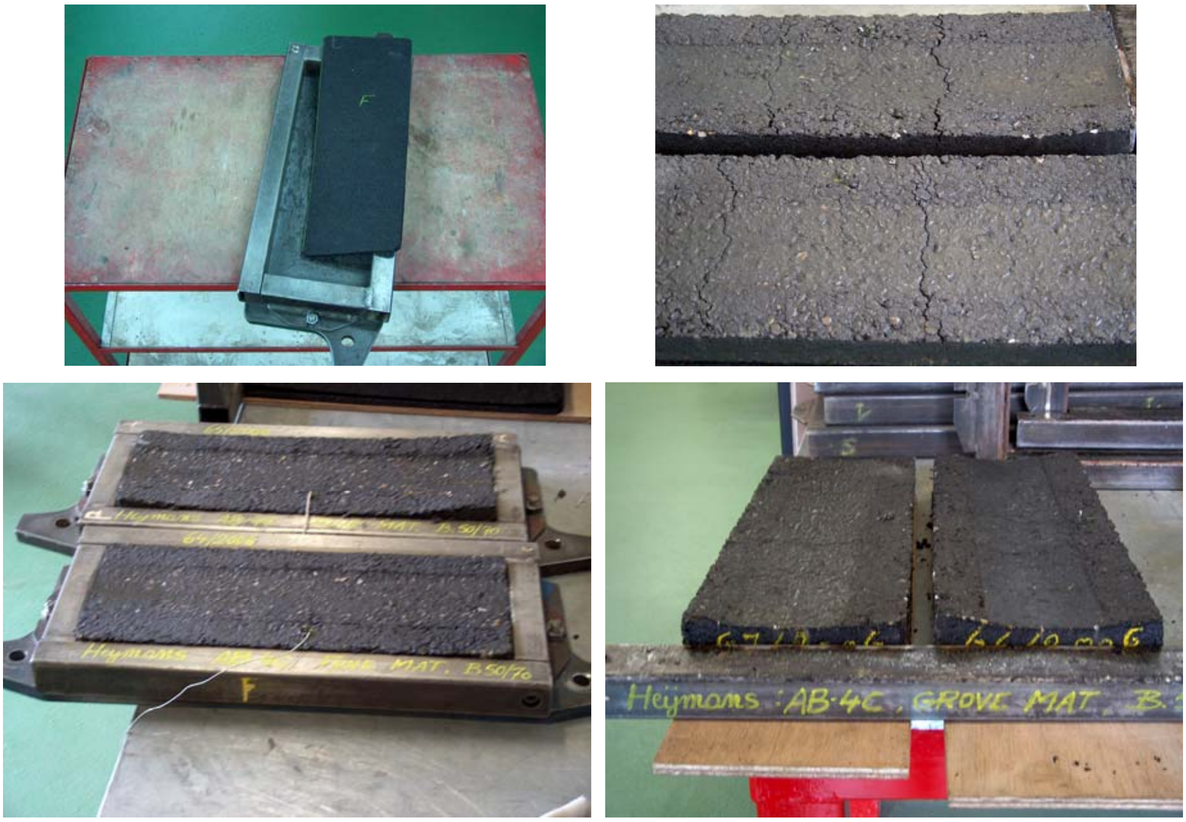

Figure 14. Test samples with the AB-4C 40 mm overlay after rutting test.

4.1.2.2 Overlay with SMA-C2

The wheel rutting test was ended after 30.000 cycles for the CDM 45. The second test plate with the CDM 45 wasn't even measurable after 10.000 cycles because it was completely broken.

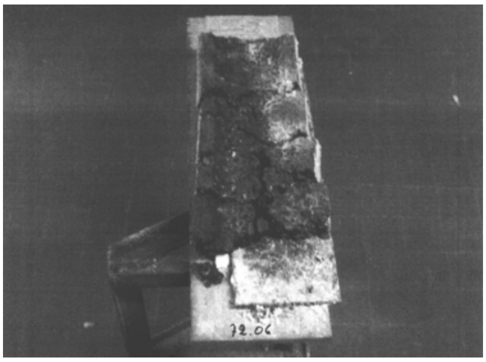

Figure 15. Test plate with SMA-C2 after rutting test.

The results with the CDM 43 were a little bit better, but also disappointing. After 50.000 and 100.000 cycles the test were ended:

CDM45: 12,24 mm

CDM43: 11,13 and 9,78 mm

Figure 16. Test plate with SMA-C2 after rutting test.

Figure 17. Test plate with SMA-C2 after rutting test.

4.1.3.2 Tests with mastic asphalt on elastic sublayer.

Tests were also performed using a mastic asphalt. The performance was a little bit better but still not acceptable.

4.2 CONCLUSIONS AND DISCUSSION ON THE TESTS REGARDING ROAD SURFACES ON ELASTIC SUBLAYERS.

It can be concluded from the above tests that the concept of a rigid asphalt top layer onto an elastic sub layer did not performed good enough on the rutting tests (cracked top layer and delamination of the sub layer) to qualify for further road test.

It can though still be of interest to further develop and refine the concept by using a more flexible top layer e.g. by adding a substantial amount of crumb rubber to the mix and combine it with a thinner and stiffer sub layer.