IN-SITU RECYCLING OF A CEMENT TREATED BASE COURSE USING FOAMED BITUMEN

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ABSTRACT

In-situ recycling of road pavement base materials using one-pass recycling machines is becoming an important pavement rehabilitation procedure for heavily trafficked urban roads. The reasons for this are :

- Reduced construction time with a consequent reduction in the amount of disruption to traffic.
- Space constraints.
- Urban road surfaces generally have level constraints which reduce the number of rehabilitation options which can be employed.
- Cost effectiveness.
- Improved quality of construction compared with conventional reconstruction techniques.

5th Avenue in Grassy Park, Cape Town is an urban road which carries between 3000 and 4000 vehicles per day in each direction. It was rehabilitated at the beginning of 1999 using the in-situ recycling process. During the recycling process the existing cement treated base was milled up and treated with foamed bitumen and ordinary Portland cement. The recycled material was then compacted and surfaced with a new continuously graded asphalt wearing course.

This paper discusses the following aspects pertaining to this project :

- The in-situ recycling process.
- Achieved production rates.
- Properties of the recycled material.
- Construction costs.
- Performance of the recycled pavement to date.

This project showed that in-situ recycling can be done cost effectively and that the process provides a high quality finished product. It is foreseen that this procedure will become more popular in future as the demand for urban road rehabilitation increases and as road maintenance budgets remain under pressure.

1. INTRODUCTION

1.1 Traffic loading and pavement structure of the existing road

5th Avenue is a 4,1 km by 9,4 m wide, two lane undivided road. It carries between 3000 to 4000 vehicles per day in each direction. Approximately 5 % of the vehicles are heavy vehicles which include buses, delivery vehicles, refuse collection trucks and a few articulated heavy vehicles. The estimated traffic loading which the pavement will carry during the rehabilitation analysis period of fifteen years is in the ES3 class (TRH4 classification), i.e. between one and three million E80 axle loads.

The existing pavement structure before recycling was as follows :

- Surfacing — 25 mm asphalt wearing course
- Upper base — 100 mm cement treated crushed stone material
- Lower base — 100 mm cement treated crushed stone material
- Sub-base — 200 mm natural gravel (Ferricrete)l
- Roadbed and SSG — Uniformly graded Cape Flat's sand

5th Avenue has carried approximately two million E80 axle loads since it was first constructed some thirty years ago.

1.2 Condition of 5th Avenue prior to rehabilitation

The rehabilitation investigation revealed that the condition of the pavement prior to rehabilitation was very poor. The predominant distress observed was block cracking varying between degrees 4 and 5 (TRH6 classification). This cracking was present over the entire length of the road. The spacing between the cracks varied between 100 and 1500 mm. As was to be expected little to no permanent deformation was observed but in some areas the surfacing and upper base had disintegrated to such an extent as to constitute pothole failures. The riding quality of the road was very poor over the entire length of the road.

A design feature of 5th Avenue was that the outer 1,0 m on either side of the road was less cemented than the inner 7,4 m. This was clearly reflected in the crack patterns in the road surface and the as-built information confirmed that only the two 3,7 m traffic lanes were stabilized.

1.3 Rehabilitation options

Since 5th Avenue is a heavily trafficked urban road it posed certain constraints on the rehabilitation options which could be employed. The main constraint was that the full width of the road had to be open during the two daily peak traffic hours. Another important aspect was that the construction had to be completed in as short a time as possible in order to reduce the disturbance and inconvenience to the local residents and businesses whose concerns were voiced at the prior public participation meeting. Two rehabilitation options were considered to overcome the above-mentioned time constraints. These were a levelling course / stress absorbing layer of continuously graded asphalt plus a bitumen-rubber asphalt overlay or in-situ recycling of the base followed by a new surfacing. Although the levelling course plus overlay option could have been executed in a slightly shorter time the employer was concerned that some of the cracks could eventually reflect through the new asphalt layers. Therefore the cold in-situ recycling option was chosen. The estimated cost of both the rehabilitation options was similar, namely R 2,4 million including VAT.

The technical aspects of the chosen cold in-situ recycling are discussed in the following paragraphs.

2. SCOPE OF THE WORK

The work carried out for this project comprised the following :

- Trials to establish the required bitumen and cement content and to check the resulting gradings.
- In-situ recycling of the CTB material to a depth of 200 mm (1,5 % foamed bitumen and 1,0 % ordinary Portland cement (OPC) by mass were mixed into the recycled CTB material).
- Restoring the camber of the road to ±3,0 %.
- Paving a 40 mm asphalt wearing course.
- Provision of new road markings and signage.

3. TRAFFIC ACCOMMODATION

Construction work was originally permitted to take place between 09h00 and 16h00 but as the traffic problems were less severe than anticipated the working period was increased by an hour. Due to the urban layout of Grassy Park it was possible to divert the traffic in both directions from 5th Avenue onto parallel roads. Thus 5th Avenue was closed to traffic in both directions for the ±500 m sections on which construction was allowed between 08h30 and 16h30. Access to the residences and businesses within the closed sections was granted at all times and no complaints were received in this regard.

4. DESCRIPTION OF THE RECYCLING EQUIPMENT AND PROCESS

The equipment necessary to undertake the in-situ recycling process consists of a water bowser, a bitumen tanker and a recycling machine. These are mechanically connected with two steel towbars to form a “recycling train”. The train is powered by the recycling machine, which pushes the train from the rear end. On this project a Wirtgen WR2500 recycling machine was used. The functional connection is established by connecting two supply pipes from the recycling machine to the water bowser and bitumen tanker. The WR2500 is equipped with a 2,5 m wide milling drum furnished with 250 pedestals, each fitted with a tooth holder and a tungsten carbide milling tooth. The milling drum is fitted inside a mixing chamber which is fitted with two sets of nozzles. The one set of nozzles is used to add the water from the water bowser to the milled material in order to increase the moisture content to approximately 80% of optimum moisture content. The other set of nozzles is used to produce and inject the foamed bitumen into the milled material. (The first set of nozzles can also be used to inject bitumen emulsion or cement slurry into the material if required).

The rotation of the milling drum is such that it cuts the pavement layer from the bottom upwards and thereby breaks the material out effectively. The mixing process in the chamber allows for effective material break down since the loosened material is flung against a breaker bar which is fitted in the front end of the milling chamber. In addition to being crushed against the breaker bar further material break down is achieved by the vigorous mixing action inside the chamber. Besides achieving proper material break down the mixing action further allows for effectively mixing the stabilizing agents uniformly into the recycled material, in this case foamed bitumen and OPC. The forward speed of the machine and the speed of rotation of the milling drum can be varied but the production rate of the recycling train is ultimately dependant on the hardness and thickness of the material being milled.

The process described above allows for the cutting, breaking, mixing and placing of the recycled material in a single pass. The evenly mixed material with the correct amount of moisture can then be compacted immediately by rollers following closely behind the recycling train. The surplus material resulting from bulking of the milled material and from lowering of the surface by 40 mm to allow for the new asphalt surfacing layer was carted to stockpile for re-use elsewhere. This surplus material contained the bitumen and cement additives; unfortunately the one-pass recycling system does not permit the removal of the surplus milled material before stabilizing agents are added.

The following steps were involved in the daily recycling process :

- Lower manholes and locate services.
- Pack out and spread the cement powder in order to achieve a 1,0 % by mass cement content.
- Recycle the existing CTB layers, adding compaction water and 1,5 % by mass foamed bitumen.
- Initial compaction of the material directly behind the recycling train using 12 ton vibratory rollers. The rolling pattern comprised 6 passes on low frequency and 4 passes on high frequency. (Damage to nearby houses and garden walls were closely monitored and only two houses were affected.)
- Cut the recycled base material to the correct levels. The camber was increased from 2 % to 3 % to improve the road surface drainage and to use up some of the surplus milled material.
- Cart away and stockpile the surplus milled material.
- Complete the compaction of the base layer.
- Slush the base course in order to obtain an adequate surface finish.
- Apply approximately 1,0 litre/m^2 of 30 % bitumen emulsion on the surface and roll it in with a pneumatic roller in order to bind the fine material together. This provides the surface with some resistance against tyre abrasion.
- Clean the side drains and sidewalks.
- Open the road to traffic for the afternoon peak traffic period.
- Subsequently broom, tack and surface the base with new asphalt wearing course as soon as possible after it has dried, preferably within 48 hours. On this project some sections were left open for more than a week before surfacing and a levelling course was required to repair areas of damaged base course.

5. THE TRIAL SECTION

5.1 Trial section

The purpose of the trial section was to determine whether 1,5 % bitumen would be sufficient to adequately stabilize the material as well as to determine whether it would reduce the permeability of the material sufficiently. It was also important for the contractor to determine what production rate could be achieved on the CTB material under urban conditions. This information was important for programming purposes.

The trial section was 150 m long across the full width of both lanes. One lane was recycled using 1,5% net bitumen and on the other lane 2,0 % net bitumen was used. In both cases 1,0 % OPC was also added as a stabilizing agent. During the trial section it was observed that the existing CTB material bulked significantly more than what was originally estimated and a larger quantity of surplus material than anticipated was produced. It was estimated at the time the contract document was compiled that the bulking factor would be 1,05 but from the trial section it was determined that the bulking factor was closer to 1,15. This resulted in a significant surplus of additional material which had to be carted away. During the trial it became apparent that the production rate of 1000 m^3 which the contractor stated that he had envisaged at tender stage was not going to be achieved. This was due both to the hardness of the CTB material, the disruption caused by having to remove the surplus material and by the fact that the milling and compaction operations were difficult to synchronize.

5.2 Material test results obtained from the trial section

In order to assess the quality of the recycled material using foamed bitumen in recycled CTB material the tests listed in Table 1 were conducted on the recycled material during the trial. From the material test results given in Table 1 it can be seen that the increase from 1,5 % and 2,0 %

bitumen resulted in a drop in the measured values of the UCS, ITS, CBR and the permeability of the compacted recycled material.

Table 1 : Material properties

Material property	**1,5 % bitumen**		**2,0 % bitumen**	
	Average	**Standard deviation**	**Average**	**Standard deviation**
Bitumen content (%)	1,6	-	2,1	-
In-situ density (Troxler) (kg/m^3)	2044,8	46,72	2054,5	35,31
In-situ density (Sand replacement) (kg/m^3)	2068,0	65,11	1981,5	25,68
Mod AASHTO density (kg/m^3)	1979,3	35,34	1949,3	34,28
Relative compaction (Troxler) (%)	103,3	-	105,4	-
Field moisture content during construction (%)	6,2	1,10	5,8	1,18
Optimum moisture content (%)	8,3	1,39	8,7	1,25
Relative moisture content	0,75	-	0,68	-
Unconfined compression strength (UCS) (kPa)	1895,0	562,17	1715,0	339,9
Indirect tensile strength (ITS) (kPa)	107,0	49,70	88,5	11,21
California bearing ratio (CBR) at 100 % Mod	163,5	79,48	93,5	23,70
Marvil permeability (l/hr)	0,8	0,56	0,5	0,37

The drop in the CBR with increase in binder content is to be expected since the bitumen provides a lubricating effect on the material which consequently reduces the CBR value. The small difference in the Marvil permeability of the material is of little significance since a measured permeability of lower than 1,0 l/hr indicates that the material is already sufficiently impermeable. It is however surprising that a binder content as low as 1,5 % can so effectively reduce the permeability of a material which has a void ratio of 21,7 % (maximum theoretical density = 2610 kg/m^3). It is assumed that priming the surface with a diluted bitumen emulsion during the final slushing operation was the main reason for the reduction in the penetration of water from the surface of the layer. However, the addition of small amounts of bitumen to reduce a compacted material's susceptibility to moisture ingress is an established construction practice.

The high void ratio is a result of the grading of the material which is both deficient in coarse material and filler (-0,075 mm fraction), see Figure 1. The achieved grading is what one would expect when milling up a cemented, crushed stone material. The milling drum can effectively break the material down but cannot produce enough filler if the original material has been strongly stabilized with cement. In this case the compressive strength of the cores taken from the CTB material varied between 5 and 25 MPa with an average of 14,4 MPa. The theory of in-situ recycling is that the grading of the milled material can be controlled by reducing the height of the exit opening behind the milling drum and / or the forward speed of the machine, thereby increasing the mixing time inside the milling chamber. However with strongly stabilized material increasing the mixing time in the milling chamber will only exacerbate the situation as the coarse material will be further broken down and the filler content will remain unchanged as the cemented fines remain bonded together. Provision had been made in the contract to add fines but in this case the achieved grading was acceptable and the addition of crusher dust fines were therefore not required. The recycled material was a little low with respect to the quantity of - 0,075 mm material but the available crusher dust was not fine enough to cost effectively improve the overall grading.

The results of the UCS tests indicate that the bitumen and cement stabilized, recycled material is well bonded and that the extra 0,5 % bitumen used for the second trial section does not significantly influence the test results. The UCS test results obtained in the laboratory (subsequent to the specified curing procedure) place the recycled material in the C3 class according to the TRH14 classification for cement stabilized materials.

The test results obtained from the trial section indicated that 1,5 % bitumen provide satisfactory material properties. It was therefore decided to use 1,5% bitumen and 1,0 % OPC as stabilizing agents.

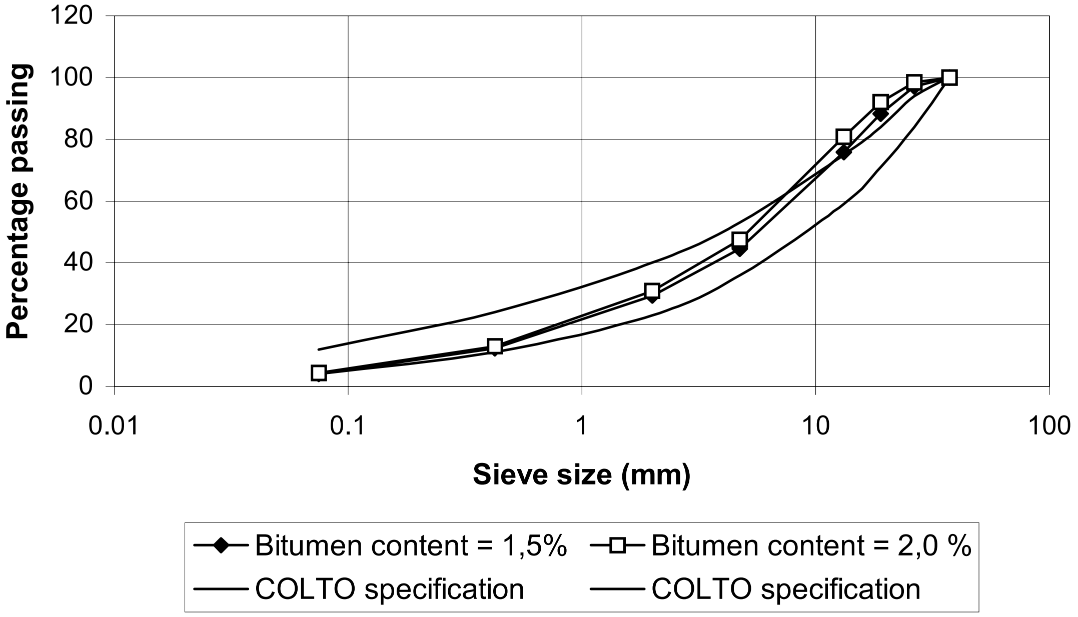

Figure 1 : Achieved grading upon recycling of the CTB material

6. PRODUCTION

6.1 Initial production

Production commenced subsequent to the analysis of the material test results obtained from the trial section. From the outset of the first day's production it was obvious that the contractor had to improve his site logistics. There was little synergy between the operations of the recycling subcontractor and the main contractor. The subcontractor's aim was to recycle at least 800 m^3 per day and he proceeded accordingly. The subcontractor proceeded to recycle a long (480 m) strip of material 2,5 m wide adjacent to the kerb. He then reversed the recycling train and commenced adjacent to the first strip with a 0,3 m overlap to complete the recycling of the one lane. The main contractor had to wait until a sufficient quantity of the material had been recycled across the full lane width before the shaping and removal of the surplus material could commence. Therefore his team stood idle for approximately 3 to 4 hours as it was apparent that the main contractor's cut and compaction operation was slower than the recycling operation of the subcontractor.

6.2 Revised procedure and achieved production

The contractor and the subcontractor continued to use the same recycling procedure for 2 days until it became clear that the overall production rate was not going to improve.

In order to increase the overall production rate it was necessary to improve the synergy between the operations of the subcontractor and the main contractor. In discussions with the consultant, it was suggested that the recycling subcontractor should first process an 80 m long strip, then reverse his train and process a second strip 200 m long adjacent to the first strip. He should then reverse his train again and resume processing a 280 m long strip from where the first strip ended. Finally he would then finish the adjacent strip which is 160 m long from the point where the second strip ended to the end of the half width section. (See Figure 2 below.) This would result in a daily production rate of approximately 340 m^3 per day. Once experience had been gained with this approach the main contractor could speed up his processing rate and the subcontractor could lengthen the recycling strips. The principle is that the main contractor needs to get access to cut and compact the recycled material as soon as possible. The daily production achieved on the first day on which the revised procedure was used was 337 m^3. On the following day 300 m^3 were processed in half a day, indicating that both teams' logistics had to a certain extent been sorted out.

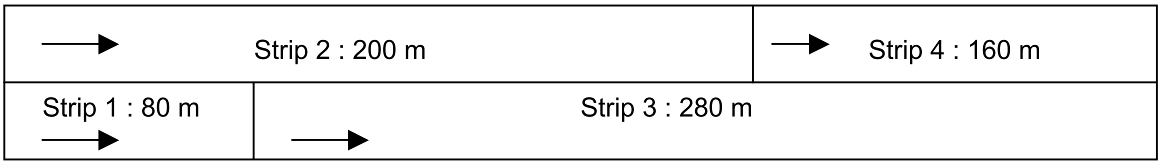

Figure 2 : Proposed recycling sequence

The daily productions achieved for the entire project are given in Table 2 (page 8). From Table 2 it can be seen that the production rate slowly improved as experience was gained with the revised procedure. It should be borne in mind that the contractor had also been given extended working hours from 08h30 to 16h30 at that time which was an hour longer than what was allowed at tender stage.

Subsequent to the completion of the recycling process all the time-motion data recorded during the contract were analyzed and it was determined that a reasonable daily production rate for this operation would have been approximately 465 m^3. If Friday 12 March 1999's production is removed from the record (cold bitumen was supplied to the site on this day) the actual average daily production achieved was 466 m^3 per day. From this operation it became obvious that the daily production rates of 800 m^3 to 1000 m^3 originally envisaged by the contractor at tender stage are not achievable on hard, cement treated base material under restricted urban working conditions similar to those existing on 5th Avenue Grassy Park.

Table 2 : Achieved daily productions

Date	**Volume of material recycled (m^3)**	**Remarks**
18 February	448	End of trial section to Lake Road : EBL (Machine breakdown delayed work)
2 March	391	Victoria Road to First Road : WBL
3 March	279	Victoria Road to First Road : WBL
4 March	337	Victoria Road to First Road : WBL
5 March	300	End of Trial section to Lotus Canal : WBL : Halfday production
9 March	439	Over Victoria Road to Perth Road : EBL
10 March	277	Victoria Road to Perth Road : WBL
11 March	430	Victoria Road to Perth Road : EBL
12 March	217	Atkins Road to Perth Road : WBL : Cold bitumen delivered on site, work stopped.
15 March	455	Atkins Road to Perth Road : EBL
16 March	601	Lake Road to Zeekoe Road : WBL
17 March	611	Lake Road to Zeekoe Road : EBL
18 March	522	Zeekoe Road to Little Lotus Canal : Full width.
23 March	634	Little Lotus to Strandfontein Road : WBL
24 March	801	Little Lotus to Strandfontein Road : EBL
Total	**7024**	

Note : Daily production was also adversely affected at times by late bitumen deliveries or machine breakdowns which must be allowed for when planning the construction programme.

7. THE RECYCLED MATERIAL

7.1 Quality control

The quality of the recycled material was controlled by monitoring the following three properties :

- The quantity of bitumen added to the material (1,5 % by mass specified).
- The quantity of cement added to the material (1,0 % by mass specified).
- The density of the compacted material (102 % of Modified AASHTO density specified).

The quantity of bitumen added was monitored by taking readings from the recycling machine's control panel as well as tanker dips at the beginning and end of each day's work. The quantity of cement added was checked by counting the number of bags and checking the spaces between the cement bags. The densities were measured using a nuclear density gauge. Table 3 shows the results achieved.

From Table 3 it can be seen that the average daily bitumen content over the whole project is 1,59 % which is slightly more than the required 1,5 %. The cement content was well monitored and was correctly applied over the whole project.

Table 3 shows the average compaction for each lot over the whole project. From Table 3 it can be seen that the field compaction achieved was generally well above the required relative density of 102 % Mod. AASHTO. The only two cases where the average density was below the required density level is for Lot No. 9 and Lot No.11. In both these cases the achieved field density was comparable with the field densities of the other lots but the recorded Mod. AASHTO densities measured in the laboratory were higher than normal. Therefore both Lot No. 9 and Lot No.11 were accepted.

Table 3 : Quality control test results

Date	Lot No.	Quantity of Bitumen	Quantity of Cement	Average Field Density	Ave. Mod. AASHTO Density	Relative density
		(% by mass)	(% by mass)	(kg/m^3)	(kg/m^3)	(% Mod.)
18 February *	1	1,59	1,0	2009,7	1885,0	106,6
2 March **	2	1,56	1,0	2051,3	1996,0	102,8
3 March **	2	1,47	1,0	2051,3	1996,0	102,8
4 March	3	1,71	1,0	2127,0	2006,5	106,0
5 March *	1	1,79	1,0	2009,7	1885,0	106,6
9 March	4	1,45	1,0	2012,8	1893,0	106,3
10 March	5	1,63	1,0	2097,2	2007,5	104,5
11 March	6	1,54	1,0	2078,8	1950,0	106,6
12 March	7	1,60	1,0	2046,5	1951,0	104,9
15 March	8	1,49	1,0	1953,0	1852,5	105,4
16 March	9	1,46	1,0	2056,1	2052,0	100,2
17 March	10	1,57	1,0	2032,3	1910,5	106,4
18 March	11	1,51	1,0	2001,5	1965,0	101,9
19 March	12	1,75	1,0	1998,7	1945,0	102,8
23 March	13	1,63	1,0	2004,3	1893,5	105,9
24 March	14	1,61	1,0	2004,8	1888,3	106,2

Note * : The results given for 18 February and 5 March belong to one test control lot.
Note ** : The results given for 2 March and 3 March belong to one test control lot.

7.2 The low Mod. AASHTO density achieved

The relative compaction achieved was generally well above this specified 102% Mod. AASHTO density required. However, these relative densities were based on a very low Mod. AASHTO density. It is important to understand the basics of the foamed bitumen process before an explanation for the low Mod. AASHTO density can be given. A brief discussion of the process is therefore given below.

Foamed bitumen is produced by injecting a small quantity (approximately 2,0 %) of cold water into super heated bitumen (200 degrees Celsius) which causes the bitumen to foam. The bitumen bubbles are supported by the steam pressure inside the bubbles. Once the bitumen is in the foamed state its viscosity drops to such and extent as to allow it to be mixed with cold aggregate. Foamed bitumen bubbles collapse once the pressure inside the bubbles drops; this occurs when the steam cools off or the bubbles are mechanically damaged by contact with aggregate. Once the foamed bitumen bubbles have all collapsed or the bitumen/water mixture has been mixed into the aggregate the small quantity of water remaining in the bitumen tends to create a quasi inverted emulsion, i.e. the cold foamed bitumen still has a lower viscosity than normal bitumen at the same temperature. Once all the water eventually evaporates from the foamed bitumen it ceases to behave like a quasi inverted emulsion and its viscosity reverts to the viscosity of normal cold bitumen. At this higher viscosity the bitumen then has a stabilizing effect on the material.

From the above it can be seen that the little bit of water (approximately 1,0 to 1,8 %) that is suspended in the bitumen is essential in order to keep the viscosity of the bitumen low after the foamed bitumen has been mixed with the aggregate. This low viscosity is required in order to compact and finish the layer. It is clear that if the water has been removed from the bitumen/water mixture before the compaction of the material has been completed a high layer density will not be achieved because the higher viscosity of the bitumen will make it difficult to compact the material.

On this project a nominal quantity of 1,0 % OPC was used together with the bitumen as stabilizing agents. Once the cement has been mixed into the material it starts to hydrate. Upon hydration the cement not only starts to bond the particles together but in this instance it also starts to destroy the quasi inverted emulsion (foamed bitumen) by absorbing water and thereby increasing the viscosity of the bitumen. On this project the recycled material was compacted directly behind the recycling machine but the Mod. AASHTO density control tests were only undertaken once the material arrived at the commercial laboratory some time later. During the time taken to transport the samples to the laboratory the cement had time to start hydrating and thereby the compaction achieved in the laboratory using the standard Mod. AASHTO effort was less than what it would have been if the samples had been compacted at the same time that the field compaction was taking place. It is therefore clear why the laboratory Mod. AASHTO densities measured on this project were considerably lower than the achieved field density. The relative field densities as high as 106 % of the laboratory obtained Mod. AASHTO density which were obtained in the field are probably only between 100 % and 102 % of the true Mod. AASHTO density. In an attempt to verify this statement the typical field density was compared with the Mod. AASHTO density of a sample containing no bitumen and no cement and a relative compaction density of only 99 % was achieved.

7.3 Unconfined compressive strength of the recycled material

The UCS values of the recycled material were monitored on a daily basis. Figure 3 shows the daily average UCS values measured for each lot, subsequent to the specified curing. Figure 3 shows that the UCS values generally remained within the C3 category (1500 kPa to 3000 kPa). The achieved UCS values shown in Figure 3 are relatively high for a material containing such low quantities of bitumen and cement.

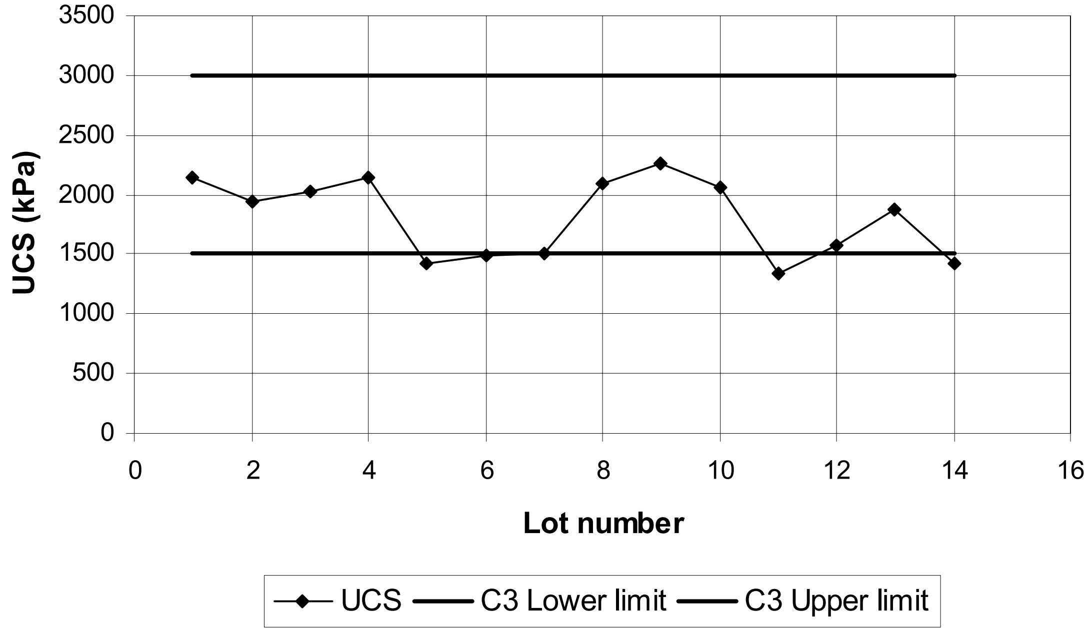

Figure 3 : Average UCS values for each lot on 5th Avenue - after specified curing

Since there is no standard curing procedure for a recycled material containing both foamed bitumen and cement it was decided to use the following two curing procedures :

<u>First curing procedure specified for this contract</u> : After compaction the material remains in the mould for 1 day before the sample is extruded from the mould. This is followed by 3 days curing in the oven at 60 degrees Celsius followed by 3 days curing at ambient temperature.
<u>Second curing procedure</u> : The standard TMH1 curing procedure for cement stabilized materials.

It is suggested that the first (specified) curing procedure dries the material to its equilibrium moisture content during the 3 days at 60 degrees Celsius. This allows the bitumen to expel all moisture it might contain and upon cooling will have a higher viscosity (its original viscosity prior to foaming). The 3 days curing at ambient temperature allows the remaining moisture to distribute evenly throughout the sample before it is tested. The second (TMH1) curing procedure keeps the moisture content in the material at optimum during the first six days, this allows proper hydration of the cement in the material.

Table 4 shows the test results obtained on duplicate samples prepared using the two different curing procedures :

Table 4 : UCS test results using the two different curing procedures

	UCS test results (kPa)				
Lot no.	**Specified curing method**		**Std. TMH1 curing method**		
	Average	**Standard deviation**	**Average**	**Standard deviation**	**Ratio of averages**
11	1331,7	164,85	828,0	323,6	0,62
12	1577,5	335,64	807,5	562,85	0,51
13	1870,0	374,01	910,0	172,16	0,49
14	1431,7	391,99	731,7	348,79	0,51

From the information presented in Table 4 it can be seen that on average the measured strength of the recycled material drops by approximately 50 % when the standard TMH1 curing procedure is used as opposed to the specified curing procedure used on this contract. This seems to indicate that the bitumen has a significant or even a dominating affect on the strength of the recycled material. When the foamed bitumen has lost its moisture the UCS increases significantly.

Until a standard curing system is set it is difficult to specify exactly what the design UCS specification should be or to confidently measure the actual UCS obtained in the field. At this stage it is suggested that the strength measured using the standard TMH1 curing procedure could be taken as a lower strength limit and that the strength measured using the specified curing procedure could be taken as an upper strength limit. The actual in-situ strength of the material would be dependent on the prevailing moisture conditions in the pavement and would probably fall between these two limits. The actual strength of the material therefore could fall in either the C4 or C3 category depending on in-situ conditions. However, it is thought that a UCS parameter is not really a suitable measure of the layer strength as the bitumen stabilized base should ideally remain a flexible layer, not a rigid cemented layer.

The effect of early trafficking (which eliminates the normal curing time allowed for a cement stabilized layer) on the final layer strength obtained on the road is also unknown.

7.4 Indirect tensile strength of the recycled material

Indirect tensile strength tests were performed on a daily basis towards the end of the project. These tests were performed in order to assess whether the two curing procedures given above had the same effect on the ITS test results as what they had on the UCS test results. The test results are given in Table 5.

Table 5 : ITS test results using the specified and the standard TMH1 curing procedures

	ITS test results (kPa)				
Lot no.	**Specified curing method**		**Std. TMH1 curing method**		
	Average	**Standard deviation**	**Average**	**Standard deviation**	**Ratio of averages**
12	49,3	38,55	78,7	50,84	1,60
13	99,0	12,12	46,0	4,00	0,46
14	123,7	23,80	35,7	10,06	0,29

From the test results given in Table 4 and Table 5 it seems as if both the UCS and the ITS values reduce by approximately 50 % when the standard TMH1 curing procedure is used as opposed to the curing procedure specified for this contract. However, the variability of the few ITS results obtained on this contract makes it difficult to draw any firm conclusions in this regard.

It has been determined that for cement bonded materials the ratio of the ITS/UCS values generally lies within the 8,0 to 12,0 % range [1]. Table 6 gives the ratios of the ITS/UCS values measured on the 5th Avenue contract using both the curing methods :

Table 6 : Ratio of ITS and UCS values obtained using both curing methods

Lot no.	ITS/UCS using specified curing method	ITS/UCS using std. TMH1 curing method
Trial section, 1,5 % bitumen	5,65 %	-
Trial section, 2,0 % bitumen	5,16 %	-
12	3,13 %	13,98 %
13	5,29 %	5,05 %
14	8,64 %	4,88 %

From the limited information presented in Table 6 it can be seen that the ratio of the ITS value to the UCS value of the material is approximately 5,0 %. This is lower than the lower limit of 8,0 % applicable for cement bonded materials. The lower ratio could be due to the effect of the bitumen in the material which renders the mechanical behaviour of the material time-temperature dependent. It can therefore be argued that if the temperature at which the material is tested is lowered the ratio of the ITS value to the UCS value will increase. This lower ratio therefore seems to indicate that the bitumen does have a significant effect on the stabilizing of the material. This also seems to indicate that the material does have some resilient behaviour which is advantageous.

8. EFFECT OF EARLY TRAFFICKING ON THE RECYCLED MATERIAL

It has been stated that recycled material containing small percentages of bitumen and cement can handle traffic a few hours after it has been compacted without an undue amount of ravelling occurring. It has further been stated that the cement accelerates the drying out of the bituminous based material and thereby provides enough cohesion to the material at an early stage to adequately cope with early traffic.

In order to check if these statements applied on this contract where a milled crushed stone base material deficient in fines was being recycled, one lane of the trial section was treated with diluted bitumen emulsion rolled into the surface during the final compaction operation and the other lane was not. It was soon apparent that the application of a diluted emulsion is beneficial with a crushed stone material as the recycled material which did not receive an emulsion treatment ravelled significantly. (A natural gravel material with a higher percentage of fines will probably perform better and the emulsion prime may not be necessary.) The trial section also showed that the final rolling and slushing operation must be done properly as a smooth, well bonded surface is essential to provide resistance to raveling as any open, coarse areas in the surface of the recycled material ravel rapidly even when a diluted emulsion is used. The time constraints the contractor had to comply with meant that in some instances the recycled material was not properly finished and in the areas where this occurred the recycled material did not perform well. The poor performance in these coarse areas was particularly marked when the filler content (–0,075 mm fraction) in the recycled material was less than 3 %.

9. CONSTRUCTION COSTS

The average direct contract cost to recycle and resurface 35 120 m^2 on 5^{th} Avenue (including all ancillary items such as kerb repairs and roadmarkings) amounted to R 67,55 per m^2 including P&G's, ancillary items of work and VAT. The recycling and asphalt resurfacing work was completed in approximately eight working weeks.

10. PERFORMANCE TO DATE

5^{th} Avenue's performance to date is very good. No defects in the form of cracks, permanent deformation or surface failures have occurred and the riding quality of the rehabilitated road is still excellent. The recycled pavement has only been in service for just over one year but a continued good performance is expected in the future.

11. CONCLUSIONS

The following conclusions can be drawn from this successful cold in-situ recycling project :

- The in-situ recycling machine can effectively recycle cement treated material; in this case with an average compressive strength of 14,4 MPa.
- An average production rate of 466 m^3 per day (200 mm recycling depth in CTB with an average compressive strength of 14,4 MPa) was achieved under the conditions of this project.
- 1,5 % bitumen and 1,0 % ordinary Portland cement sufficiently stabilized the recycled CTB crushed stone material on this project.
- The UCS of the recycled material varied between 1400 and 2300 kPa.
- The ITS of the recycled material varied between approximately 40 and 120 kPa.
- Current indications are that the recycled base layer should be capable of carrying the fifteen year design traffic loading of between one and three million E80 axle loads.
- The recycled material appears to have some resilient behaviour which will be advantageous in preventing reflective cracking.
- A filler content in excess of 3,0 % provides a recycled material which is adequately resistant to ravelling under early trafficking until it can be surfaced provided the surface is well finished and bonded with diluted bituminous emulsion before it is opened to traffic.
- This rehabilitation procedure provided good value for money at a direct contract cost of R 67,55 per m^2 including P&G's, ancillary works and VAT.

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IN-SITU RECYCLING OF A CEMENT TREATED BASE COURSE USING FOAMED BITUMEN

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