



TAMPERE UNIVERSITY OF TECHNOLOGY
Institute of Structural Engineering
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Dear Mr. Max Wallis

Thank you for sending treatment agents for testing. Our time schedule was unfortunately stretching a lot because of severely reduced funding of our research. Finally we have done tests with treatment agents with two different crushed rocks and also written a work report from the results in Finnish. Enclosed you will have a shorter version of the work report in English as we promised earlier. In the report your treatment agent is marked as treatment agent D.

Thank you again for your support to our research.

Yours sincerely

Prof. Pauli Kolisoja

Testing of the different treatments agents using Tube Suction Test

Four treatment agents (A, B, C and D) were tested with two different crushed rock aggregates using Tube Suction Test (TST) (Saarenketo 2000. *Tube Suction Test – Results of round robin tests on unbound aggregates. Finnish National Road Administration, Lappi region, Publications*). The crushed rock aggregates were Lillby, a fairly weak acidic granite-granodiorite, and Emet, an alkaline volcanite.

In the Tube Suction Tests the maximum grain size that was used was 20 mm, while the sample size was 180-200 mm in height and 150 mm in diameter. The sample was compacted using an ICT gyratory compaction machine. After compaction the sample was put into oven (40-45 °C) for 3-4 days. After that the sample was aged at room temperature for at least two days. Dielectricity and electric conductivity were measured from top of the sample at different time intervals after putting the bottom of the sample about 10-15 mm in distilled water. Measurements were done for about two weeks. Based on earlier experience a good quality base course material has lower dielectric value than 10 (9). Respectively, a poor quality material has higher dielectric value than 16.

Both crushed rock aggregates were first tested at three different fines content (low fines, normal fines and high fines). Figures 1 and 2 indicate the measured dielectric and electric conductivity values of Lillby crushed rock. Correspondingly, figures 3 and 4 present the test results obtained with Emet crushed rock. Figures show that high dielectric values indicating problems in unbound base course materials were measured with normal and high fines contents. Based on these tests only Emet aggregate with fines content 2,7 % can be recommended to used in unbound base courses.

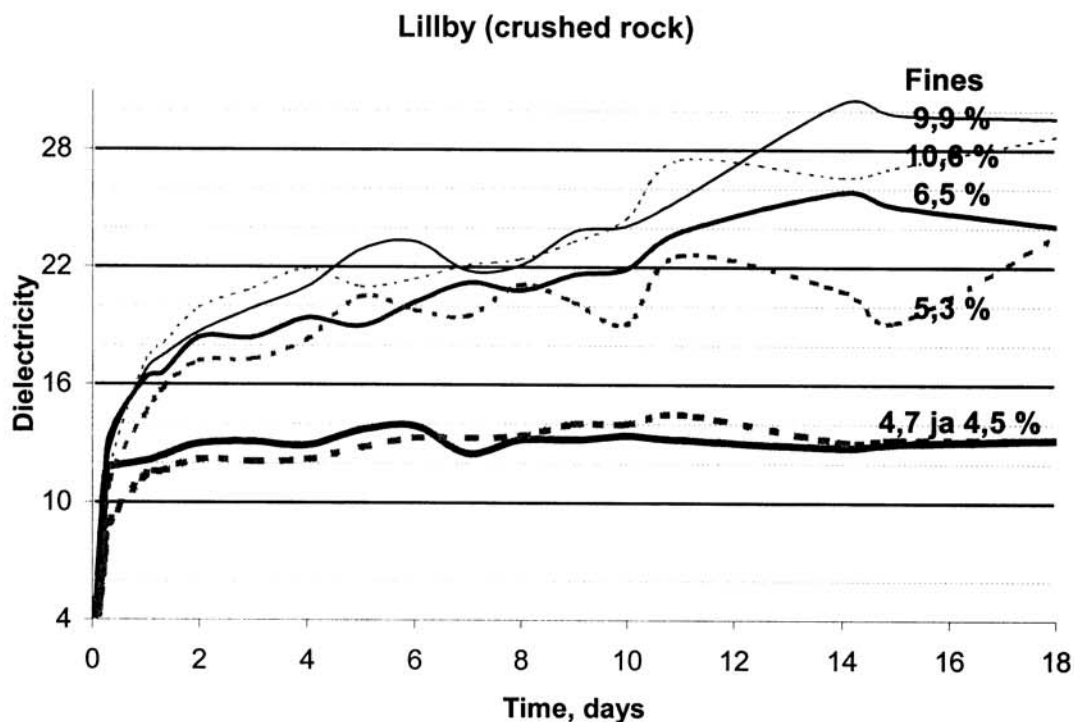


Figure 1. Dielectricity curves of Tube Suction Tests for Lillby aggregate with different fines contents (< #0,063 mm). Fines contents were determined from top of the sample using wet sieving.

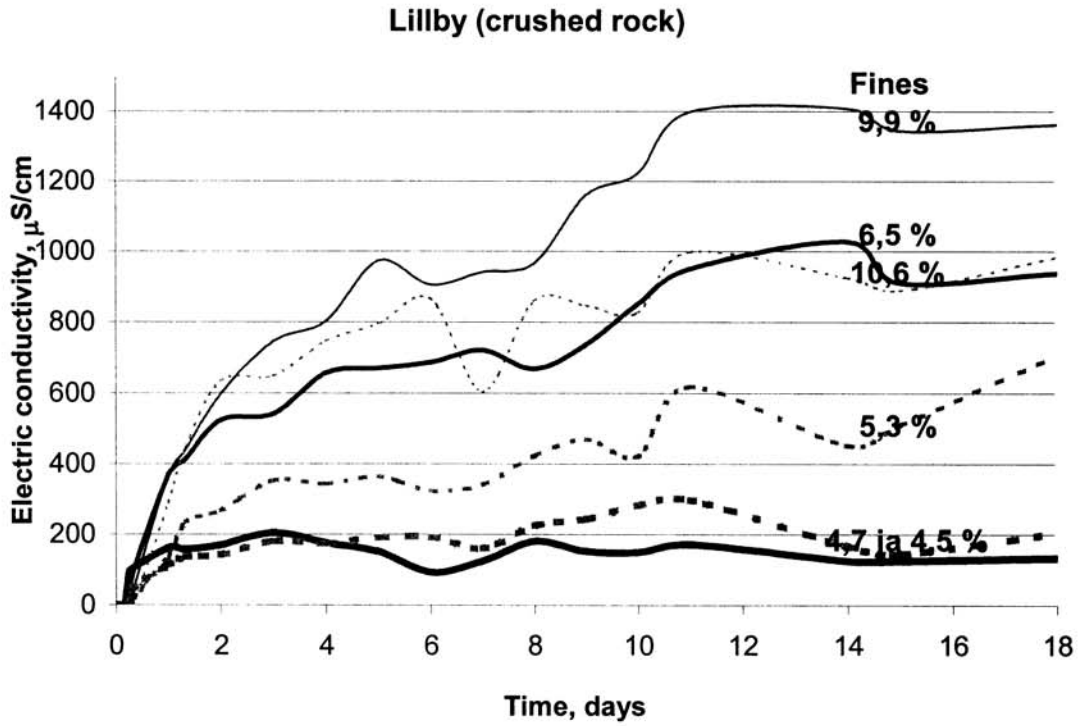


Figure 2. Electric conductivity curves of Tube Suction Tests for Lilby aggregates with different fines contents (< # 0,063 mm). Fines contents were determined from top of the sample using wet sieving..

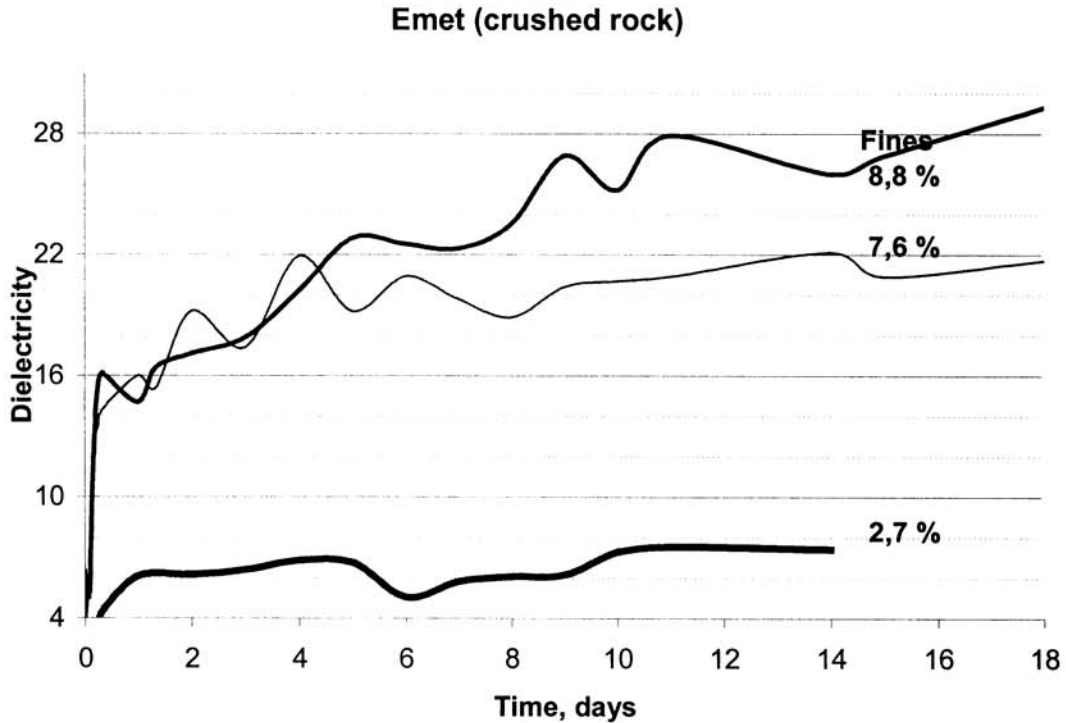


Figure 3. Dielectricity curves of Tube Suction Tests for Emet aggregate with different fines contents (< # 0,063 mm). Fines contents were determined from top of the sample using wet sieving.

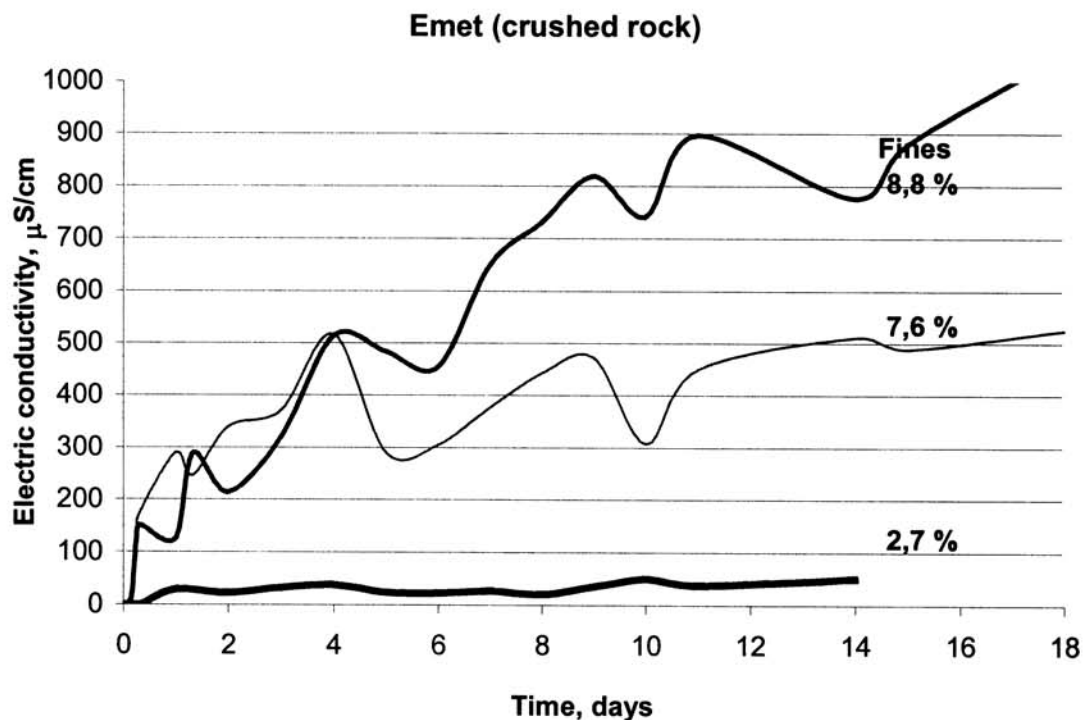


Figure 4. Electric conductivity curves of Tube Suction Tests for Emet aggregate with different fines contents ($< \# 0,063 \text{ mm}$). Fines contents were determined from top of the sample using wet sieving.

Effectiveness of the different treatment agents was tested using normal fines contents of the Lillby and Emet aggregates. Two of the treatment agents were of newer types while the others can be considered as traditional ones. Figures 5 and 6 show the effect of the treatment agents in Lillby aggregate. Only the treatment agent D drops the dielectric values below 9. Treatment agents B and A show some improvement, but not much enough.

Figures 7 and 8 show the effect of treatment agents in Emet aggregate. Treatment agents B and D indicate now good results as the dielectric values drop below 9 and electric conductivity values were near to zero.

Lillby and treatment agents

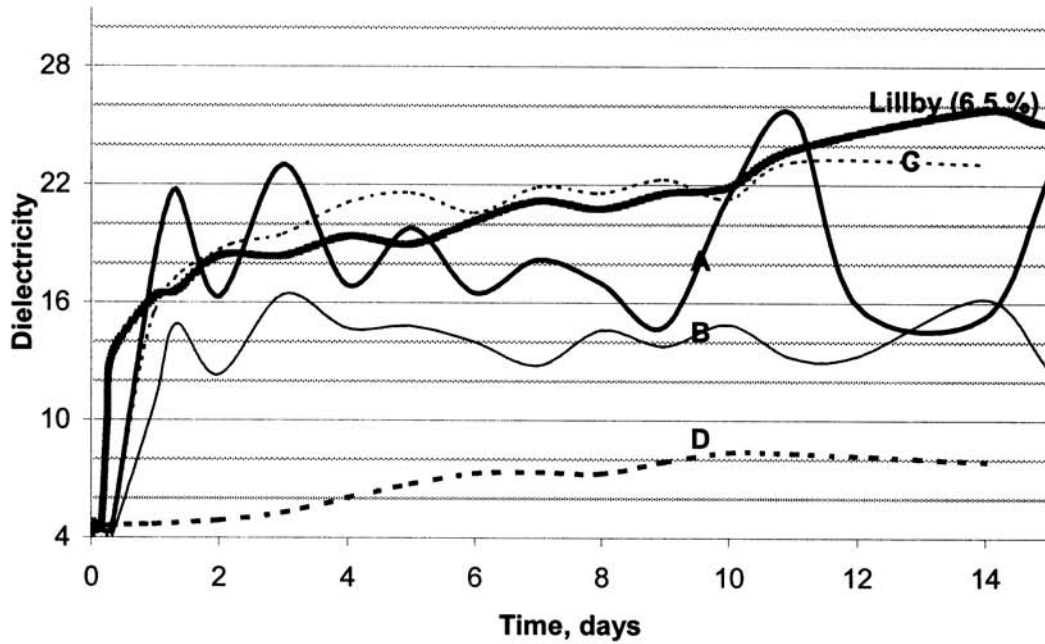


Figure 5. Dielectricity curves of Tube Suction Test for the original Lillby aggregate compared to the samples mixed with different treatment agents.

Lillby and treatment agents

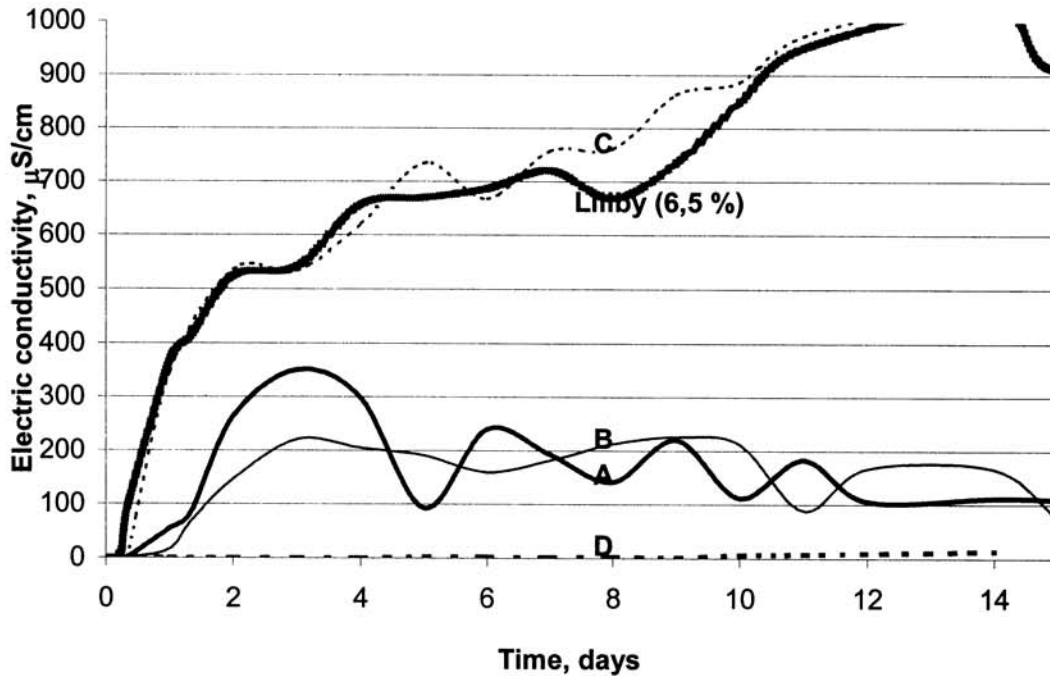


Figure 6. Electric conductivity curves of Tube Suction Tests for the original Lillby aggregate compared to the samples mixed with different treatment agents.

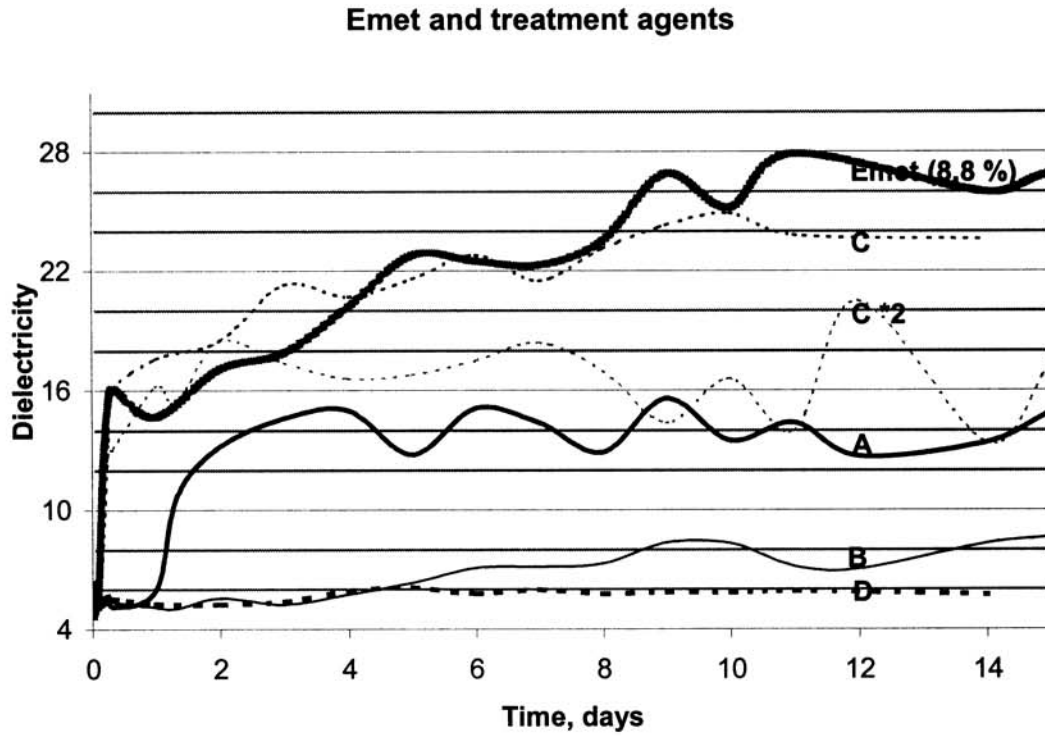


Figure 7. Dielectricity curves of Tube Suction Test for the original Emet aggregate compared to the samples mixed with different treatment agents.

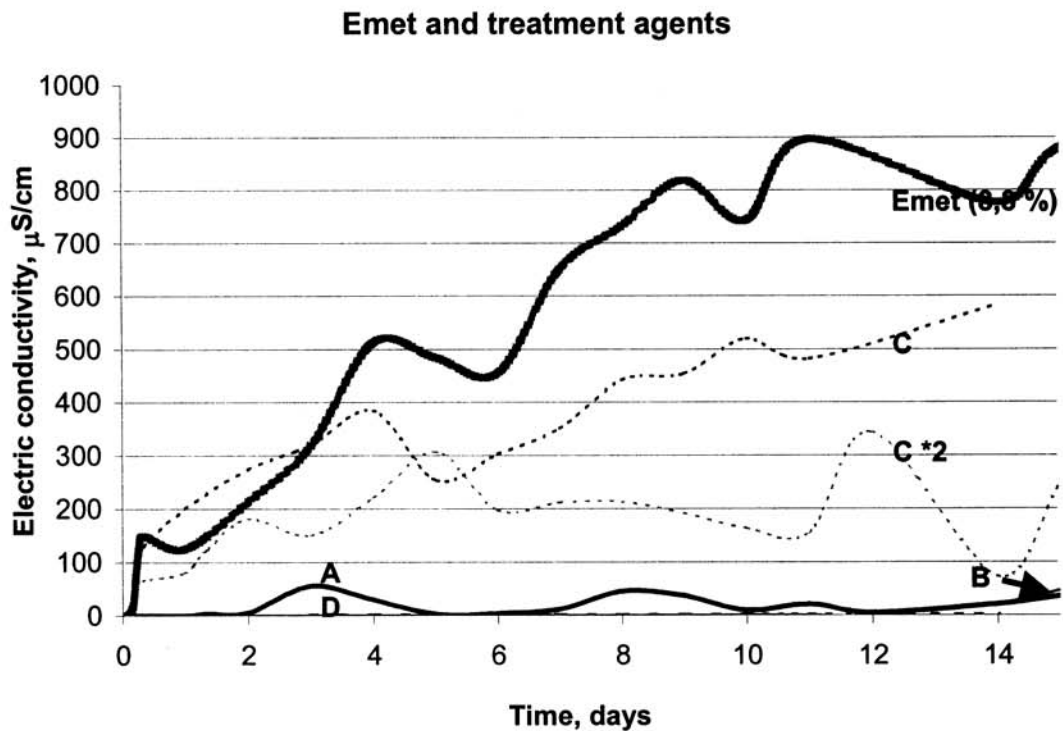


Figure 8. Electric conductivity curves of Tube Suction Test for the original Emet aggregate compared to the samples mixed with different treatment agents.

Tables 1 and 2 show the basic properties of the TST samples. The most interested observation is that materials mixed with treatment agent D have not compacted as well as the others.

Table 1. Basic properties of the Tube Suction Test samples prepared using Lillby crushed rock aggregate.

Name	Dielectricity (14 days)	Electric conductivity (14 days) $\mu\text{S}/\text{cm}$	Fines content _{5 cm} %	Dry unit weight kN/m^3	$W_{5 \text{ cm}}$ %
Normal fines content	25	1000	6,5	22,9	5,6
High fines	30	1400	9,9	22,9	5,9
Low fines	13	130	4,7	21,2	5,3
Normal fines + C	23	1000	9,1 ^)	22,6	5,7
Normal fines + D	8	10	-	19,3	3,7
Normal fines + B	15	150	-	22,1	3,9
Normal fines + A	18	120	-	22,1	4,6
Normal fines content ~)	22	500 *)	5,3	22,6	5,0
More fines ~)	27	950 *)	10,6	23,1	5,4
Less fines ~)	14	200	4,5	21,2	5,3

~) During compaction tap water was used instead of distilled water.

*) Old Percometer was used, which shows lower electric conductivity values at high values.

^) Wet sieving was not done from top of the sample.

Table 2. Basic properties of the Tube Suction Test samples prepared using Emet crushed rock aggregate.

Name	Dielectricity (14 days)	Electric conductivity (14 days) $\mu\text{S}/\text{cm}$	Fines content _{5 cm} %	Dry unit weight kN/m^3	$W_{5 \text{ cm}}$ %
Normal fines content	21	500	7,6	23,2	3,7
High fines	27	850	8,8	22,8	4,3
Low fines	7	50	2,7	21,4	2,1
Normal fines + C	24	550	6,6 ^)	22,9	3,7
Normal fines + C *2	17	200	6,2	22	3,2
Normal fines + D	6	0	-	19,9	1,7
Normal fines + B	8	20	-	23,5	1,2
Normal fines + A	14	30	-	22,4	3,3

^) Wet sieving was not made from top of the sample.

Seasonal variation tests

Three specimens were tested in cyclic loading triaxial tests simulating the effect of seasonal variations. These included:

- Lillby 0-20 mm aggregate, which had the same grain size distribution as the Lillby aggregate with normal fines content in the Tube Suction Test
- Lillby 0-32 mm aggregate, which had more coarse grained material than Lillby 0-20 mm aggregate
- Lillby 0-20 mm aggregate added with treatment agent D.

The resilient deformation tests were carried out with the specimen when it was dry, after it had adsorbed water and after it had gone through a freeze-thaw cycle. Resilient modulus values were determined according to SHRP protocol P46 (AASHTO 1992) at each of the

stages. After determination of the resilient modulus values with the specimen that had gone through a freeze-thaw cycle the specimen was loaded a maximum of 100 000 cycles in a permanent deformation test. In that test stage the confining pressure that was used was 50 kPa while the deviator stress was about 300 kPa.

The size of the triaxial test specimen was 400 mm in height and 200 mm in diameter. The specimen was compacted in four layers using a vibrator hammer type of compaction machine. After compaction the dry unit weight of Lillby 0-20 mm aggregate was 21,5 kN/m³ while in Lillby 0-20 mm aggregate added with treatment agent D it was 20,9 kN/m³ i.e. the difference in the densities was quite small in comparison to the difference in the densities of the respective Tube Suction Test samples (Table 1).

During the freezing phase the frost heaves of the samples were measured. Lillby 0-20 mm aggregate indicated a frost heave of about 16 mm and Lillby 0-32 mm a frost heave of about 9 mm while the Lillby 0-20 mm + D sample had no significant frost heave.

Figure 9 compares the resilient modulus values of the Lillby samples based on cyclic loading triaxial tests carried out for dry, adsorbed and freeze-thaw sample. It indicates that the resilient modulus of the Lillby 0-32 mm aggregate is reasonably good, while the Lillby 0-20 mm aggregate after a freeze-thaw cycle is not good enough for base course. Mixing treatment agent D into Lillby 0-20 mm aggregate increased the resilient modulus values significantly. The increase was significant also after the adsorption stage and after the freeze-thaw cycle.

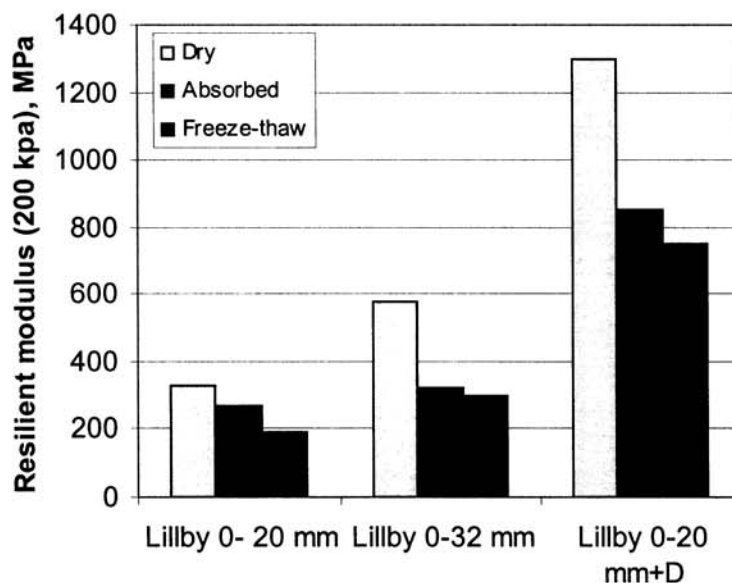


Figure 9. Resilient modulus values of the Lillby samples (grading 0-20 mm, 0-32 mm and grading 0-20 mm with treatment agent D) for a dry sample, for a sample that has adsorbed water and for a sample that has gone through a freeze-thaw cycle. The values are determined at a stress level corresponding to a sum of principal stresses 200 kPa.

Figure 10 presents the measured permanent deformations during determination of the resilient modulus values. The original Lillby aggregates indicated quite large permanent deformations after the freeze-thaw cycle. As the Lillby 0-20 mm aggregate with treatment agents D did not indicate practically any frost heave it did not have permanent deformations either.

Figure 11 shows the measured permanent deformations during the permanent deformation tests. In each of the tests the confining stress was 50 kPa. The deviator stress was planned to be 300 kPa, but the measured average deviator stress were between 315 and 380 kPa. Figures 10 and 11 show clearly how well the treatment agent D prevented permanent axial deformation during the cyclic loading.

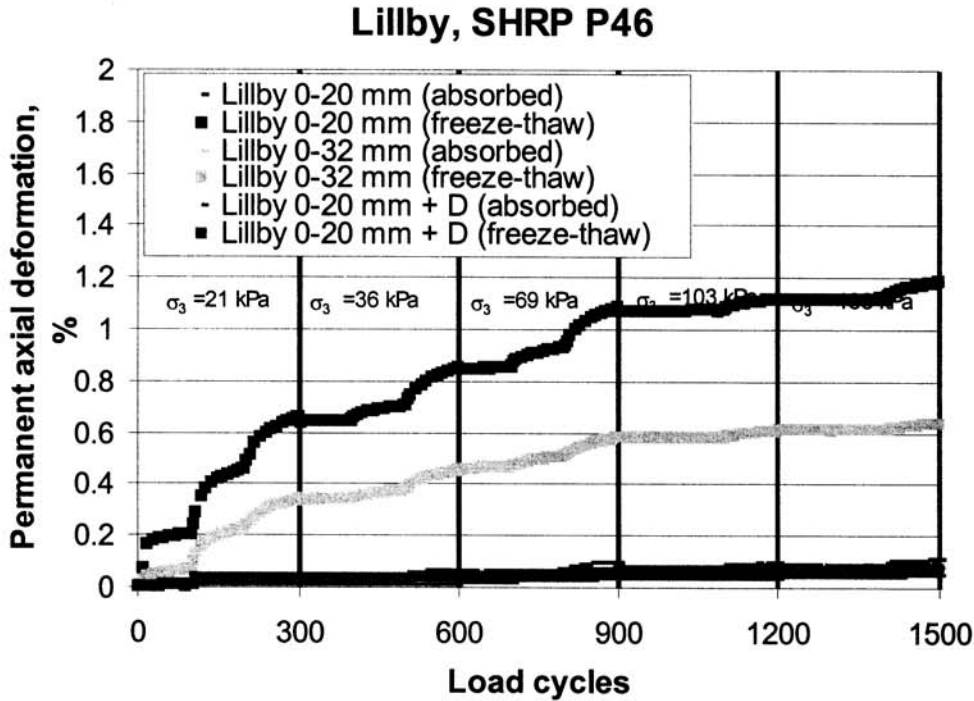


Figure 10. Permanent deformations during determination of the resilient modulus values of the Lillby samples. In all cases the deformations were small before the freeze-thaw cycle.

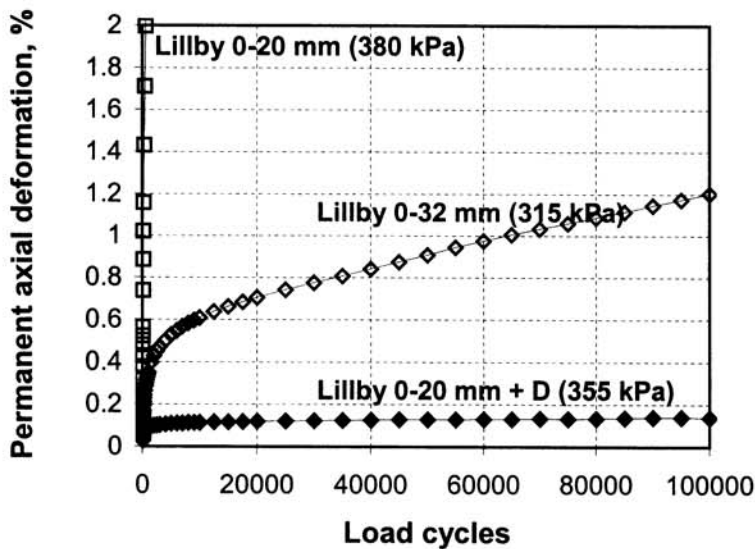


Figure 11. Permanent deformations measured with the Lillby samples during the permanent deformation test performed after a freeze-thaw cycle and determination of the resilient modulus values. Confining stress was 50 kPa while the average deviator stresses are indicated in brackets.