INVESTIGATION INTO THE EARLY TRAFFICKING OF EMULSION TREATED (ETB), FOAMED BITUMEN (FB) BASES TREATED IN COMBINATION WITH CEMENT AND CEMENT (OPC) ONLY

P B Botha
Transportek, CSIR, Republic of South Africa
pbotha1@csir.co.za
C J Semmelink
Construction Problem Solutions cc, Republic of South Africa
conprosol@lantic.net
J Raubenheimer
Raubex, Republic of South Africa
raubex@roadworks.co.za
B Perry
C&CI, Republic of South Africa
bryan@cnci.org.za
A Hodgkinson
CONCOR, Republic of South Africa
Athol@

ABSTRACT

The South African Road Agency Limited (SANRAL Northern Region) requested that more information be generated to determine the early trafficking potential of ETB, FB and Cement stabilized materials, in order to determine when the traffic could safely be placed on the recycled layer. The ETB and FB treatments are usually done in combination with cement. The dynamic mechanical triaxial test (K-Mould test) was used to evaluate the maturity of all three stabilized materials in the laboratory after different curing periods. To compare the different treatment methods the results were converted into predicted life expectancy of 80 kN axle loads required to cause a surface rut of 10 mm in the 200 mm stabilized layer. What the results showed was that the greatest contribution to the final strength came from the cement. This result was later confirmed by independent tests done on another project comparing the contributions of the stabilization agents towards the ITS of the stabilized material.

KEYWORDS

STABILIZATION/ CEMENT/ BITUMEN EMULSION/ FOAMED BITUMEN/ RECYCLING/ STRENGTH

1. INTRODUCTION

Emulsion Treated Base (ETB) and Foamed Bitumen Base (FB) bases, where cement and bitumen emulsion or foamed bitumen are used simultaneously in very low percentages in recycled and new gravel or crushed stone bases, are very popular in South Africa. In order to avoid the increasing cost of building bypasses or extended traffic control, Clients and Engineers would prefer the recycled base to be opened to traffic “as soon as possible”. Initially it was deemed safe to open the recycled base to traffic in as little as 2 hours after finishing the construction process. This however led to surface failures on a number of projects. Research was therefore carried on site and in the laboratory on a particular Heavy Vehicle Simulator (HVS) Site. This research showed if the recycled base could be kept free from traffic for at least 48 hours, the structural life expectancy was more than 400 per cent that of opening the base to traffic after 2 hours. Considering the long term costs (including road user costs) it would seem well worthwhile to control the traffic for 48 hours.

Till recently it was thought that the bulk of the strength of these stabilized layers was being supplied by the bituminous component of the mix in the case of ETB and FB stabilisation, while the cement only acted as a catalyst to break the emulsion. Recent investigation by one of the authors, very clearly showed that the main component for the tensile strength are the cement bonds, although their contribution decreases somewhat when the material becomes wet.

2. THE DYNAMIC MECHANICAL TRIAXIAL (K-MOULD) SAMPLE PREPARATION

The K-mould samples were scalped on the 37,5mm sieve and compacted in a single layer at optimum moisture content and optimum stabiliser content for the ETB, FB and Cement on the Transportek vibratory compaction table. Samples were compacted within 1 hour after mixing in the FB, emulsion and cement, and cured at ambient temperature to simulate the curing conditions in the road pavement itself and then tested in approximately the following time sequence:

- Sample 1: 2 hours after compaction (i.e. normal period before opening to traffic) for first 10000 load repetitions followed by another 20000 load repetitions after a rest period of 1 hour (all at 850 kPa) (site compaction usually stops at 15h00 and section opened to traffic at 17h00).
- Sample 2: 6 hours after compaction – both cycles
- Sample 3: 12 hours after compaction – both cycles
- Sample 4: 1 day (18 hours) after compaction – both cycles
- Sample 5: 2 days after compaction – both cycles
- Sample 6: 5 days after compaction – both cycles
- Sample 7: 10 days after compaction – both cycles
- Sample 8: 15 days after compaction – both cycles
- Sample 9: 20 days after compaction – both cycles
- Sample 10: 30 days after compaction – both cycles

At least 12 samples of each stabilization process were compacted to cover for all eventualities. Unfortunately time and space does not allow the discussion of all these results and only the results after 48 hours of curing are reflected for the HVS site. The K-mould results of recycled crushed stone base on a taxiway of the Johannesburg International Airport reflect the laboratory design results of samples prepared by another laboratory after a two weeks curing period.

3. K-MOULD TEST PROCEDURE FOLLOWED

Normally the dynamic testing with the K-mould is done for at least 30000 load repetitions to ensure that the base material response is recorded and that the resistance to rutting can be recorded fairly accurately. The K-mould test is normally performed at stress levels that are expected in the actual material in the pavement structure under traffic.

The first 10000 load cycles are normally performed in the following sequence and stress levels:

- 0 –1005 cycles 200 kPa
- 1005-2005 cycles 300 kPa
- 2005–3005 cycles 400 kPa
- 3005-4005 cycles 500 kPa
- 4005-6005 cycles 600 kPa
- 6005-8005 cycles 700 kPa
- 8005-10005 cycles 800 kPa

After this the sample is allowed to recover for at least one hour before the remaining 20000 load repetitions are applied at 800 kPa (i.e. the maximum tyre pressure used on the HVS tests). In the case of the recycled crushed stone base the applied stresses started at 1000 kPa and ended up at 2000 kPa for the last 20000 load repetitions. The full load in each load repetition is applied with a haversine curve of 0.2-second duration (i.e. equal approximately 2.74 km/h) followed by a rest period of 0.2 second to allow the material to recover from the load application as traffic loading is not continuous either. Data windows of 1.2 seconds covering at least three load cycles are normally recorded for the first load cycle as well every multiple of 500 load cycles thereafter at a sampling density of about 800 per second. The information captured in each data window is then used to determine the E_{sec} value of the material at different stress levels as well as the material rut resistance characteristics.

Graphs showing the predicted permanent deformation for a 250 mm thick layer as used on the HVS site at Heidelberg, as well as the E-values, calculated from the maximum and minimum values of the stresses and strains in each of these data files are included. The predicted number of 80 kN axle loads required to give a rut depth of 10 or 5 mm in the 250 mm thick layer at the maximum stress level are normally calculated for three ranges of data in each case but are not discussed in this paper.

Figures 1 and 2 show that the strength and deformation characteristics of the three treated materials are very similar but much better than that of the untreated material at the same

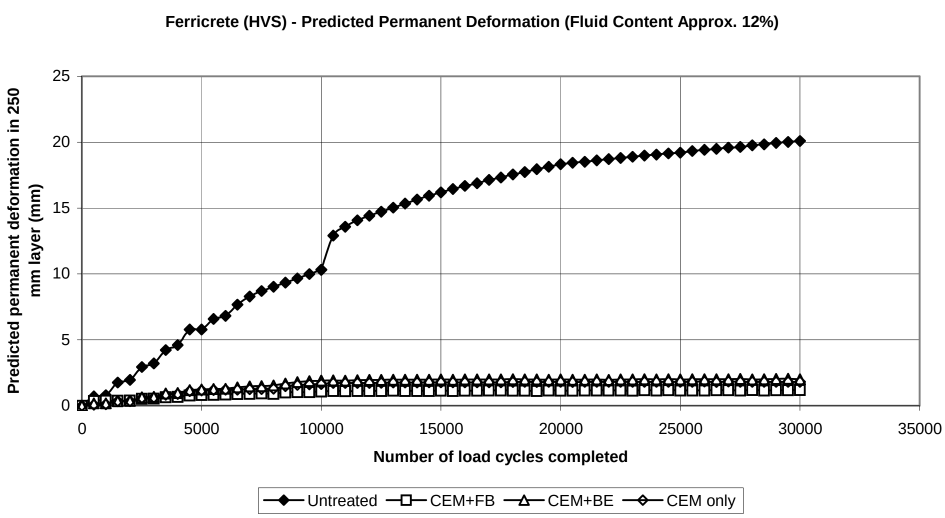

Figure 1: Permanent deformation against load repetitions in a 250 mm layer for untreated layer, or layer treated with 2 % cement, 2% cement plus 1.8% foam bitumen, or 2% cement plus 3% bitumen emulsion (i.e. 1.8 % residual bitumen) at a fluid content of 12%

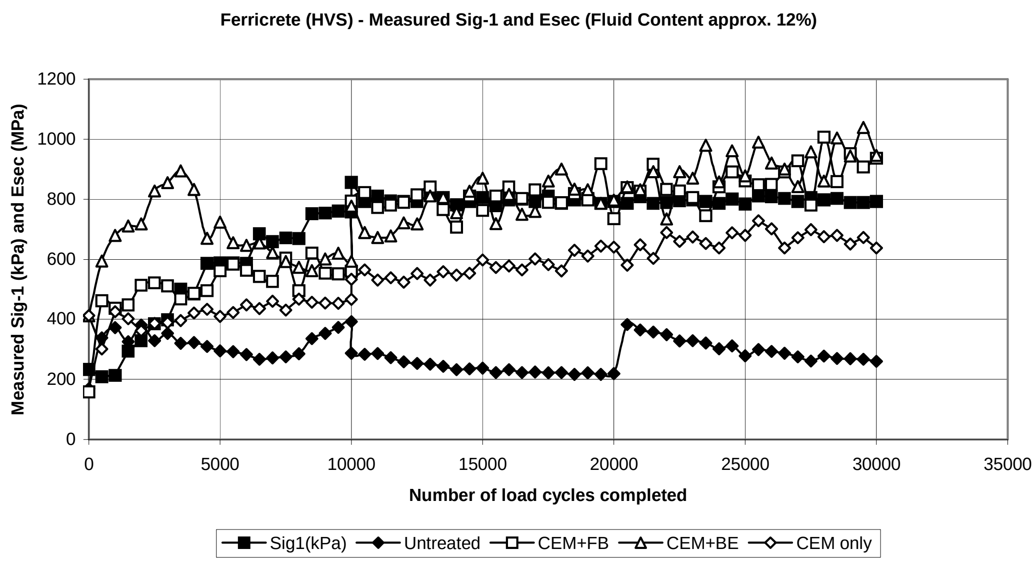

Figure 2: σ_1 and E_{sec} against load repetitions for untreated layer, or layer treated treated with 2 % cement, 2% cement plus 1.8% foam bitumen, or 2% cement plus 3% bitumen emulsion (i.e. 1.8 % residual bitumen) at a fluid content of 12%

moisture content. A possible reason why the E_{sec} value of the material treated with cement only is slightly lower than the other two treatments is probably partly due to a higher moisture content as the 1.8 per cent residual bituminous binder makes out part of the 12 per cent fluid content in the other materials, while they are not in a fluid condition at the time of testing anymore. A similar response was found when comparing the K-mould results of a recycled stabilized crushed stone that was stabilized with similar combinations for a taxiway on the Johannesburg International Airport (see Figures 3 and 4).

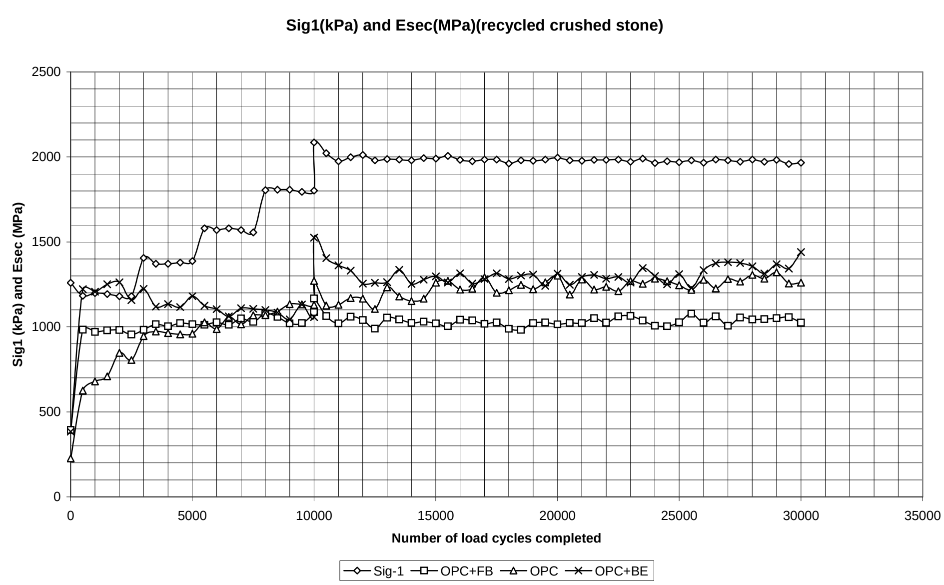

Figure 3: σ_1 and E_{sec} against completed load cycles for crushed stone recycled with 2% cement only, or 2% cement plus 1.8% foamed bitumen or 3% bitumen emulsion

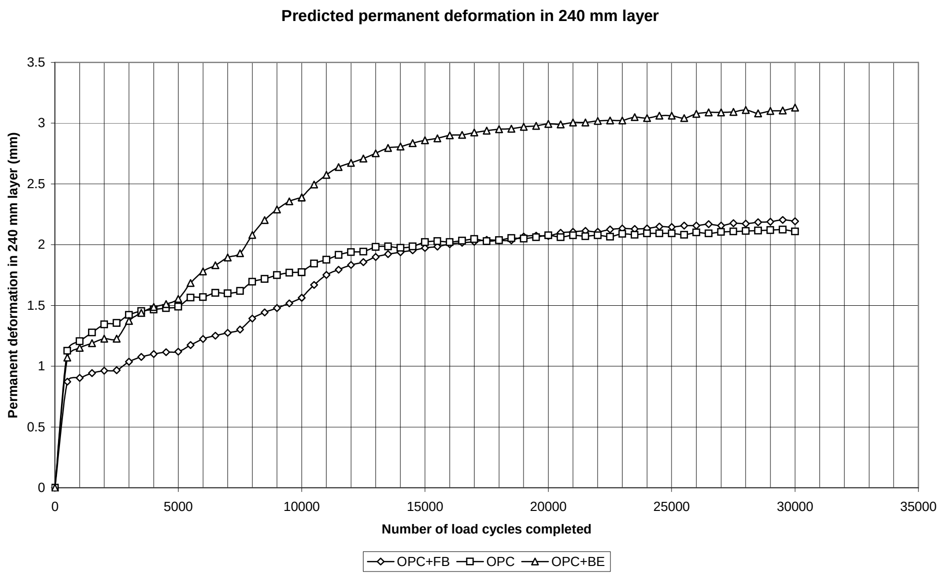

Figure 4: Predicted permanent deformation against completed load cycles for 240 mm crushed stone layer recycled with 2% cement only, or 2% cement plus 1.8% foamed bitumen or 3% bitumen emulsion

It could be argued that these results reflect the strength of the materials in compression, and because cement is generally considered weak in tension that the tensile strength of these stabilized materials may be quite different.

However, in an effort to determine the contribution of bituminous and cement components separately in these stabilized materials Hodgkinson (2003) tested a particular base material, using 1.5 per cent of different types of cement (or filler), and different percentages of 60 % anionic stable grade bitumen emulsion and foamed 80/100 pen bitumen (percentages in tables reflect residual bituminous binder content). Base material from one construction site was treated with different strengths cement (i.e. sample range 1 was CEM I 42.5, sample ranges 2 to 4 were CEM II AV 32.5, CEM II BV 32.5 and CEM II AL 32.5 respectively), and different percentages of residual bituminous binder using foamed bitumen and bitumen emulsion, in order to get a range of differently treated samples. In an effort to isolate the effect of the cement component the cement was replaced by granulated blast furnace slag in range 5 and rock flour in range 6 or left neat in range 7. Two samples of each combination were prepared. After curing the samples were tested in the unsoaked and in the soaked condition (soaked for 24 hours). The percentage moisture in the samples were unfortunately not determined after determining the ITSs. The ITS results were then set up in a matrix with different cement strengths, percentage of bitumen emulsion or foamed bitumen (i.e. residual binder) and analyzed by multiple regression. These results are reflected in Tables 1(a) and 1(b) for Bitumen Emulsion in the un-soaked and soaked conditions respectively, and in Table 2 for Foamed Bitumen in both the un-soaked and soaked condition respectively.

Table 1: Combinations of ETB samples and their predicted and measured ITS values as well as percentage contribution of each component of the sample composition to the predicted ITS

(a) Un-soaked bitumen emulsion treated samples

Dry	%voids	BD(kg/m3)	cem strength	%Emul	ITSdry	%BD	%cem	%Emul		Pred(-voids)	ITSdry	%voids	%BD	%cem	%Emul		Pred(+voids)
1	13.6	2130	42.5	1.2	476	44.1	42.7	13.2	100.00	444	476	-51.2	101.7	37.7	11.8	100.00	479
1	13.7	2137	42.5	1.8	502	41.4	40.0	18.5	100.00	474	502	-48.7	96.4	35.6	16.7	100.00	508
1	13.8	2124	42.5	2.4	574	38.9	37.8	23.3	100.00	502	574	-46.9	91.6	34.1	21.3	100.00	531
1	14.8	2083	42.5	3	598	36.3	36.0	27.8	100.00	528	598	-50.3	89.7	34.0	26.5	100.00	532
					Average	40.2	39.1	20.7	100.00		Average	-49.3	94.9	35.4	19.1	100.00	
2	15.8	2118	32.5	1.2	250	48.9	36.4	14.7	100.00	398	250	-72.3	122.9	35.1	14.3	100.00	394
2	15.3	2098	32.5	1.8	338	45.3	34.1	20.6	100.00	426	338	-64.7	112.5	32.4	19.8	100.00	427
2	15.3	2085	32.5	2.4	441	42.2	32.0	25.8	100.00	454	441	-61.1	105.5	30.6	25.0	100.00	452
2	14.3	2065	32.5	3	470	39.4	30.1	30.4	100.00	481	470	-52.3	95.7	28.0	28.6	100.00	494
3	12.9	2145	32.5	1.2	486	49.2	36.2	14.6	100.00	401	486	-51.4	108.4	30.5	12.5	100.00	453
3	13.8	2128	32.5	1.8	518	45.6	33.9	20.5	100.00	428	518	-54.0	105.7	30.0	18.4	100.00	461
3	15.9	2073	32.5	2.4	514	42.1	32.0	25.9	100.00	453	514	-65.4	108.2	31.5	25.7	100.00	439
3	13.3	2101	32.5	3	614	39.8	29.9	30.2	100.00	485	614	-46.1	92.4	26.6	27.1	100.00	520
4	16.9	2094	32.5	1.2	312	48.6	36.6	14.8	100.00	396	312	-82.7	129.9	37.5	15.3	100.00	369
4	19.1	1997	32.5	1.8	333	44.1	34.8	21.1	100.00	416	333	-102.8	136.3	41.2	25.2	100.00	335
4	20.5	1967	32.5	2.4	342	40.8	32.8	26.5	100.00	443	342	-111.7	135.9	41.7	34.1	100.00	331
4	16.2	1942	32.5	3	357	38.0	30.9	31.2	100.00	470	357	-67.8	103.0	32.0	32.7	100.00	432
					Average	43.7	33.3	23.0	100.00		Average	-69.3	113.0	33.1	23.2	100.00	
5	14.2	2175	10*	1.2	335	65.9	14.7	19.3	100.00	303	335	-75.3	146.2	12.5	16.6	100.00	341
5	16.7	2095	10*	1.8	349	59.2	13.7	27.0	100.00	325	349	-98.7	157.1	13.9	27.7	100.00	305
5	13.9	2152	10*	2.4	349	55.0	12.4	32.6	100.00	360	349	-63.2	124.0	10.7	28.4	100.00	397
5	12.8	2164	10*	3	429	51.0	11.4	37.6	100.00	390	429	-51.6	110.6	9.5	31.5	100.00	448
6	17.4	2094	10*	1.2	318	65.1	15.1	19.8	100.00	296	318	-118.8	181.4	16.1	21.4	100.00	264
6	17.8	2072	10*	1.8	352	59.0	13.8	27.2	100.00	323	352	-114.6	169.3	15.2	30.2	100.00	280
6	15.7	2119	10*	2.4	321	54.6	12.5	32.9	100.00	357	321	-79.3	135.8	11.9	31.6	100.00	357
6	15.6	2101	10*	3	309	50.2	11.6	38.1	100.00	384	309	-73.5	125.6	11.1	36.8	100.00	383
7	17.4	2104	5*	1.2	300	70.5	8.1	21.4	100.00	274	300	-128.0	196.4	8.7	23.0	100.00	245
7	16.6	2109	5*	1.8	303	63.7	7.3	28.9	100.00	304	303	-103.6	167.0	7.4	29.3	100.00	289
7	14.5	2144	5*	2.4	354	58.5	6.6	34.8	100.00	336	354	-72.1	135.1	5.9	31.1	100.00	363
7	15.8	2093	5*	3	344	53.3	6.2	40.6	100.00	361	344	-80.0	134.5	6.0	39.6	100.00	356
					Average	58.8	11.1	30.0	100.00		Average	-88.2	148.6	10.7	28.9	100.00	

* The low strengths of 10 and 5 reflect the addition of granulated blast furnace slag rock flour with a “strength” of “10 MPa” (estimate) and the neat material with a “strength” of 5 MPa (estimate)

(b) Soaked bitumen emulsion treated samples

Wet	%voids	BD(kg/m3)	cem strength	%Emul	ITSdry	%BD	%cem	%Emul		Pred(-voids)	ITSdry	%voids	%BD	%cem	%Emul		Pred(+voids)
1	13.6	2130	42.5	1.2	464	37.5	49.7	12.8	100.00	461	464	-4.9	43.1	49.2	12.6	100.00	464
1	13.7	2137	42.5	1.8	550	35.4	46.7	18.0	100.00	491	550	-4.6	40.6	46.2	17.8	100.00	494
1	13.8	2124	42.5	2.4	487	33.2	44.1	22.6	100.00	519	487	-4.4	38.2	43.7	22.4	100.00	522
1	14.8	2083	42.5	3	502	31.0	42.0	26.9	100.00	545	502	-4.5	35.9	41.8	26.8	100.00	546
					Average	34.3	45.6	20.1	100.00		Average	-4.6	39.4	45.2	19.9	100.00	
2	15.8	2118	32.5	1.2	410	42.4	43.2	14.5	100.00	406	410	-6.5	49.0	43.0	14.4	100.00	406
2	15.3	2098	32.5	1.8	442	39.3	40.4	20.3	100.00	434	442	-5.9	45.4	40.2	20.3	100.00	434
2	15.3	2085	32.5	2.4	410	36.6	37.9	25.4	100.00	462	410	-5.5	42.4	37.8	25.4	100.00	462
2	14.3	2065	32.5	3	566	34.2	35.8	30.0	100.00	490	566	-4.9	39.5	35.5	29.8	100.00	491
3	12.9	2145	32.5	1.2	421	42.7	42.9	14.4	100.00	408	421	-5.2	48.8	42.3	14.2	100.00	413
3	13.8	2128	32.5	1.8	445	39.6	40.2	20.2	100.00	436	445	-5.2	45.5	39.7	20.0	100.00	439
3	15.9	2073	32.5	2.4	467	36.5	38.0	25.5	100.00	461	467	-5.8	42.3	38.0	25.5	100.00	460
3	13.3	2101	32.5	3	436	34.6	35.6	29.8	100.00	493	436	-4.5	39.8	35.2	29.5	100.00	496
4	16.9	2094	32.5	1.2	392	42.1	43.4	14.5	100.00	404	392	-7.0	49.0	43.5	14.6	100.00	402
4	19.1	1997	32.5	1.8	422	38.1	41.2	20.7	100.00	426	422	-7.6	44.9	41.8	21.0	100.00	418
4	20.5	1967	32.5	2.4	453	35.3	38.7	26.0	100.00	453	453	-7.7	41.8	39.5	26.5	100.00	442
4	16.2	1942	32.5	3	530	32.9	36.5	30.6	100.00	480	530	-5.7	38.3	36.6	30.7	100.00	476
					Average	37.9	39.5	22.7	100.00		Average	-6.0	43.9	39.4	22.7	100.00	
5	14.2	2175	10*	1.2	253	61.1	18.6	20.3	100.00	289	253	-8.1	69.8	18.3	20.0	100.00	293
5	16.7	2095	10*	1.8	214	54.5	17.3	28.2	100.00	312	214	-9.0	63.4	17.3	28.3	100.00	310
5	13.9	2152	10*	2.4	344	50.5	15.6	33.9	100.00	346	344	-6.6	57.8	15.4	33.5	100.00	350
5	12.8	2164	10*	3	444	46.7	14.3	39.0	100.00	377	444	-5.6	53.2	14.1	38.3	100.00	382
6	17.4	2094	10*	1.2	278	60.2	19.1	20.8	100.00	283	278	-10.4	70.3	19.2	20.9	100.00	280
6	17.8	2072	10*	1.8	309	54.2	17.4	28.4	100.00	310	309	-9.7	63.5	17.5	28.7	100.00	306
6	15.7	2119	10*	2.4	325	50.1	15.7	34.2	100.00	344	325	-7.6	57.9	15.6	34.1	100.00	344
6	15.6	2101	10*	3	331	45.9	14.5	39.6	100.00	371	331	-7.0	53.1	14.5	39.4	100.00	371
7	17.4	2104	5*	1.2	299	66.6	10.5	22.9	100.00	257	299	-11.4	77.8	10.6	23.1	100.00	254
7	16.6	2109	5*	1.8	326	59.8	9.4	30.8	100.00	286	326	-9.7	69.5	9.4	30.8	100.00	285
7	14.5	2144	5*	2.4	369	54.7	8.5	36.9	100.00	319	369	-7.5	62.7	8.4	36.5	100.00	321
7	15.8	2093	5*	3	318	49.4	7.8	42.7	100.00	344	318	-7.7	57.2	7.8	42.6	100.00	343
					Average	54.5	14.1	31.5	100.00		Average	-8.4	63.0	14.0	31.4	100.00	

Table 2: Combinations of FB samples and their predicted and measured ITS values as well as percentage contribution of each component of the sample composition to the predicted ITS

Dry		BD(kg/m3)	cem strength	%FB	ITSdry	%BD	%cem	%FB		Pred(-voids)	ITSdry
1		2162	42.5	1	620	14.7	78.6	6.7	100.00	694	620
1		2134	42.5	2	647	13.6	73.8	12.6	100.00	739	647
1		2108	42.5	3	829	12.7	69.6	17.8	100.00	784	829
1		2074	42.5	4	755	11.8	65.8	22.4	100.00	829	755
					Average	13.2	71.9	14.9	100.00		
2		2164	32.5	1	553	18.0	73.8	8.2	100.00	566	553
2		2126	32.5	2	725	16.4	68.4	15.2	100.00	610	725
2		2109	32.5	3	760	15.2	63.6	21.2	100.00	656	760
2		2080	32.5	4	794	14.0	59.5	26.5	100.00	701	794
3		2187	32.5	1	396	18.2	73.6	8.2	100.00	567	396
3		2146	32.5	2	572	16.5	68.3	15.2	100.00	611	572
3		2107	32.5	3	670	15.1	63.6	21.3	100.00	656	670
3		2080	32.5	4	704	14.0	59.5	26.5	100.00	701	704
4		2161	32.5	1	507	18.0	73.8	8.2	100.00	566	507
4		2126	32.5	2	646	16.4	68.4	15.2	100.00	610	646
4		2089	32.5	3	794	15.0	63.7	21.3	100.00	655	794
4		2074	32.5	4	749	13.9	59.5	26.5	100.00	701	749
					Average	15.9	66.3	17.8	100.00		
5		2148	10*	1	260	36.7	46.5	16.8	100.00	276	260
5		2107	10*	2	333	31.0	40.0	29.0	100.00	321	333
5		2096	10*	3	494	27.0	35.0	38.0	100.00	367	494
5		2064	10*	4	433	23.6	31.2	45.2	100.00	412	433
6		2107	10*	1	370	36.2	46.8	16.9	100.00	274	370
6		2080	10*	2	240	30.7	40.2	29.1	100.00	319	240
6		2066	10*	3	328	26.7	35.2	38.2	100.00	365	328
6		2036	10*	4	286	23.4	31.3	45.3	100.00	410	286
7		2120	5*	1	313	47.5	30.5	22.1	100.00	211	313
7		2085	5*	2	304	38.5	25.1	36.4	100.00	255	304
7		2060	5*	3	270	32.3	21.3	46.4	100.00	301	270
7		1924	5*	4	137	26.6	18.8	54.5	100.00	341	137
					Average	31.7	33.5	34.8	100.00		
Wet		BD(kg/m3)	cem strength	%FB	ITSdry	%BD	%cem	%FB		Pred(-voids)	ITSdry
1		2162	42.5	1	473	-18.4	107.0	11.4	100.00	456	473
1		2134	42.5	2	478	-16.3	95.9	20.4	100.00	509	478
1		2108	42.5	3	534	-14.6	86.8	27.7	100.00	562	534
1		2074	42.5	4	509	-13.1	79.3	33.8	100.00	615	509
					Average	-15.6	92.3	23.3	100.00		
2		2164	32.5	1	342	-24.6	109.4	15.2	100.00	341	342
2		2126	32.5	2	388	-20.9	94.6	26.3	100.00	395	388
2		2109	32.5	3	511	-18.3	83.5	34.8	100.00	447	511
2		2080	32.5	4	668	-16.1	74.6	41.5	100.00	500	668
3		2187	32.5	1	271	-24.9	109.7	15.3	100.00	340	271
3		2146	32.5	2	353	-21.1	94.8	26.4	100.00	394	353
3		2107	32.5	3	305	-18.3	83.5	34.8	100.00	447	305
3		2080	32.5	4	523	-16.1	74.6	41.5	100.00	500	523
4		2161	32.5	1	338	-24.6	109.4	15.2	100.00	341	338
4		2126	32.5	2	429	-20.9	94.6	26.3	100.00	395	429
4		2089	32.5	3	501	-18.1	83.3	34.8	100.00	448	501
4		2074	32.5	4	623	-16.1	74.6	41.5	100.00	500	623
					Average	-20.0	90.5	29.5	100.00		
5		2148	10*	1	105	-100.0	137.7	62.3	100.00	83	105
5		2107	10*	2	170	-59.7	83.9	75.8	100.00	137	170
5		2096	10*	3	250	-43.0	60.7	82.3	100.00	189	250
5		2064	10*	4	254	-33.0	47.4	85.7	100.00	242	254
6		2107	10*	1	78	-96.2	135.1	61.1	100.00	85	78
6		2080	10*	2	114	-58.5	83.3	75.3	100.00	138	114
6		2066	10*	3	177	-42.1	60.3	81.8	100.00	190	177
6		2036	10*	4	170	-32.5	47.2	85.3	100.00	244	170
7		2120	5*	1	80	-304.0	212.2	191.8	100.00	27	80
7		2085	5*	2	100	-100.7	71.5	129.2	100.00	80	100
7		2060	5*	3	104	-60.0	43.1	116.9	100.00	133	104
7		1924	5*	4	77	-39.2	30.2	109.1	100.00	190	77
					Average	-80.7	84.4	96.4	100.00		

Table 3 – Summary of the average contributions of the different components

(a) Emulsion

Dry	%BD	%cem	%Emul	r^2-value	%voids	%BD	%cem	%Emul	r^2-value
42.5	40.2	39.1	20.7	0.54	-49.3	94.9	35.4	19.1	0.69
32.5	43.7	33.3	23.0	0.54	-69.3	113.0	33.1	23.2	0.69
Fillers	58.8	11.1	30.0	0.54	-88.2	148.6	10.7	28.9	0.69
Wet	%BD	%cem	%Emul	r^2-value	%voids	%BD	%cem	%Emul	r^2-value
42.5	34.3	45.6	20.1	0.79	-4.6	39.4	45.2	19.9	0.80
32.5	37.9	39.5	22.7	0.79	-6.0	43.9	39.4	22.7	0.80
Fillers	54.5	14.1	31.5	0.79	-8.4	63.0	14.0	31.4	0.80

(b) Foamed bitumen

Dry	%BD	%cem	%FB	r^2-value
42.5	13.2	71.9	14.9	0.82
32.5	15.9	66.3	17.8	0.82
Fillers	31.7	33.5	34.8	0.82
Wet	%BD	%cem	%FB	r^2-value
42.5	-15.6	92.3	23.3	0.87
32.5	-20.0	90.5	29.5	0.87
Fillers	-80.7	84.4	96.4	0.87

4. CONCLUSIONS

The following can be concluded:

- The K-mould results show that the long-term performance of a material can only be established with a substantial number of load repetitions (i.e. in the order 30000 load cycles). These load repetitions should be carried at traffic related stress levels.
- Figures 1 to 4 show that the strength and deformation characteristics of the three treated materials are very similar but much better than that of the untreated material. The cement in all three of the treatment techniques is probably responsible for the bulk of the initial strength in the material (provided the material is well compacted). This would mean that one could also consider using cement on its own in deep in situ recycling projects which have to be opened to traffic fairly rapidly provided no unwanted cementing reactions are observed when a particular cement is used on its own with the material. Note that different cements have different reactions due to differences in their formulation and that the formulation of cements may change with time.

5. RECOMMENDATIONS

In order to optimize the design and minimize the possibility of unwanted cementing reactions occurring on site during construction it is essential that cement-treated materials be evaluated in the laboratory under similar time constraints, moisture and temperature conditions as expected on site.

Use the K-mould test to determine the time interval required for curing of the cement-treated layer, before opening to traffic. The minimum period does not necessarily have to be 7 days or more.

The K-mould should be incorporated in stabilization manuals to calibrate the DCP data. The effect of temperature on stabilization must also be investigated. Use the sand replacement and nuclear density tests to monitor volume changes, and the DCP to measure the in situ strength development. The latter can then be confirmed in the laboratory with K–mould time study tests.

The results above indicate that the behaviour of soils with stabilizing agents can be modeled to save costs. Correlations between the UCS and ITS and the K-Mould should be established for general use. If the brush test or the erosion test is incorporated the long-term durability of the stabilized layer could also be assessed (wet, dry durability tests).

REFERENCES

Semmelink CJ, Liebenberg JC, Botha PB. 2001. K-mould evaluation of crushed stone layer from an airport taxilane treated with cement, cement and foamed bitumen or cement and bitumen emulsion. 1st International symposium on subgrade stabilisation in situ pavement recycling using cement. Salamanca (Spain) 1-4 Oct 2001

Semmelink C.J., Botha P.B. 2001. Strength of foamed bitumen-cement and emulsion cement stabilised ferricrete base material from HVS test site at Heidelberg as measured with K-mould. Technical Report TR2001/14, Transportek, CSIR, Pretoria, South Africa.

Semmelink C. J., Botha P. B. 2001. Strength of cement stabilized ferricrete material from HVS test site as measured with K-mould. Contract Report CR-2001/24, Transportek, CSIR, Pretora, South Africa.

Hodgkinson A. L. 2003. Investigation into the role of cementitious binder when recycling with foamed bitumen or bitumen emulsion. M.Sc. (Applied Sciences)(Transport Technology) Thesis, Faculty of Engineering, University of Pretoria, South Africa.