WARM MIX ASPHALT TRIALS
LEICESTER ROAD: MAY & JUNE 2009

CONTENTS

APPENDICES

WARM MIX ASPHALT TRIALS - LEICESTER ROAD

1. INTRODUCTION

This report covers Warm Mix Asphalt trials carried out on a section of Leicester Road in Durban's industrial area of Mobeni during late May, and early June 2009.

These trials follow the first WMA trials in RSA, which were undertaken on Brackenhill Road, Waterfall, a suburb approximately 30 km inland of Durban, during November 2008.

Warm Mix Asphalt, a process whereby the mixing and paving temperatures of conventional hot-mix asphalt are significant reduced, resulting in benefits of lower burner fuel consumption and decreased emission of greenhouse gases, is gaining considerable interest around the world.

Here in South Africa, a SAT seminar on WMA was held in Pretoria on 9 July 2008 where it was proposed to form a task team to develop guidelines to conduct trial sections to assess the benefits of the various WMA technologies.

Subsequently an Interest Group was formed, comprising representatives of eThekwini Municipality, road authorities, asphalt suppliers, contractors, technology suppliers and consultants, as well as SABITA, with the aim of properly evaluating the Warm Asphalt Mix process.

The Brackenhill Road WMA Trials, which are documented in a separate report, were deemed successful, and at an Interest Group meeting on 28 January 2009, it was decided to carry out a second trial using other WMA technologies, applying the experience gained in the first trials.

2. DISCLAIMER

Opinions expressed in reports by the WMA technology suppliers and the manufacturers of compaction equipment included in the appendices to this report may not necessarily be those of the WMA Interest Group. The WMA Interest Group does not accept responsibility, or guarantee for the information provided in these reports.

3. EXPERIENCE GAINED FROM THE BRACKENHILL ROAD TRIALS

The trials carried out on Brackenhill Road extended from the intersection of Brackenhill Road and Inanda Road (29^o 44' 57 S, 30^o 48' 55 E), to the T junction at Fischer Road (29^o 44' 13 S, 30^o 47' 58 E), distance of approximately 2 km. The asphalt mixes used in these trials were produced in National Asphalt's manufacturing plant situated near Shongweni (29^o 48' 40 S, 30^o 41' 05 E).

The decision taken by the WMA Interest Group to implement as far as possible the experience gained from the first WMA trials on Brackenhill Road, included the following main items:

Site selection
The first trials included sections on fairly steep grades. The difficulty in paving and compacting the asphalt surfacing on these grades adds to the number of factors that could cause variability of mix performance. It was therefore decided that a section of road would be chosen with only very moderate grades.

In view of the variable support on Brackenhill Road that could affect the long-term performance of the various mixes, it was decided to ensure a stable, uniform support under the asphalt surfacing layer.

Basic mix type

In order to expand the information obtained from the first trials, the same basic mix type, eThekwini's Mix "D", which is similar to the COLTO "coarse" continuously graded asphalt surfacing mix, was used. It was decided to include 10% of reclaimed asphalt (RA) in all the mixes as the addition of recycled material had proved successful in the Brackenhill Road trials and contributed to cost savings as well as to promoting the use of recycled hot mixed asphalt.

Number of trials per day

Including more than one trial per day resulted in a logjam of samples, consequent delays in testing and the potential for errors. It was therefore decided to carry out only one trial per day.

Mixing plant temperature control

Some difficulty was experienced in reducing the temperature of the mix to around 20^{o}C below that of conventional asphalt and in maintaining it at this reduced temperature. It was therefore decided that thorough checking of this aspect should be carried out well ahead of the actual trials.

The "shift' between laboratory mix design results and results of tests on full-scale plant mixed results

Due to the significant differences found between the results of mix designs carried in the laboratory and those obtained from the testing of samples from the mixing plant, it was decided that this "shift" should be properly investigated so that any necessary adjustments to the mix could be made timeously.

Monitoring at the mixing plant and paving site

Considerable effort is required to comprehensively monitor all the relevant aspects of the mixing and paving process. This relates directly to ensuring that sufficient numbers of personnel are available to carry out the required monitoring, in particular to record the rolling pattern and number of roller passes, as well as to measure the rate of density gain after each roller pass.

Human resource training

The need to ensure that human resource skills at both the mixing plant and paving site are upgraded so that there is a full understanding of all instructions. This is particularly important as the WMA trials include some changes to the usual procedures with which the personnel are familiar.

Emission testing

Due to difficulties found in evaluating emission testing, caused by the relatively short duration of the trials, as well as the effects of changes in ambient conditions during this limited period, it was decided that emission testing would not be included in these trials. There are enough published emission data and these are in good correlation with one another to form an acceptable base line.

Compilation of template

A template was devised, based mainly on experience gained in the first WMA trials. This was thoroughly workshopped, as a checklist as well as a decision making tool, by the WMA Interest Group. The template was strictly implemented throughout these trials. ***A copy of the template is included in Appendix 1.***

4. ORGANISATIONAL ARRANGEMENTS

The decision was taken by the WMA Interest Group to use Much Asphalt's mixing plant at Coedmore (29^o 53' 56 S, 30^o 57' 02 E) to manufacture the trial mixes, and for National Asphalt to pave the trials. Much Asphalt's plant offered the opportunity to use a batch-type plant to manufacture the mixes, whereas the first WMA trials were manufactured in National Asphalt's continuous drum mixer type plant. It was decided to limit the variables at the paving site by using as far as possible the same team and equipment that National Asphalt had used on the first trials. As mentioned above, the WMA Template was strictly applied from this early stage.

These trials included several meetings of the WMA Interest Group. During the course of the actual trials, meetings were held on a regular basis, a pre-trial meeting in the morning and a post-trial meeting in the late afternoon, after the day's trial had been completed. This enabled the normal organisation of the day's work to be discussed and also afforded the opportunity for last-minute decisions to be taken.

5. SITE SELECTION

A basic premise was that a section would be selected that had been highlighted by eThekwini Municipality's Pavement Management System as being distressed and in need of rehabilitation. Several sections of road on the southern side of the City that carry fairly heavy traffic were inspected and the section of Leicester Road between Grimsby Road (29^o 56' 13 S, 30^o 57' 32 E) and Pendlebury Road (29^o 56' 40 S, 30^o 57' 09 E) was finally selected as it offered the following features:

- the section is quite close to Much Asphalt's mixing plant
- it is situated on a very gentle grade
- the section carries a fair amount of heavy traffic
- it offers just over 1 km of dual carriageway
- traffic accesses between the two carriageways mean that some handwork is required. This is an opportunity to assess the use of WMA in handwork

6. SITE INVESTIGATION

The investigation of this section of Leicester Road is documented in a report entitled "Rehabilitation of Leicester road between Grimsby road and Pendlebury Road" dated February 2009 and is ***included in Appendix 2 of this report***.

The investigation of this section included a detailed visual inspection, trial pits and Benkelman Beam deflection measurements.

An analysis of traffic information indicates Design Traffic for a 20 year structural design period of approximately 7×10^6 ESALs. The main finding was that the thick layers of asphalt in the existing pavement tend to be of poor quality with low void contents.

Taking into account this finding, as well the analysis of the deflection results, the Leicester Road rehabilitation report recommends that the existing pavement be milled out to a depth of 90 mm and replaced with minus 19 mm continuously graded asphalt modified with 4.23% Sasolwax Flex™. A similar mix modified with 3% blend of SBS/Sasobit was successfully used in the asphalt base on the Argyle Road–Goble Road section of Umgeni Road, which carries heavy traffic.

The report recommends a 50 mm asphalt wearing course on top of the asphalt base inlay.

The WMA Interest Group agreed that this project was well suited to be used for the second Warm Mix Asphalt trials.

7. SITE PREPARATION

Milling and paving was carried out during the early part of May 2009, with most of the work being carried out at night. A summary of the test results of the asphalt mix, as well as compaction tests on the completed base layer, is ***included in Appendix 3.***

8. SCOPE OF THE TRIALS

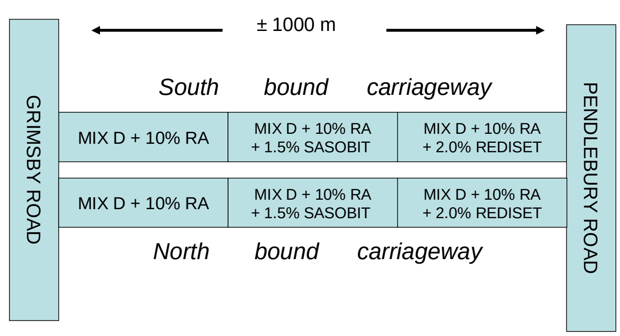
The scope of the trials was discussed at several WMA Interest Group meetings, including those held on 28 January, 5 March and 7 April. At the WMA Interest Group meeting on 20 April 2009, the final scope of the work was agreed.

It was decided that the trials would include both carriageways, a total area of approximately 20 000 m^2, using three different mixes:

- Mix D with 10% RA
- Mix D with 10% RA + Rediset
- Mix D with 10% RA + SASOBIT®

Sections of each mix would be paved on each carriageway as shown diagrammatically in **Figure 7.1.**

Figure 7.1 Trial sections on Leicester road.



Advantages of carrying out sections using the same mixes on each of the carriageways included the opportunity to compare the performance of the mixes in the respective carriageways under slightly different traffic loadings, as well as the chance to assess the mixes during different days of production.

As covered later in this report, the replicate sections using the same type of mix provided a useful opportunity to assess different compaction technologies with other factors remaining fairly constant.

9. WMA TECHNOLOGIES USED IN THE TRIALS

An early decision already mentioned in this report was to use 10% of reclaimed asphalt in all the trial's mixes, and to base all the mixes on the grading requirements of eThekwini

Municipality's Mix D, which is similar to that of COLTO "coarse" continuously graded asphalt surfacing mix.

The SASOBIT® technology, which had been used previously in the first WMA trials on Brackenhill Road, was used again. Similar to the first trials, 1.5% SASOBIT® was added to the 40/50 pen bitumen used in the mix.

REDISET, a product of Akzo Nobel, was used for the first time in RSA with 2.0% of REDISET being blended into the 40/50 pen bitumen.

Technical data of both these WMA technologies **is included in Appendix 4.**

In comparing the total energy and carbon impact of Warm Mix Asphalt with that of conventional hot-mixed asphalt, it is necessary to include the carbon footprint of the respective WMA technologies in the calculations. Calculating the carbon footprint of these technologies is no easy task as they tend to be highly integrated with other products which are produced by these companies. To date Sasol Wax has provided a CO_2 value for SASOBIT®, but Akzo Nobel is still to provide a CF figure for REDISET.

10. SAFETY MEASURES

No changes in Much Asphalt's Health and Safety protocol's at the mixing plant were found to be necessary for these trials. At the paving site National Asphalt implemented their Safety Plan which is contained in their Safety File. Both companies utilise aspects of Sabita's HSE Charter for the handling of bituminous products.

11. SOURCING, STORAGE & PREPARATION OF MATERIAL USED IN THE MIXES

11.1 Aggregate, sand, and filler.

The aggregate was sourced from two quarries,

- the nearby Coedmore Quarry, which is operated by Afrisam. Two fractions of the quartzitic sandstone aggregates, 13.2 mm and 6.7 mm from this quarry, were used in the mixes.

- Lafarge's quarry at Ridgeview. The Tillite crusher dust was resourced from this quarry

Coarse river sand from Multisand was also used in the mixes

Details of these materials are included in the mix designs **in Appendix 5**.

Active filler, consisting of 1% hydrated lime, was used in the control mix, as well as in the SASOBIT "warm" mix. As the REDISET protocol does dot require an active filler in the mix, the quantity of lime used in the other mixes was replaced with a similar quantity of baghouse fines.

11.2 Bitumen

Bitumen was supplied by Shell & BP Refineries. Copies of the certificates of quality for the three batches of the 40/50 penetration grade bitumen that were used in the mixes **are included in Appendix 6.** Also, as already mentioned above, this bitumen was used as the base binder into which SASOBIT and REDISET, respectively, was blended to produce the two different "warm' mixes". Differences in the results of Penetration and Softening Point tests obtained by the refinery, and SRT, who carried out the specialised testing on this project, are covered later in Section 19.4 of this report.

11.3 WMA technologies

As already covered in this report, bitumen blends containing the two WMA technologies, SASOBIT and REDISET, were produced by Colas in Jacobs, and the heated binder was transferred by tanker to the storage tanks at Much Asphalt's mixing plant.

11.4 Reclaimed asphalt

The reclaimed asphalt (RA), sourced from various projects in the eThekwini Metro, was initially stockpiled at eThekwini Municipality's asphalt plant in Umhlatuzana Road. A sufficient quantity for the trials was taken to National Asphalt's mixing plant site near Shongweni where it was screened using a triple deck screening unit. Two fractions of screened RA, one consisting of minus 16 mm plus 8 mm material, and the other with all material passing the 8 mm sieve, were produced and then hauled to Much Asphalt's mixing plant site where they were stockpiled separately.

Further details of the RA properties, grading and binder properties, are included in Table 16.2. As noted later in this report, in Section 18.5, it would be beneficial to stockpile the RA, as well as the fine aggregate fractions used in the mix, under cover in order to reduce the chance for high and variable moisture contents.

11.5 Burner Fuel

The burner fuel used to heat the aggregates and RA in much asphalt's asphalt plant consisted of a blend of HFO and LFO known as R50/50. Quality certificates and a specification for this fuel **are included in Appendix 7.** The specification shows, inter alia, that the gross energy content of this fuel is typically 4300 kJ/kg.

12. MANUFACTURING PLANT

12.1 Mixing plant details & operation

As already mentioned, Much Asphalt's plant consists of a batch-type plant with a pugmill capacity of 2.5 tons. The plant is equipped with a recycling system which is calibrated and controlled by means of the plant's microprocessor control system. Besides the usual cold feed bins for virgin aggregates, the plant is equipped with two dedicated RA cold feed bins which feed RA onto a separate belt conveyor. This deposits the RA into the base of the hot elevator. The RA falls into the buckets of the hot elevator, which already contain hot virgin aggregate from the drum drier.

The heated virgin aggregate/RA mixture is carried upwards and falls into the hot storage bin. Once the required mass of aggregate/RA mixture has been weighted it is deposited into the pugmill where it is mixed together with a predetermined mass of binder and filler.

It should be noted that the screens in the tower of this plant have been removed and the heated aggregates are not separated into fractions before they are weighed and mixed together with the binder in the pugmill.

The RA is mainly heated by conduction, as heat is transferred from the heated virgin aggregate to the RA in the hot elevator buckets, in the aggregate hot storage bins, as well as during the period the two products are mixed together in the pugmill. Some convectional heating of the RA occurs during the time that that it is exposed to the hot environment in the hot elevator.

Mixing time in the pugmill is approximately 40 seconds, after which the mix is dropped into a skip which transfers it to the hot storage silo.

Drying and heating of the virgin aggregate is carried out using a 50/50 blend of HFO and LFO burner fuel. Fuel consumption is monitored by a flow gauge as well as by taking dip measurements in the fuel tank at the start and end of production. The pugmill's electrical power usage, which accounts for a large proportion of the plant's total power usage, can be monitored by two ammeters, one for each pugmill motor.

The plant is normally operated in the 150°C to 170°C temperature range, but in the case of Warm Asphalt Mix the temperature has to be lowered to between 120°C and 140°C. This is achieved by reducing the fuel flow to the drier drum burner. During the production of WMA the normal production rate of Much Asphalt's plant can be maintained at the same tonnage rate as for conventional asphalt, approximately 120 to160 tons per hour.

Blending of the SASOBIT® and REDISET with the 40/50 pen bitumen was carried out off-site at Colas' plant. The binder was then transported to Much Asphalt's mixing plant where the binder tanks are electrically heated, with lagged oil-heated delivery pipes and return pipes. The same tank was used to store for both WMA technologies in turn, with the tank being emptied before being filled again with the other binder. A separate tank was used for the 40/50 pen bitumen used in the control mixes. No changes to the pump settings for conventional penetration-grade bitumen were found necessary to deliver the respective binders to the weigh pot.

The need to meet routine customers' asphalt mix supply demands during each day's trials was a programming challenge that had to be met. Generally the routine mixes were produced during the early part of the day, with the mixing for the trials commencing in mid-morning.

Prior to commencing the trials, a detailed inspection of the plant was carried out by members of the WMA Interest Group and its condition was found to be satisfactory.

12.2 Mixing plant personnel & management

The staff complement at Much Asphalt's mixing plant normally consisted of:

- Plant Manager
- Production Manager
- Plant Operator
- Loader Operator
- 3 Workers.

During the course of the trials, additional personnel were required to assist with taking temperatures of the asphalt in the skip.

12.3 Monitoring at the mixing plant

Monitoring at the mixing plant included:

- Temperatures of every 5th skip load of asphalt mix
- Temperatures of each truck load of mix at the weighbridge
- Ammeter readings at 5 minute intervals
- Fuel consumption from flow gauge readings and fuel tank dips
- Ad hoc thermal images

13. LABORATORY TESTING

Prior to starting the trials, the scope of laboratory testing was thoroughly discussed by the WMA Interest Group. With one of the main goals of the trials being to compare the properties of WMA with that of conventional hot-mixed asphalt, was felt important to include all the relevant tests.

A matrix, which provides details of the required tests, was devised and proved to be very useful to check that all the prescribed testing had been undertaken.

In essence the sampling, sample preparation and routine tests were undertaken in Much Asphalt's laboratory at their mixing plant. Other more specialised testing was carried out by Specialised Road Technologies (SRT), with a few tests being carried out by the CSIR.

13.1 Sampling & testing in the mixing plant laboratory

Much asphalt's laboratory is staffed by the Laboratory Manager and two testers. Prior to the trials, an inspection of this laboratory carried out by members of the WMA Interest Group found it to be satisfactory in terms of testing equipment as well as the staff's testing competency. It was not found necessary to supplement the number of personnel in the laboratory during the trials.

The laboratory carried out daily grading and moisture checks of the various aggregates as well as the RA used in the mixes.

During the manufacture of the trial mixes the laboratory took four samples from each of the trial mixes and carried out the following tests:

- Binder content
- Aggregate grading
- Marshall void content
- Marshall stability and flow
- Indirect tensile strength
- Immersion Index
- Asphalt moisture content (Oven dried)

A sample was delivered to SRT in a hotbox, for moisture content determination. Another large sample of each mix was taken, cooled and then delivered to SRT for the other tests detailed below.

13.2 Specialised testing

The scope of tests carried out by SRT on the mixes from each of the trial sections included:

- Moisture content (Dean & Stark)
- Sharp Gyratory void content after 300 gyrations (carried out at a temperature of 145°C for the reference mix and 125°C for the WMA)
- Resilient modulus
- Dynamic creep modulus
- Air permeability at 7% void content
- Recovered penetration and softening Point
- MMLS rutting after 100k axle loads

The following tests were carried out on the three binders used in the trials; 40/50 pen bitumen, 40/50 pen bitumen with 1.5% SASOBIT®, 40/50 pen bitumen with 2% REDISET:

<u>Tests before RTFOT</u>

- Penetration
- Softening point (R&B)
- Dynamic viscosity @ 60°C
- Dynamic viscosity @ 135°C
- Spot test

<u>Tests after RTFOT</u>

- Mass loss
- Retained penetration
- Softening point (R&B)
- Dynamic viscosity @ 60°C

Compacted specimens of samples taken from the three main mix types (Mix D with 10% RA, Mix D with 10% RA + Rediset, and Mix D with 10% RA + SASOBIT®) were sent to the

CSIR for Hamburg Rut and Repeated Simple Shear Tests At Constant Height (RSST-CH) testing.

14. TRANSPORTATION OF THE MIX FROM THE MIXING PLANT TO THE PAVING SITE

Transportation of the various trial mixes from Much Asphalt's mixing plant to the paving site on Leicester Road proved to be a challenge as additional trucks had to be resourced. The haulage distance between the mixing plant and Leicester Road is 16 km through a heavily trafficked, built-up area. The usual travel time from the mixing plant to the paver was around 45 minutes. Routing was sometimes a problem, with unnecessary delays occurring between the mixing plant and paving site. Although this obviously had an effect on the temperature at which the mix arrived on site only a few temperature problems were experienced during course of the trials.

A variety of trucks, with carrying capacities ranging from 7 tons to 16 tons were used. The asphalt mix in the trucks was covered with a tarpaulin to reduce temperature loss.

Some very isolated cases were reported where foreign material was found in the mix. As this contamination could have been caused by material left in the trucks prior to loading the asphalt, closer inspection of trucks is warranted. It is also recommended that some form of accreditation of trucks, as well as truck drivers, should be considered.

As a means of improving these aspects in future trials, it is felt that the person responsible for the transportation of the mix should be requested to join some of the daily team meetings, so that they can gain a first-hand appreciation of transportation requirements.

15. PAVING AND COMPACTION EQUIPMENT

15.1 Paving team & equipment details

The trial mixes were paved by National Asphalt using a team comprising:

- paving foreman
- paver operator
- screed operator
- paving conductor
- 3 men operating rakes
- operators for the three rollers
- water tanker operator
- tractor operator
- tack spray operator
- 3 general workers
- tally man

The paving was carried out using a Svedala Demag DF 145 P asphalt paver, which has a screed equipped with tamper bar and vibration system. The paving speed varied between 2 m and 3 m per minute.

15.2 Compaction plant details

The compaction train used in the trials consisted essentially of an approximately 9 ton vibratory roller, a 22 ton pneumatic tyred roller and a 2.5 ton vibratory roller.

Three different models of the large vibratory roller were used as primary compaction units:

Bomag BW 151 AD – 4 AM tandem vibratory roller
This roller, which features a system known as the "Asphalt Manager", has an operating mass of 9 250 kg. It was used to compact the three trial sections on the south bound carriageway.

Bomag's technical report, which covers technical aspects of this roller, as well as the compaction of the asphalt in these trial sections, **is included in Appendix 8.**

Hamm HD O 90 V tandem roller with oscillation
The Hamm HD O 90 V roller, which features vibration on the front drum and oscillation on the rear drum, has an operating mass of 9 180 kg. It was used to compact the asphalt on the north bound carriageway, except for the fast lanes of the two sections mentioned below, where a Hamm HD 70 tandem vibratory roller was used. A technical report prepared by Wirtgen South Africa, which includes details of compaction using the HD O 90 V roller with oscillation technology, **is included in Appendix 9.**

Hamm HD 70 tandem vibratory roller
The opportunity was taken to compact the fast lanes of the trials carried out on the north bound carriageway on 3 June (SASOBIT® WMA technology) and 4 June (Mix D control section) using a Hamm HD 70 tandem vibratory roller. This is a conventional vibratory roller with an operating mass of 7 265 kg.

As mentioned above, the Bomag BW 151 AD – 4 AM tandem vibratory roller worked on the south bound carriageway while the Hamm HD O 90 V tandem roller with oscillation undertook most of the compaction on the north bound carriageway. The Hamm HD 70 tandem vibratory roller was used to a limited extent on the fast lanes of the northbound carriageway.

These rollers carried out the primary compaction on the newly paved mat behind the paver. Most of the compaction was achieved by these vibratory rollers, however, as can be seen from the detailed compaction data covered later in this report, the pneumatic tyred roller did in fact provide a significant amount of additional compaction.

The smaller 2.5 ton vibratory roller was used for follow-up compaction and in the compaction of the asphalt in the traffic accesses.

It should be mentioned that National Asphalt's team were not familiar with the Bomag BW 151 AD – 4 AM tandem vibratory roller or the Hamm O 90 V tandem roller and the rolling techniques had to be adjusted during the initial stages. As the trial sections are relatively short there was a sharp learning curve which most probably impacted on the effectiveness of both the Bomag Asphalt Manager and Hamm Oscillation compaction technologies.

16. MANAGEMENT & SUPERVISION

As already alluded to in Chapter 3 "Organization Arrangements", careful attention was paid to managing and supervising these trials, utilizing persons with extensive experience in each of the most important sectors of the trials.

Key areas that were covered in this way included:

Mixing plant
Management responsibilities here covered:
- general plant operation – resourcing of aggregates, RA, binder
- adjustments to produce mixes at the required temperatures
- binder selection
- temperature monitoring in skip and delivery truck
- mix sampling

- sample preparation, testing in the plant laboratory
- arrangements for delivery of samples for specialised testing
- transportation – delivery trucks, routing

Paving site

Management responsibilities at the paving site included:

- traffic accommodation
- preparation of the trial section to be paved, transverse joints
- spraying of tack coat
- paver preparation
- preparation of the rollers
- general supervision of the paving and team
- asphalt temperature in delivery trucks upon arrival and after tipping into the paver hopper
- ambient temperature and wind speed monitoring
- monitoring of roller passes of each individual roller
- checking final compaction of the asphalt using a nuclear gauge

Monitoring and testing at the paving site

Responsibilities here included:

- supervision of team carrying out rate of compaction checks
- core sampling
- collation of data

Overall management and supervision of the trials were also addressed by appointing a manager to coordinate all aspects of the work, at the mixing plant as well as at the paving site.

In additional to the management and supervision, special attention was paid by the two WMA Technology Suppliers in the process of blending the bitumen together with their respective technologies. Besides this, both of the technology suppliers had highly experienced persons on site to observe the paving process and give ad hoc advice, as well as to contribute in the meetings.

Specialised management and supervision was also provided by the two compaction technology suppliers.

This careful attention to management and supervision no doubt paid off in the successful completion of these trials, however from the practical experience gained, an area that required special effort in future trials is in the coordination of extensive site testing programme.

17. MIX DESIGNS

The design of the various mixes for the trials was carried out in two distinct steps; firstly laboratory mix designs was carried out and this work was followed by plant mix designs, where the mix was produced full-scale in the mixing plant.

17.1 Laboratory mix designs

Separate mix designs were carried out for each of the three mixes used in the trials, with the mixing and compaction of Marshall briquettes for the control mix being carried out at conventional temperatures, while the other two mixes were mixed and compacted at around 20°C below conventional asphalt temperature, as shown in **Table 17.1**.

The SANS 3001 – AS 1: 2009 test method was following in carrying out the laboratory mix designs. The binder was prepared by blending the SASOBIT® and the REDISET, respectively, into the heated 40/50 pen bitumen before it was added to and mixed together with the prepared, heated aggregate and RA fractions.

Table 17.1 Details of mixing and compaction temperatures

MIX	MIXING TEMPERATURE (°C)	COMPACTION TEMPERATURE (°C)
Mix D + 10% RA	165	145
Mix D + 10% RA + 1.5% SASOBIT®	140 - 145	125
Mix D + 10% RA + 2.0% REDISET	140 - 145	125

A full set of these designs **is included in Appendix 7**. It was found that the two fractions of RA, which make up 10% of the aggregates in the mix, could be proportioned using 4% of the coarser, minus 16 mm plus 8 mm fraction, and 6% of the finer, minus 8 mm fraction.

Pertinent details of these RA fractions are summarised in **Table 17.2.**

Table 17.2 Summary of RA properties

GRADING	**COARSER FRACTION - 16 mm + 8 mm**	**FINER FRACTION - 8 mm**
Sieve size (mm)	**% Passing**	
19.0	100	
13.2	97	
9.5	74	100
6.7	49	99
4.75	37	96
2.36	27	87
1.18	22	46
0.600	18	34
0.300	13	25
0.150	9	16
0.075	6.1	10.1
Binder content	3.8	5.2
Recovered penetration/ softening point (°C)	9 / 73.7	5 / 80.0

As mentioned previously, in accordance with the WMA Technology supplier's requirements, no active filler was included in the warm asphalt mix containing REDISET, but 1% hydrated lime was added in the other two mixes.

All three of these designs showed that a binder content of approximately 5.2% would achieve void contents in the 4% to 5% range.

17.2 Plant mix designs

The next stage was to carry out full-scale plant mix designs. On 6 May 2009 approximately 155 tons of Mix D containing 1.5% SASOBIT® were manufactured and paved as a 40 mm overlay on Caber Road and Grant Road in Mosely Park near Pinetown. The mix was produced at an average temperature of 133 °C. The average temperature of the asphalt in the paver hopper was recorded as 117°C.

Another plant mix design using Mix D containing 2% REDISET was carried out on 8 May 2009 and was paved on Clyde Road, also in Mosely Park. In this trial, average mix temperatures at the mixing plant and in the paver hopper were, respectively, 136°C and 129°C.

Both plant mix designs showed slightly higher voids than the laboratory mixes. Valuable practical experience was gained in producing these "warm" mixes with regard to adjusting the mixing plant to produce the lower temperature mixes.

Another important milestone was the favourably low moisture contents found in these "warm" mixes, with moisture contents of only 0.1% in comparison with the 0.5% maximum limit.

Further plant mix design work was carried out on 13 and 14 May 2009 in order to gain more data and to fine-tune the mix proportions to be used in the actual trials. In this case the mixes included 10% RA. The moisture content of the mix produced on 13 May was 0.1%; similar to that of the previous mixes.

18. MANUFACTURING AND PAVING THE TRIAL MIXES

18.1 Sequence of the trials

As already mentioned, a pre-trial meeting was held each morning before the trials commenced.

A post mortem of events was held in the late afternoon after the day's trials had been completed.

These meetings were structured to include the following agenda:

- raw materials
- manufacturing
- transportation
- paving
- compaction
- monitoring
- testing
- general

Typically the mixing started at around 10h00 after the "grocer trade" customers had been served.

With reference to Figure 7.1, the trials commenced on the south bound carriageway at the Grimsby Road end of the project, with the first trial being started on Monday 25 May using the control mix (Mix D with 10% RA). Due a plant breakdown it was not possible to complete the full section and the balance of the trial was completed on 26 May. The first WMA trial section, containing 1.5% SASOBIT®, was paved on 27 May while the WMA trial section containing 2% REDISET was carried out on 1 June. This completed the trials on the south bound carriageway. As mentioned previously, the compaction of all these sections was carried out using the Bomag BW 151 AD – 4 AM tandem vibratory roller as the primary compaction unit.

The trials then continued on the north bound carriageway, starting at the Pendlebury Road end, with the second WMA trial using REDISET being completed on 2 June, the second SASOBIT® WMA trial on 3 June and the final section comprising the Mix D + 10% RA control on 4 June. As mentioned under Chapter 12.2, most of the compaction on this carriageway was carried out using a Hamm HD O 90 V tandem roller with oscillation, the exceptions being the fast lanes on the SASOBIT® section and Mix D + 10% RA control section, where a Hamm HD 70 roller with conventional vibration was used as the primary compaction unit.

18.2 Paving site preparations

All preparation and paving work on the Leicester Road trials was carried out by National Asphalt.

In order to reduce the level of asphalt that would protrude above the edge of the concrete side channel on the lower side of each carriageway, a small milling machine was used to mill out a 500 mm strip to the depth of 25 mm before the paving of the surfacing course commenced. The full paver width of the asphalt base was then tacked using 0.5 litre/m^2 of diluted SC 60 cationic bitumen emulsion.

18.3 Mix temperature limits

It was decided that the following mix temperature limits would be strictly enforced, and that any loads which did not conform to these limits would not be paved:

Control Mix D + 10% RA

Temperature at weighbridge:	145 °C to 160 °C
On arrival at paving site:	140 °C to 160 °C

Warm mixes

Temperature at weighbridge:	120 °C to 140 °C
On arrival at paving site:	120 °C to 140 °C

18.4 Monitoring at the paving site

The following aspects were monitored at the paving site:

- temperatures were taken of the mix in each truck before the mix was tipped into the paver hopper
- the mix temperature was checked again as it was being tipped into the paver hopper
- ad hoc temperature measurements of the mix were taken behind the paving screed
- the number of passes of the vibratory roller and the pneumatic tyred roller were recorded by two inspectors
- a team used a nuclear gauge to take density measurements of the asphalt layer behind the screed before it had been compacted by the rollers, and then took density measurements on the same spot after each roller pass. This sequence was undertaken at several positions along each trial
- density measurements were taken after the layer had been finally compacted using another nuclear gauge
- ad hoc thermal images were taken at relevant locations, of the mix tipping into the paver hopper, behind the screed, and during the compaction of the mat
- wind speeds using an anemometer
- ambient temperatures

Core samples were taken on the day following the completion of each of the trial sections, to determine the final density of the asphalt layer.

18.5 Salient details of each trial section

25 MAY 2009: MIX D + 10% RA CONTROL MIX

The trials commenced on Monday 25 May with the paving of the first control section of asphalt produced at conventional mix temperatures. The low filler/bitumen ratio made compaction difficult. Unfortunately the breakdown of the mixing plant meant that the full quantity could not be paved. There were problems with transportation; some loads took a long time to arrive at the paving site. This was addressed by arranging for additional trucks and ensuring that the drivers used the same route from the mixing plant to Leicester Road. The quantity of asphalt paved during the day was 180 tons. The weather was fine, with an ambient temperature of 27°C and a wind speed of 11.5 km/h.

A summary of relevant results of the day’s trial is given below.

Section details	Units	SBC SV 0 to 350
Average temperature at mixing plant	^oC	151
Average temperature at paver	^oC	149
Average Binder content	%	5.1
Average Marshall Void content*	%	6.9
Average ITS	kN	1251
Gyratory Void content @ 300 gyrations*	%	-
MMLS rut depth	mm	-
Average density (based on MTRD)	%	93.1

* Compacted @ 145^{o}C

26 MAY 2009: MIX D + 10% RA CONTROL MIX

With the mixing plant having been repaired, the balance of the control mix, 130 tons, was manufactured and paved on Tuesday 26 May. The filler content was increased slightly. Two loads were rejected as being over the upper temperature limit. The transportation situation had improved. It was noted that the mix seemed “tender” under compaction, even when the asphalt was at the lower temperature limit and consideration was given to reduce the filler content slightly. The trial was carried out in sunny weather conditions with ambient temperature and wind speed being recorded as 25.7^{o}C and 7 km/h, respectively.

Section details	Units	SBC SV 0 to 350
Average temperature at mixing plant	^oC	155
Average temperature at paver	^oC	160
Average Binder content	%	5.3
Average Marshall Void content*	%	5.2
Average ITS	kN	1154
Gyratory Void content @ 300 gyrations*	%	4.7
MMLS rut depth	mm	1.9
Mod. Lottmann Test	TSR	0.83
Air permeability	x 10^{-8}	1.48
Dynamic creep modulus	MPa	24.2
Resilient modulus	MPa	4012
Recovered penetration / SP	d.mm / ^oC	35 / 53.6
Average density (based on MTRD)	%	94.0

* Compacted @ 145^{o}C

27 MAY 2009: WMA MIX D + 10% RA + 1.5% SASOBIT®

The first Warm Mix Asphalt trial containing SASOBIT® was manufactured and paved on Wednesday 27 May. After discussion it was decided not to reduce the filler content and to keep the binder content at 5.2%. Transportation was much improved and the number of trucks that transported the mix to the trial site was sufficient. One truck arrived at the paver without a tarpaulin covering the mix. Mix temperatures were found to be close to the upper temperature limit. The fine weather continued, with an ambient temperature of 24.6^{o}C having been recorded.

Section details	Units	SBC SV 350 to 690
Quantity paved	ton	295
Average temperature at mixing plant	^oC	134
Average temperature at paver	^oC	132
Average Binder content	%	5.2
Average Marshall Void content*	%	6.0
Average ITS	kN	1213
Gyratory Void content @ 300 gyrations*	%	2.5
MMLS rut depth	mm	1.65
Mod. Lottmann Test	TSR	0.98
Air permeability	x 10^{-8}	0.44

Dynamic creep modulus	MPa	29.2
Resilient modulus	MPa	3720
Recovered penetration / SP	d.mm / °C	33 / 55.3
Average density (based on MTRD)	%	94.4

* Compacted @ 125°C

1 JUNE: WMA MIX D + 10% RA + 2.0% REDISET

The trials were delayed until Monday 1 June due to a burst water pipe which damaged a short section of the pavement, a plant breakdown on 28 May and the pay weekend which commenced on 29 May.

The binder, which had been blended by Colas and delivered to the mixing plant, was kept at 100 °C over this period. As this mix did not require hydrated lime filler, this was replaced by adding 50 kg of baghouse filler.

The area that had been damaged by water from the pipe burst was repaired over the weekend so the first REDISET trial was able to proceed on the final section on the south bound carriageway, as originally planned. The weather was sunny and calm with a wind speed of only 2.8 km/h and ambient temperature of 26°C.

Section details	Units	SBC SV 690 to 974
Quantity paved	ton	300
Average temperature at mixing plant	°C	132
Average temperature at paver	°C	131
Average Binder content	%	5.4
Average Marshall Void content*	%	4.6
Average ITS	kN	1283
Gyratory Void content @ 300 gyrations*	%	1.2
MMLS rut depth	mm	2.47
Mod. Lottmann Test	TSR	0.85
Air permeability	$x\ 10^{-8}$	0.32
Dynamic creep modulus	MPa	26.5
Resilient modulus	MPa	3837
Recovered penetration / SP	d.mm / °C	30 / 54.7
Average density (based on MTRD)	%	95.4

* Compacted @ 125°C

2 JUNE 2009: WMA MIX D + 10% RA + 2.0% REDISET

The second REDISET trial was carried out on the north bound carriageway with the Hamm HD O 90 V tandem vibratory roller being used for the first time as the primary compaction unit on these trials. It was decided to lower the binder content by 0.1%. Some fatty spots were noted; thought to be caused by the build-up of fines on the rear edge of the paving screed. This fine material dislodges itself from time to time, causing very isolated, small patches of very finely graded mix that are visible on the surface after compaction has been completed.

During the day's trial the weather was fine, with a light wind of 10 km/h and ambient temperature of 26°C.

Handwork was carried out in the traffic accesses between the two carriageways using the WMA.

Section details	Units	NBC SV 1050 to 789
Quantity paved	ton	275
Average temperature at mixing plant	^oC	133
Average temperature at paver	^oC	129
Average Binder content	%	5.1
Average Marshall Void content*	%	4.6
Average ITS	kN	1215
Gyratory Void content @ 300 gyrations*	%	1.6
MMLS rut depth	mm	2.01
Hamburg Rut Test – max rut depth	mm	10.9
RSST-CH permanent strain	%	2.5
Mod. Lottmann Test	TSR	0.82
Air permeability	$x\ 10^{-8}$	0.58
Dynamic creep modulus	MPa	25.4
Resilient modulus	MPa	3964
Recovered penetration / SP	d.mm / ^oC	33 / 54.2
Average density (based on MTRD)	%	94.6

* Compacted @ 125^oC

3 JUNE 2009: WMA MIX D + 10% RA + 1.5% SASOBIT®

The second SASOBIT® WMA trial was carried out on the north bound carriageway on Wednesday 3 June. The asphalt surfacing in the slow lane was compacted using the Hamm HD O 90 V roller using oscillation technology while the fast lane was compacted using the HD 70 with normal vibration.

Some very isolated, large, hard clods of uncoated crusher dust in the mix were noted, also a few large stones. This was found to originate in material delivered to the mixing plant from the quarry. Sufficient trucks were available for most of the day, but there were some delays caused by the late arrival of the last few trucks. The wind speed was a light 6 km/h during most of the day but picked up towards the late afternoon.

Handwork was carried out at the end of the work day on the traffic accesses areas between the carriageways using the SASOBIT® WMA, with the asphalt being fed through the paver with its screed raised. During the paving of the traffic lanes the air temperature was a warm 28^oC, but it dropped some 5 ℃ by the time that the ha ndwork was undertaken, making it a challenge to place, rake and achieve density with a rapidly cooling mix. The thermal images in Appendix 10 depict how the mat cooled to mid-70 at the end of job. The rollers employed on these sections did not make use of BituGlide™, but water, which cooled the asphalt even quicker. The workers reported ease of workability and the compaction results show that density was achieved without a problem (94%).

Section details	Units	NBC SV 789 to 389
Quantity paved	ton	300
Average temperature at mixing plant	^oC	131
Average temperature at paver	^oC	131
Average Binder content	%	5.2
Average Marshall Void content*	%	4.0
Average ITS	kN	1203
Gyratory Void content @ 300 gyrations*	%	2.7
MMLS rut depth	mm	1.43
Hamburg Rut Test – max rut depth	mm	3.2
RSST-CH permanent strain	%	0.5
Mod. Lottmann Test	TSR	0.80
Air permeability	$x\ 10^{-8}$	0.695
Dynamic creep modulus	MPa	30.2
Resilient modulus	MPa	4187
Recovered penetration / SP	d.mm / ^oC	18 / 61.2

Average density (based on MTRD)	%	94.6

* Compacted @ 125°C

> ***NOTE***
> *As the recovered binder properties reflected a significantly harder binder than that found in the other trial sections, core samples were taken from the section in November 2009. The results yielded a penetration value of 25 and R&B Softening Point of 58.0°C. It therefore appears that the original binder properties were erroneous; especially taking into account the aging of the binder that would has occurred since the trial section was paved.*

4 JUNE 2009: MIX D + 10% RA CONTROL MIX

The final section of the Leicester Road trials, consisting of the control mix at conventional asphalt mixing and compaction temperatures, was carried out on Thursday 4 June. Although a quantity of the poor quality crusher dust found in the previous day's trial had been removed and new material had been brought in, some foreign objects and uncoated clods in the paved mat were still noticed.

The mix in the slow lane was found to move excessively under the HD O90 V roller, even though the temperature was within acceptable limits. This was thought to be caused by moisture in the mix, however the moisture content of the mix was found to be only 0.1%. The real cause of this mix sensitivity problem is still unknown.

As a precaution, several changes were instituted for the mix on the fast lane, including reducing the mixing plant's production rate, reducing the filler content by 5 kg, and the binder content by 0.1%. These measures cured the sensitivity problem and the mix was successfully compacted using the Hamm HD 70 roller as the primary compaction unit.

Some "fatty" spots were noted. There were some supply problems, with long delays before the trucks arrived at the paving site. Several trucks were found to be over the upper temperature limit and were rejected. The weather remained fine with an ambient temperature of 25°C.

Section details	Units	NBC SV 389 to 89
Quantity paved	ton	300
Average temperature at mixing plant	°C	152
Average temperature at paver	°C	160
Average Binder content	%	5.1
Average Marshall Void content*	%	4.8
Average ITS	kN	1201
Gyratory Void content @ 300 gyrations*	%	3.2
MMLS rut depth	mm	1.64
Hamburg Rut Test – max rut depth	mm	22.4
RSST-CH permanent strain	%	2.8
Mod. Lottmann Test	TSR	0.80
Air permeability	$x 10^{-8}$	0.880
Dynamic creep modulus	MPa	27.5
Resilient modulus	MPa	2594
Recovered penetration / SP	d.mm / °C	29 / 55.5
Average density (based on MTRD)	%	93.8

* Compacted @ 145^{o}C

Notes

*The following testing protocol was used for the **MMLS3 Wheel track testing**:*
Temperature 50 ± 2^{o}C, 7200 load repetitions per hour, wheel pressure 700 kPa, 2.7 kN wheel load with no lateral wander. Briquettes were cut to a width of 105mm. transverse rut measurements were taken at 3 mm intervals. The tests were carried out dry.

Briquettes were compacted at 150 mm diameter on a Troxler SGC to 7 ± 1% void content.

***The Hamburg Rut tests** were carried out in accordance with AASHTO test method T 324-04 at a test temperature of 50^{o}C. The tables reflect maximum rut depth after 20 000 passes.*
***The REPEATED SIMPLE SHEAR TESTS AT CONSTANT HEIGHT (RSST – CH) tests** were performed according to the AASHTO 320-03 standard test protocol. Percentage permanent strain after 5k cycles is shown in the tables.*

Due to the limited number of specialised tests carried out, and the resulting small statistical population, care should be should be exercised when reading into the results.

19. MAIN FINDINGS OF THE TRIALS

Results of the routine tests carried out on each of the trial mixes as well as a full set of reports on the specialised tests that were carried out as part of these trials **is included in Appendix 10.**

19.1 Compaction

As already mentioned in this report, the rate at which compaction was achieved in each of the trial sections was carefully monitored, with density checks being carried out behind the paving screed and again at exactly the same position after each pass of the primary compaction unit. The monitoring was carried out at several locations along each section, with the numbered light poles being used as reference points. The full set of compaction test results and mix temperatures **is included in Appendix 11.**

The average number of roller passes that were carried out on each of the trial sections is summarised in **Table 19. 1**

Table 19.1 Average number of roller passes carried out on each trial section

DATE	TANDEM PASSES	PTR PASSES	TOTAL PASSES	COMPACTION
25 MAY	8	9	17	*Bomag*
26 MAY	4	9	13	
27 MAY	4	6	10	
1 JUNE	5	5	10	
2 JUNE	7	6	13	*Hamm*
3 JUNE HD O 90 V	7	6*	13*	
3 JUNE HD 70	5	6*	11*	
4 JUNEHD O 90 V	8	7	15	
4 JUNEHD 70	6	6	12	

* assumed PTR passes

SASOBIT®
REDISET
Control Mix D + 10% RA

From this summary it is evident that the number of roller passes, which include initial compaction by the steel drum tandem rollers and final compaction using the pneumatic tyred roller, varies quite considerably between the different trial sections.

Several factors that influence the compaction of a particular section come into play, including:

- mix components, particularly filler/binder ratio, as well as mix temperature
- ambient conditions, including air temperature and wind speed
- effect of WMA technologies
- rolling patterns
- technologies used for primary compaction
- initial learning curve when working with new rollers

The relatively high number of roller passes required on 25 May could be attributed to the low filler/binder ratio of the first day's mix, around 1:1, which was rectified in the subsequent trial mixes by increasing the filler content to achieve a filler/binder ratio of approximately 1: 1.4.

Likewise the greater number of passes needed on 4 June to compact the asphalt in the outer lane was due to sensitivity of the mix under compaction.

It should be noted that all the six trial sections achieved the required minimum 92% MTRD level of compaction. Note should also be taken that no unusual difficulties were experienced in compacting the Warm Mix Asphalt sections.

In fact the results give some indication that both warm mix technologies resulted in easier compaction compared to the HMA control sections, thereby exceeding the objective set out for the trial, in terms of compaction.

No particular problems were found in laying the WMA in the traffic accesses between the two carriageways. This operation was mostly carrying out using handwork.

19.2 Burner fuel consumption, power usage

Fuel consumption at the asphalt mixing plant was measured using a flow meter and also by dipping the fuel tank before and after completing the production of the respective trial mixes. The fuel consumption for each day of the trials is summarised in **Table 19.2.**

As mentioned in Section 12.1, the normal production rate was maintained, and the reduction in the mix temperature was achieved by reducing the flow of fuel to the burner, which in turn lowered the temperature of the aggregates and RA. It is therefore obvious that fuel consumption of the WMA mixes is less than those of the control mixes which were manufactured at higher temperatures.

However there are some anomalies in the figures in Table 19.2, for instance the large difference in the fuel consumption based on dips and flow meter readings on 27 May; the high flow meter reading appears to be an outlier and should be disregarded. Also no clear trend is evident to show the expected differences in fuel consumptions between the control mixes and the "warm" mixes; an 11% to 12% saving in burner fuel is reported in the report on the first WMA trials carried out on Brackenhill Road in November 2008.

It therefore seems likely that these results do not reflect fuel consumption for these trials correctly and that a more accurate burner fuel measuring system should be installed to monitor burner fuel consumption in the next trials.

Table 19.2 Burner fuel consumption during the trials

Date	Mix Type	Fuel Dip (l/ton)	Flow meter (l/ton)	Average
25-May-09	Mix D +10% RA	6.67	6.19	6.43
26-May-09	Mix D +10% RA	n/a	6.36	6.36
27-May-09	Mix D + 10% RA + 1.5% SASOBIT®	6.84	8.13	7.49
01-Jun-09	Mix D + 10% RA + 2% Rediset	6.63	6.33	6.48
02-Jun-09	Mix D + 10% RA + 2% Rediset	n/a	6.36	6.36
03-Jun-09	Mix D + 10% RA + 1.5% Sasobit®	6.50	6.53	6.52
04-Jun-09	Mix D + 10% RA	n/a	7.06	7.06

During the course of each trial the amp readings of the two electric motors that drive the pugmill were taken at regular intervals. These readings remained fairly consistent and do not show any significant trends that would indicate differences in power usage to manufacture the various trial mixes.

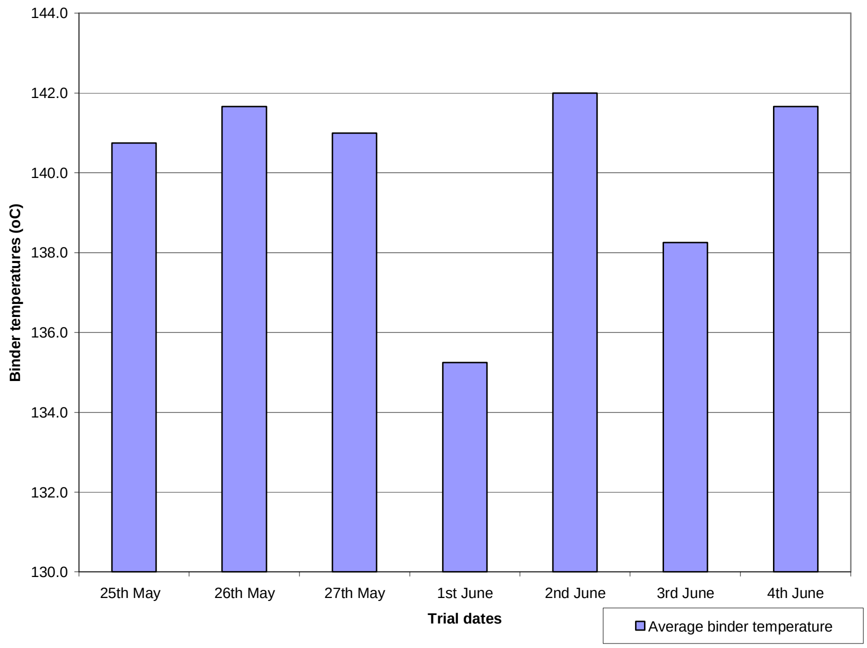
The significance of this finding is that the reduced viscosity binders of the warm mixes, and their resultant lower resistance to flow, yielded equi-viscosities at a temperature 30°C lower than their hot mix [control] counterparts.

19.3 Binder temperatures

The temperature of the binder monitored several times during the manufacture of each of the trial mixes. The average temperature for each day's production is shown in graphical form in **Fig 19.1.**

It can be seen that, except for mixes produced on 1 June (Mix D + 10% RA + 2.0% REDISET) and 3 June, where the average temperatures of the binder were 135°C and 138°C, respectively, the binder temperatures were in a close range around 141°C to 142°C.

Figure 19.1 Binder temperatures during the manufacture of the trial mixes



19.4 Binder properties

The properties of the 40/50 penetration grade bitumen used in the trials, as well as the bitumen treated with SASOBIT® and REDISET, were tested on each day of the trials. The results of these tests, which are summarised in **Table 19.3,** show that the bitumen is generally on the soft side of the specified SANS 307 penetration range, with softening point on the low side of the specification both before and after aging. As mentioned in Section 11.2, these results differ from those supplied by the refinery, which show the results to be in the middle of the specified limits. The use of SASOBIT® had the effect of slightly decreasing the penetration and increasing the softening point of the binder so that the results fall within the SANS 307 limits.

It is interesting to note that there is only a marginal reduction in the viscosity at 135^{o}C after the addition of SASOBIT®; a more marked drop in viscosity would have been expected to achieve the successful production and paving of mixes at lower temperatures found in practise in these trials. It is therefore evident that the testing protocols used do not fully illustrate the product's beneficial characteristics in this respect.

Unfortunately testing of the binder used in the manufacture of the asphalt on 1 June could not be carried out as it was apparently contaminated.

The lower penetration values as well as the higher viscosity values at 60^{o}C obtained on the SASOBIT® modified binder samples shown in Table 19.3 collate with relatively less rutting obtained under the MMLS using this WMA technology (see tables in Section 18.5).

With reference to the tables in Section 18.5, the slightly highly level of rutting under the MMLS found on the two sections where REDISET WMA technology was used could be attributed to the fact that no lime filler was used in these mixes. As noted previously, lime was added as an active filler to all the other mixes used in the trials and would have imparted a stiffening effect to these mixes.

TABLE 19.3 Properties of binder before and after RTFOT aging

TESTS BEFORE RTFOT	40/50 pen			40/50 pen + 1.5% SASOBIT®		40/50 pen + 2.0% REDISET	SANS 307
DATE TESTED	25 May	26 May	4 June	27 May	3 June	2 June	
Penetration (d.mm)	55	52	49	43	46	50	40 – 50
Softening Point (R&B) (°C)	48.0	48.1	48.2	51.4	49.2	48.1	49 - 59
Dynamic viscosity @ 60°C (Pa.s)	275.5	276	313	570.8	400	316	220 - 400
Dynamic viscosity @ 135°C (Pa.s)	0.416	0.419	0.435	0.391	0.420	0.364	0.27 – 0.65
Spot test	15	15	15				30 Max

TESTS AFTER RTFOT							
Mass loss (%)	0.104	0.087	0.074	-0.019	0.111	-0.154	0.3 Max
Retained penetration (%)	63.6	67.3	71.4	65.1	60.9	62	60 Min
Softening Point (R&B)	51.7	52.7	52.3	56.3	53.7	53.2	52 Min
Difference in Softening (R&B) (°C)	3.7	4.6	4.1	4.9	4.5	5.1	7 Max
Dynamic viscosity @ (% of original)	224.8	235.3	198	253.0	214.8	151	300 Max

19.5 Moisture contents of aggregates and RA

Moisture contents of the coarse aggregates taken during the course of the trials were found to be less than 0.5%.

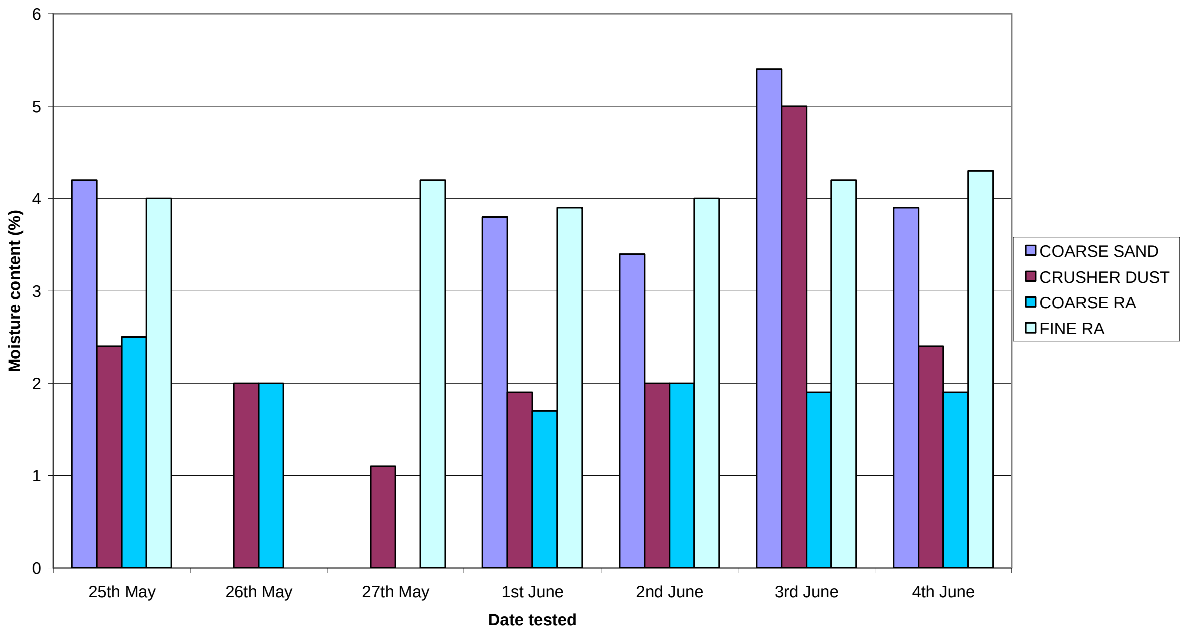
The moisture contents of the finely graded aggregates and RA used in the trial mixes are shown graphically in **Fig 19.2.**

Supplies of the coarse sand and crusher dust were replenished on 3 June. It can be seen that the moisture contents of these materials are noticeably higher than those previously stockpiled at the mixing plant.

The moisture content of the fine RA fraction is stable throughout the trials at around 4%, with the coarse fraction’s moisture content significantly lower at approximately 2%.

These relatively high moisture contents indicate the need to consider stockpiling fine aggregates and RA under shelter, such as in open sided sheds, to keep the moisture content as low as possible and thus reduce the amount of energy required to dry and heat them to the required temperature.

Figure 19.2 Moisture contents of fine aggregates and RA



19.6 Moisture contents of the trial mixes

During the course of the trials hotbox samples of newly mixed asphalt were delivered to SRT for moisture content determination using the Dean and Stark method. The moisture content of the control mixes manufactured on 25 May and 4 June was determined as 0.2% and 0.09% respectively, while that of the "warm mix" produced on 2 June, which contained 10% RA and 2% REDISET, was 0.13%.

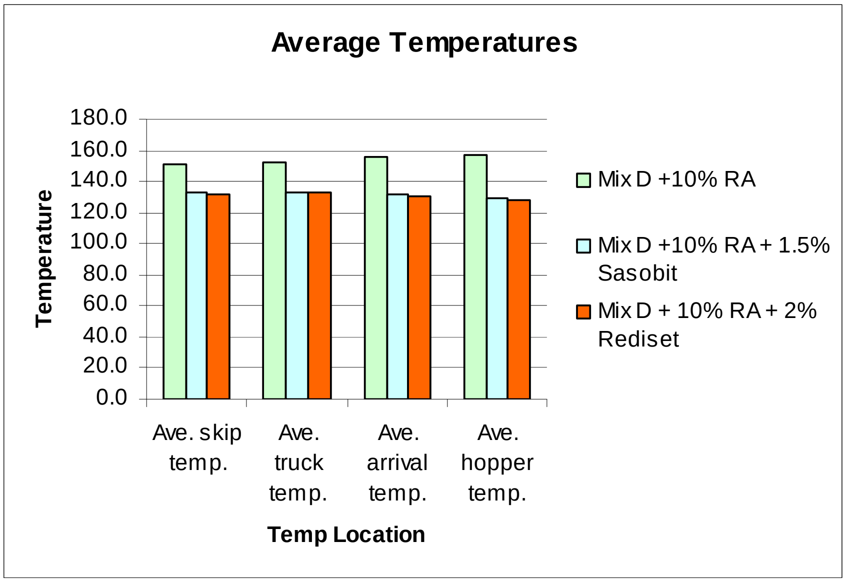
These results confirmed those obtained during the initial plant mix trials and it is evident that asphalt mixes at both normal mixing temperatures and at the reduced "warm mix" temperatures could be produced with acceptable moisture contents, well below the maximum 0.5% moisture content requirement.

19.7 Trial mix temperatures

As already mentioned, an important facet of these trials was the monitoring of mix temperatures, with temperatures being taken of every 5th skip load of freshly manufactured asphalt before it was tipped into the hot storage silo. A second temperature measurement taken of each truck load of mix, on the weighbridge. The temperature of the truck was taken again when it arrived at the paving site. Finally the temperature of the asphalt was taken as it was tipped into the paver hopper.

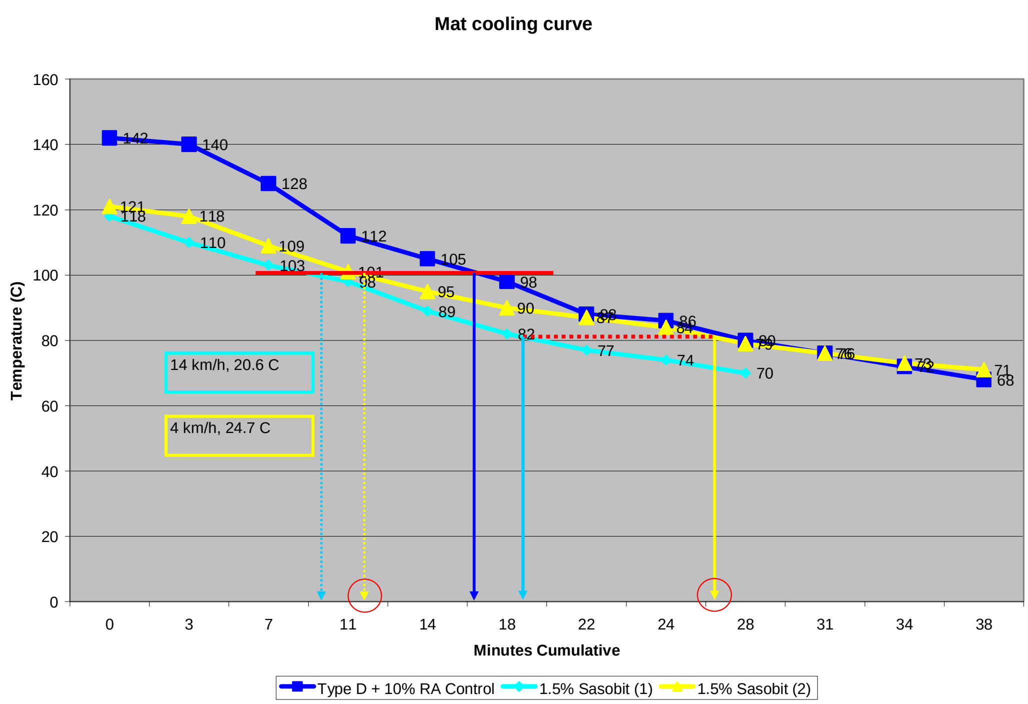
The full set of temperature measurements **is included in Appendix 11** while the average temperatures of the mixes at each monitoring point are summarised in **Figure 19.3.**

Figure 19.3 Summary of average mix temperatures at monitoring points



From this summary it is evident that the aim of producing "Warm Mix Asphalt" at temperatures at least 20°C below those of conventional asphalt mixes was achieved in these trials.

The further benefit of a widened compaction window is appropriately demonstrated when one compares the WMA cooling curves against that of the control mix and the temperature predicted by PaveCool. The curves were produced by placing a TelTru thermometer in the mat and taking readings to a minimum of 70 ℃. It i s clear that an additional 8-16 minutes (depending on air temperature and wind speed) are afforded to the paving team to reach density when using the WMA mix.



19.8 Thermal Imagery

Extensive use was made of thermal imagery to determine the temperature of the various mixes at the manufacturing plant, as well as at the paving site. This technique is useful to indicate variations in mix temperature in delivery trucks and in the newly paved asphalt mat. A set of selected thermal images and other relevant photographs **is included in Appendix 12.**

19.9 Use of a release agent on the roller drums

A release agent, Sasolwax BituGlide ™ was used on both the PTR's and Bomag & Hamm steel drum compaction rollers for the full duration of the trials. The water reservoirs of these rollers were dosed with this product where it was diluted with water and sprayed onto the roller drums.

Further details of the application of this release agent, and its benefits, **are included in Appendix 13.**

20. LONG TERM PAVEMENT PERFORMANCE MONITORING

20.1 Overview

It is intended to implement a protocol that has been developed by the Warm Mix Asphalt Interest Group to monitor long-term pavement performance (LTPP) of the trials on Leicester Road.

The pre-trial part of this protocol was carried in February 2009 and is reported in the report entitled "Rehabilitation of Leicester road between Grimsby road and Pendlebury Road" which is included in Appendix 2 of this report. It is nevertheless included below for completeness.

20.2 Pre-trial information recording

Two main types of information are gathered before the asphalt surfacing is paved:

- **Detailed Visual Inspection.** One end of the trial is designated the zero stake value, and the road is marked at intervals of 20 m across each of the traffic lanes. A detailed visual inspection is carried out by walking along each traffic lane and noting the position, extent, and severity of each type of pavement distress that occurs in each 20 m block. This information is recorded as a sketch on a suitable form. The positions of intersecting roads as well as the road widths should also be shown on these forms. The position and extent of any patching and other types of repair that are carried out on the pavement prior to paving the trial asphalt surfacing mixes should be recorded.
- **Deflection measurements.** Maximum deflection measurements are carried out at intervals of not more than 50 m using either a Falling Weight Deflectometer (FWD) or Benkelman Beam in each traffic lane. Deflection bowl measurements should be carried out at intervals not exceeding 500 m in each of the traffic lanes, or at closer intervals if the pavement design changes, using either of the deflection measuring methods mentioned above.

20.3 Post-trial monitoring

Within two weeks of the completion of the trials, the position of the zero stake value as well as the interfaces of the various sections/mix types that make up the trial should be marked using sturdy concrete posts.

The obvious aim of this work is to ascertain trends regarding the performance of the various sections/mixes.

The required type and frequency of post-trial monitoring is presented in the **Table 20.1.**

Table 20.1 LTPP monitoring period, type and frequency

PERIOD AFTER COMPLETION OF THE TRIALS	TYPE OF MONITORING	FREQUENCY
Within 1 week	Photographs	Photos showing general condition of pavement as well as any deficiencies within each mix type/section of the trials
3 to 4 months	Maximum deflection measurements Deflection bowl measurements Rut depth measurements Riding quality measurements (IRI) Detailed visual assessment Photographs Traffic data Weather	Intervals not less than 50 m in each traffic lane Intervals not less than 500 m in each traffic lane, or at closer intervals where there are changes in the pavement design. Intervals not less than 20 m in each traffic lane, with measurements in each wheel track. Intervals not less than 20 m in each traffic lane. Mark road at 20m in each traffic lane. Record type, extent and severity of pavement distress as a sketch on a suitable form. Typical pavement distress patterns on each section/mix Record any changes in traffic patterns that have occurred since the trials. Record any anomalies regarding temperature and rainfall compared to mean values for the area
12 to 14 months	Repeat monitoring as above	.
24 to 26 months	Repeat monitoring as above, check traffic counts	
36 to 38 months	Repeat monitoring as above	
48 to 50 months	Repeat monitoring as above	
60 to 62 months	Repeat monitoring as above	

20.4 Detailed visual inspection 25 September 2009

The first detailed visual inspection was carried out as part of the LTPP protocol on 25 September 2009. The road was marked at 20 m intervals on both carriageways and a thorough visual inspection was undertaken by walking along the full lengths of the carriageways, with defects being recorded on appropriate forms. Photographs of the road's surface were taken at intervals of at least one photograph per 100 m.

The detailed visual inspection forms and photographs **are included in Appendix 14.**

Very few serious defects were noted at this relatively early stage in the pavement's life. Two aspects were however notable:

- the surface texture of the two sections of the Control Mix as well as the WMA sections containing SASOBIT tends to be more open that that of the two WMA Sections containing REDISET. Indeed, the surface texture of the REDISET section paved on 2 June on the north bound carriageway is quite smooth and closed where heavy vehicle loads tend to be concentrated, near the Leicester Road/ Pendlebury Road intersection.

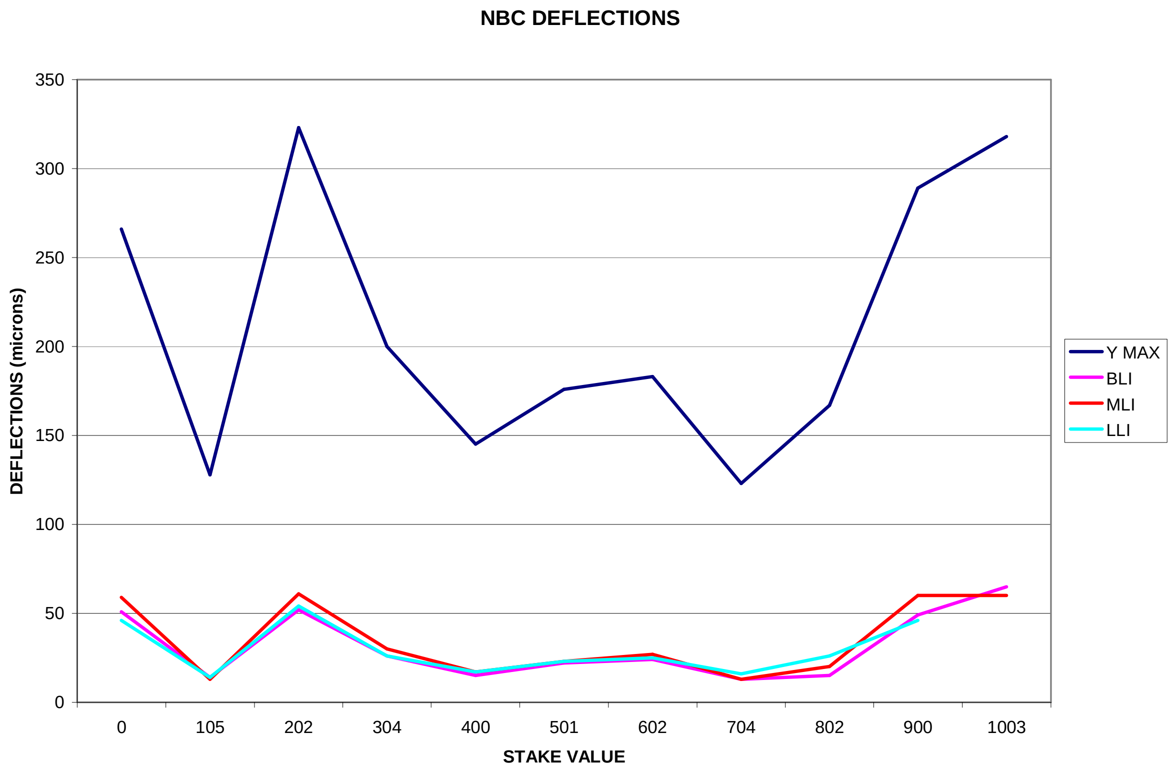
- the longitudinal joint is tending to ravel in places; this is particularly evident on the control sections as well as on the WMA sections where SASOBIT was used in the mix. This problem is less evident on the REDISET sections and could relate to the tendency for mixes using this technology to be more pliable under the wheel loads.

20.5 Deflection measurements

During September 2009 deflection measurements were carried out along the slow lanes in both carriageways at intervals of 100 m using a Falling Weight Deflectometer.

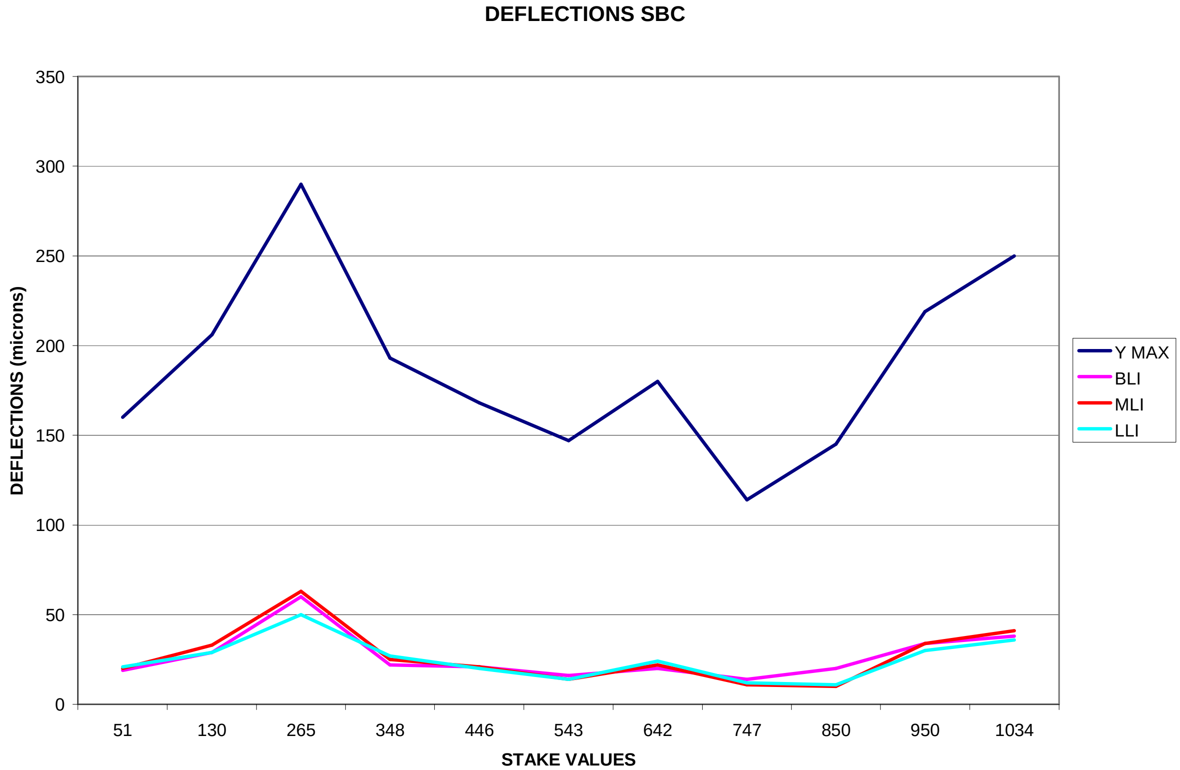
The maximum deflection measurements (Y Max), as well at Base Layer Index, Middle Layer Index, and Lower Layer Index for each carriageway are plotted in **Figures 20.1 and 20.2.**

Figure 20.1 Deflection measurements North Bound Carriageway



Average Y max	90th Percentile Y max
211	318

Figure 20.2 Deflection measurements South Bound Carriageway



Average Y max	90th Percentile Y max
188	250

A full set of the deflection measurements is included in Appendix 14.

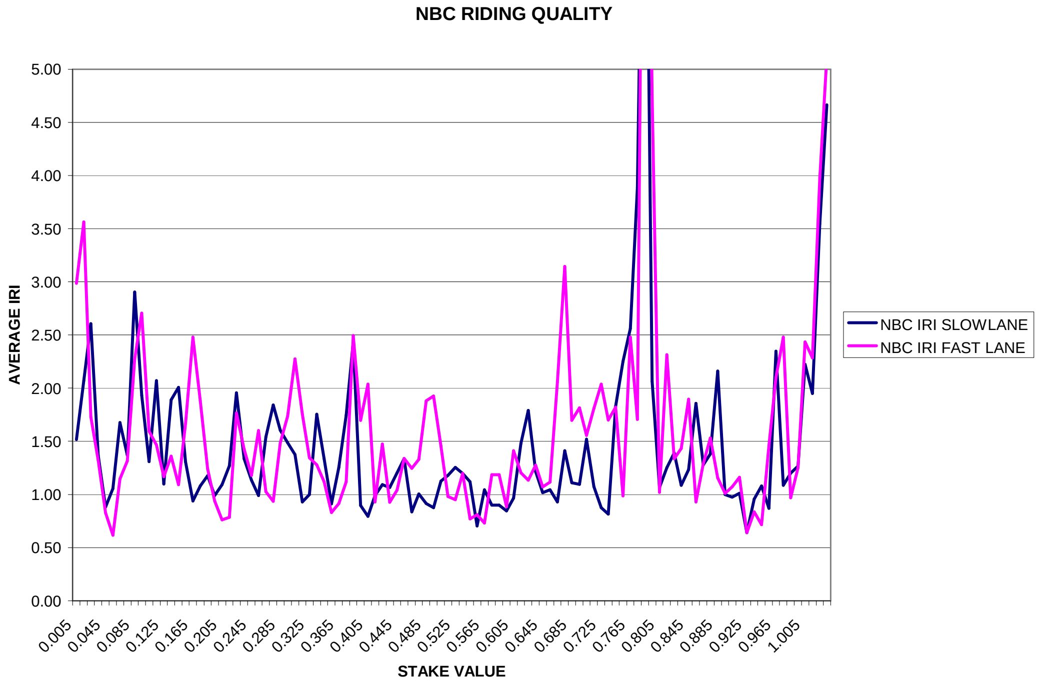
20.6 Riding quality and rut depth measurements

Rut depth and riding quality measurements were carried out by SRT using their Road Profiler during October 2009. The measurements were carried out in both slow and fast lanes of each carriageway.

The riding quality measurements, expressed as International Roughness Index (IRI) are plotted in **Figures 20.3 and 20.4 for north and south bound carriageways respectively,** with average and 90th percentile values tabled below each figure.

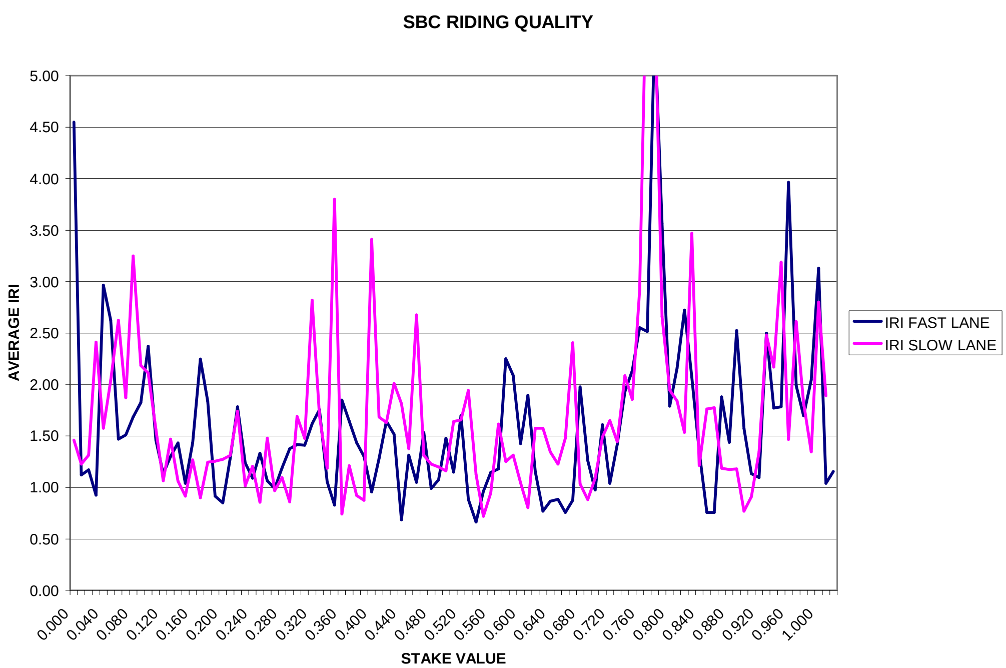
It should be noted that the riding quality measurements close to the intersections at both ends of the trials are not included in these analysis as the relatively high level of roughness in these areas would tend to distort the overall riding quality values.

Figure 20.3 Riding quality measurements (IRI) North Bound Carriageway



Lane	Average IRI	90th Percentile IRI
Fast	1.6	2.5
Slow	1.5	2.2

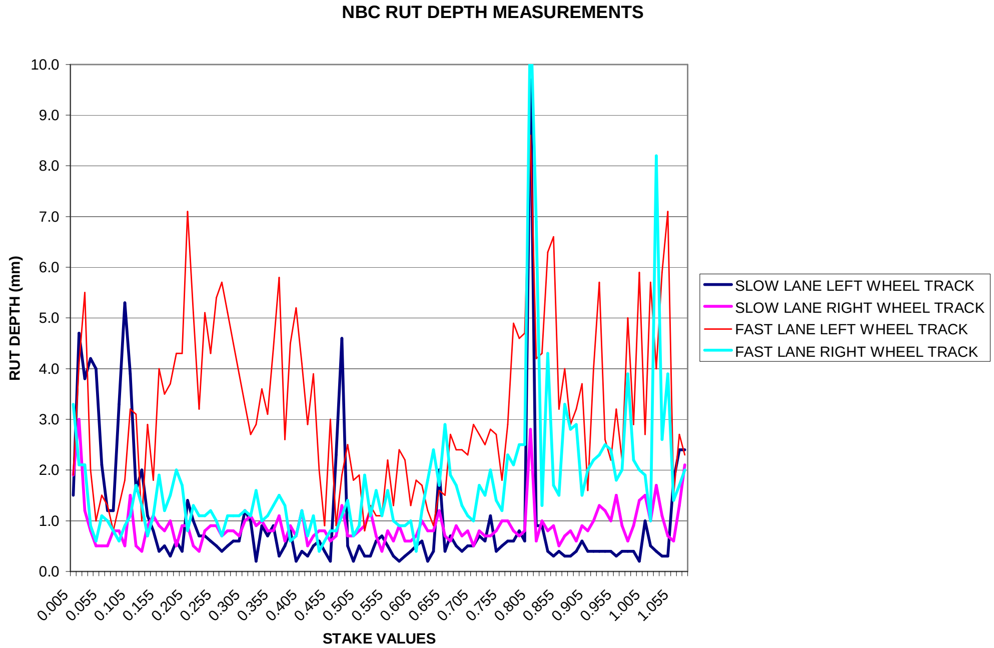
Figure 20.4 Riding quality measurements (IRI) South Bound Carriageway



Lane	Average IRI	90th Percentile IRI
Fast	1.6	2.5
Slow	1.8	2.8

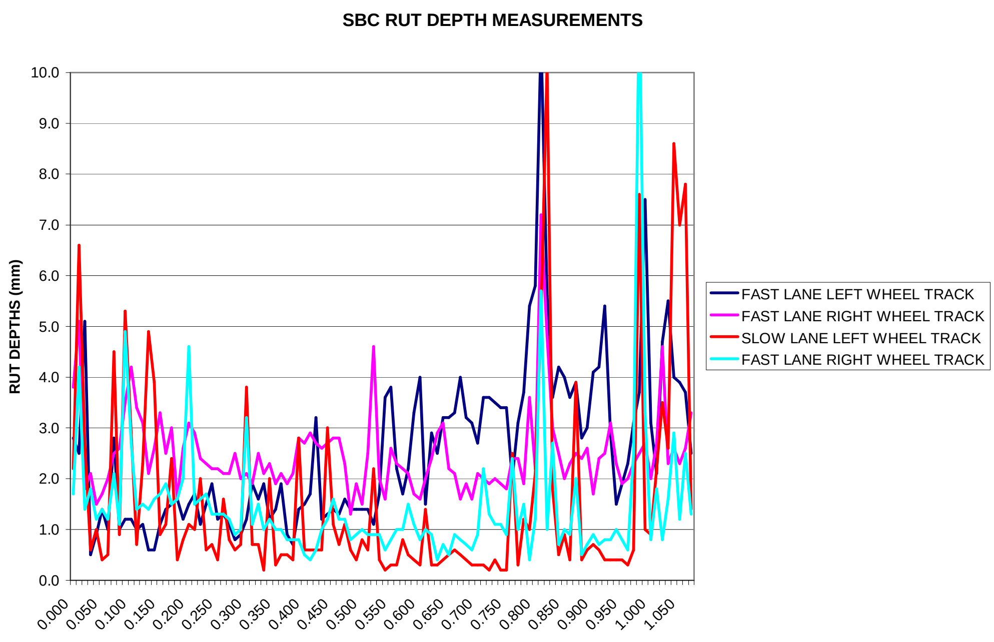
The rut depths were measured along the left and right hand wheel tracks in each of the traffic lanes. The measurements are plotted in **Figures 20.5 and 20.6**. Average maximum rut depths and 90th percentile values are tabled below the plots.

Figure 20.5 Rut depth measurements on North Bound Carriageway in slow and fast traffic lanes, in left and right hand wheel paths



Lane	Left hand wheel track		Right hand wheel track	
Rut depth	Max. average	90th percentile	Max. average	90th percentile
Fast	3.2	5.6	1.7	2.7
Slow	1.0	2.3	0.9	1.3

Figure 20.5 Rut depth measurements on South Bound Carriageway in slow and fast traffic lanes, in left and right hand wheel tracks



Lane	Left hand wheel track		Right hand wheel track	
Rut depth	Max. average	90th percentile	Max. average	90th percentile
Fast	2.5	4.1	2.5	3.3
Slow	1.5	3.9	1.5	2.5

A complete set of the riding quality and rut depth measurements is included in Appendix 14.

The survey carried out by the Road Profiler also included a sequence of photographs taken at 10 metre intervals along each traffic lane. These comprehensive set of photographs will be useful in the future, to supplement those taken as part of the Detailed Visual Assessment, in monitoring the pavement's performance. Due to the considerable size of the files containing the photographs they are not included in the appendices, but have been stored on disk for later use in assessing long-term pavement performance.

20.7 Summary of LTPP monitoring to date

LTPP monitoring to date consists of a detailed visual inspection, as well as deflection, riding quality and rut depth measurements. As this is only the first set of LTPP data available it is too early to make any real comparisons in the relative performance of the trial sections. It does however form a strong and comprehensive base for future use in terms of the LTPP protocol.

21. SUMMARY OF FINDINGS

A great deal of effort was put into these, the second WMA trials in South Africa, to apply the lessons learnt in the first WMA trials on Brackenhill Road. Based on this experience, a template was drawn up to include a large number of factors that would affect the quality of information gained from these trials. This template was used throughout the trials and proved invaluable as a comprehensive checklist.

Considerable attention was given to managing all aspects of the trials, in particular to ensure that there were sufficient persons at various levels to cope with the work, from overall management of the project, management and supervision of the manufacturing and paving processes, to the monitoring of temperatures and roller passes. The effort required to manage and coordinate the large sampling, testing and monitoring programme should not be underestimated and it is recommended that this aspect be given special attention in future trials.

Leicester Road provided an excellent test bed, with a flat grade and sufficient space to carry out replicate trials on each of its dual carriageways. A 90 mm thickness of the existing aged asphalt was milled out and inlaid with new asphalt to provide a uniform, stable platform under the 50 mm asphalt surfacing that formed the trials.

The trials included two WMA technologies, SASOBIT®, which was used previously in the Brackenhill road trials, and REDISET, an Akzo Nobel product that was to be used for the first time in this country.

It was decided that the trials would include a total area of approximately 20 000 m^2, using three different mixes:

- Mix D with 10% RA
- Mix D with 10% RA + Rediset
- Mix D with 10% RA + SASOBIT®

Sufficient quantities of RA were provided by eThekwini Municipality and were taken to National Asphalt plant in Shongweni where it was screened into two fractions.

Much Asphalt's batch-type mixing plant at Coedmore was used to manufacture all the mixes, which were paved by National Asphalt on the section of Leicester Road between Grimsby Road and Pendlebury Road.

Routine testing of the asphalt mixes was carried in Much Asphalt's laboratory at their mixing plant, while specialised testing was undertaken by SRT and the CSIR.

Before the trials commenced the designs of the three mixes were thoroughly explored in the laboratory as well as in full-scale plant trials. Preliminary paving trials were carried out using the two "warm mixes" so as to pinpoint any problems peculiar to these mixes prior to the actual trials.

A feature of these trials was the use of two specialised compaction technologies; Bomag demonstrated their Asphalt Manager technology while Hamm, which is part of the Wirtgen Group, displayed their Oscillation compaction technology.

The most pertinent findings from these trials include:

- The core aim of the WMA Interest Group's work of "producing WMA at the target temperatures with a resulting pavement that is at least as good as the control HMA" was successfully achieved. Two of the WMA mixes were in fact slightly superior to the control HMA as far as deformation resistance under MMLS accelerated trafficking is concerned.

- All six trial sections were successfully compacted to achieve the required minimum 92% MTRD level of compaction. There is some indication that, in general, the WMA mixes required fewer roller passes to reach density than the control Type D mix.

- The trials showed that asphalt mixes containing 10% RA could be manufactured in the batch-type mixing plant at both normal HMA and reduced "warm mix" temperatures with moisture contents well below the usual maximum 0.5% permissible moisture content.

- The principle aim of producing "Warm Mix Asphalt" containing 10% RA, at temperatures at least 20^{o}C below those of conventional asphalt mixes, was achieved in these trials.

- No significant trends in the amount of energy required to produce the different mixes were obvious from amp readings taken during the manufacture of the six mixes. The significance of this finding is that the reduced viscosity of the binders used in the warm mixes, and their resultant lower resistance to flow, yielded equi-viscosities at temperatures of at least 20^{o}C lower than their hot mix (control) counterparts.

- The reduction in the temperature of the "warm" mixes was achieved by reducing the flow of fuel to the burner while maintaining the usual production rate. Nevertheless no distinct trend was found between the burner fuel consumption figures of the control mixes and the "warm" mixes. This is contrary to the finding from the Brackenhill WMA trials as well as the general trend of a minimum saving of 15% as reported from other international projects. It is recommended that closer attention be paid to the fuel measurement system to ensure their accuracy in future WMA trials.

- Emission measurement were not carried out in these trials, however fuming and strong odours emanating from the "warm" mixes were noticeably less than that of the conventional HMA mixes. The lower temperatures of the WMA mixes also made for more pleasant working conditions at the paving site.

- The trials have confirmed that the period available to compact the asphalt layer after it has been paved, commonly known as the "compaction window", is significantly extended in the case of WMA.

Lessons learnt and Recommendations

As already mentioned, the template was found to be an extremely valuable tool, and very little modification to it will be necessary when it is used again in the next trials.

However two lessons learnt from these trials are that:

- Consideration should be given to thoroughly check the quality of the full quantity of all the aggregates that are to be used in the trials. Preferably sufficient quantities of aggregates that are to be used in the trial mixes should be stockpiled beforehand so that it will not be necessary to replenish these material during the course of the trials. These measures will assist in ensuring that the trial mixes are of consistent quality

- With burner fuel consumption being an important factor, a concerted effort should be made to monitor this parameter carefully

It is clear from this trial that the production and construction temperatures of the WMA mixes can be reduced even further. A target of 40℃ below conventional HMA temperatures is felt to be achievable.

The advantage of a wider "compaction window" should be explored further. Significant benefits could be expected in being able to pave at lower ambient temperatures and in extended haulage distance/time.

The Warm Mix Asphalt Interest Group feels confident to recommend that future trials should be structured to incorporate higher percentages of RA to optimise the cost and environmental benefits.

The inclusion of RA that already contains WMA technologies in recycled asphalt mixes would be worthwhile investigating - it may be possible to utilise any active ingredients or characteristics in the recycled mixes.

Conclusion

Excellent cooperation and technical backup was received from both the WMA Technology and Compaction Technology suppliers during the entire course of the trials. Similarly there is no doubt that the exceptionally good relationship and team spirit that was evident throughout the work between the client, manufacturing and paving contractors contributed to the success of these trials.