Case Study on the Developments Towards More Environmentally Sustainable Road Design and Construction

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***Abstract* — Over the past few decades the global development of infrastructure has shifted towards a more environmentally friendly route. This has triggered Engineers to consider alternatives that are less harmful to the ecosystem.**

The Department of Transport in KwaZulu-Natal is responsible for the provision and maintenance of approximately 8100 kilometres of paved roads. Environmentally sustainable development is in demand; however, it is becoming a challenge to ensure that the current road network is preserved to provide an adequate Level of Service whilst mitigating harmful effects on the environment. There are merits in the preservation of virgin materials removed from the earth, as well as reducing greenhouse gas emissions and consequently the reduction of waste in landfills.

The recycling of waste material has a positive outlook in lieu of the depletion of non-renewable resources and decreasing the carbon footprint. In an effort to prevent such effects from occurring, re-using waste material in pavement construction may achieve just that. This approach has been used in the upgrading of a six-kilometer urban arterial between Durban's Hillcrest and Waterfall suburbs which has proven to be successful.

This paper outlines several environmentally beneficial alternatives such as the recycling of concrete waste, in-situ pavement layers and reclaimed asphalt (RA) in pavement rehabilitation. Warm Mix Asphalt (WMA) which has significantly reduced mixing and paving temperatures is also discussed.

This paper details the process and covers the benefits that were found by recycling/re-using waste material.

Keywords — Warm mix asphalt, reclaimed asphalt, recycled waste concrete

I. Introduction

Due to the rapid development of Durban's Western Suburbs, the Province of Kwa-Zulu Natal decided to upgrade the existing Provincial Road P255 between Hillcrest and Waterfall from a single carriageway to a divided dual carriageway facility. VNA Consulting undertook the design, contract documentation and supervision of the project, which is located about 30 kilometres inland of Durban. The upgrading of this strategic six-kilometre urban arterial included widening the existing road prism to accommodate the additional traffic lanes as well as the construction of bus bays and turning lanes at major intersections. The work also involved the rehabilitation/strengthening of the existing pavement. A centre median island was constructed to divide the two carriageways.

The installation of new storm water and sub-surface drainage systems was a significant and integral aspect of the project. Appurtenant works included, inter alia, the installation of guardrails, construction of sidewalks, installation of street lighting and signalisation of the major intersections. The design also required the relocation of electrical, water and telephone services.

The pavement along the existing traffic lanes was in a poor condition and required strengthening. Innovations on this project included an asphalt base using Warm Mix Asphalt containing 25% reclaimed asphalt (RA), as well as the utilisation of crushed concrete waste that was generated from this contract in the reconstruction of the pavement and sidewalks.

II. Materials Investigation

The materials investigation and pavement design of Provincial Road P255 was completed in 2011. Non-intrusive investigations included a detailed visual inspection [1] as well as deflection measurements using a Falling Weight Deflectometer (FWD) along both of the existing traffic lanes [2]. The intrusive investigations comprised of test pits in the traffic lanes as well as in areas where the road prism was to be widened while Dynamic Cone Penetrometer (DCP) [3] testing was carried out along the existing traffic lanes.

The detailed visual inspection showed that a large proportion of the total length of the project was in the "severe" condition, particularly in terms of structural pavement distress.

The maximum deflection measurements showed the pavement to be in a "severe" condition over most of the project, with high 90th percentile deflections of over 1000 microns, indicating that the pavement structure was approaching the end of its structural life. A more detailed analysis of the deflection bowls indicated that the upper pavement layers were comparatively weak, while the lower layers and subgrade displayed adequate to good stiffness values.

In general, the test pits verified the weak pavement structure indicated by the deflection measurements. Over most of the project's length, the surfacing consisted of aged, brittle and cracked gap-graded asphalt on top of the original chip seal surface treatment.

The thickness of the asphalt in the test pits, as well as from additional core samples, was found to be at least 40 mm. Testing was carried out to recover the binder [4] from the cores. The results of penetration and softening point are useful to ascertain the aged properties of the binder; typical results of these tests are shown in Table I.

TABLE I. TYPICAL RECOVERED BINDER PROPERTIES

Core No.	Location (km)	Binder Content (%)	Penetration (1/10mm)	Softening Point (°C)
5	2.440	5.7	13	74.0
8	3.510	6.3	18	65.0
10	4.150	5.9	14	68.6

It can be seen from these results that the binder recovered from the asphalt surfacing had aged and exhibited relatively low penetration and high softening values compared to the 40/50 penetration grade bitumen that was probably used in the original mix. Taking these results into account, it made good sense to specify that the asphalt be milled off so that it could be utilised in recycled asphalt mixes on this or other projects in its vicinity.

III. PAVEMENT DESIGN

The pavement design, which was based on a 20-year structural design life, utilised information obtained from a 7-day electronic traffic count carried out in 2011. An analysis of this data resulted in design traffic of approximately 5 million Equivalent Standard Axle Loadings (ESALS) and the following pavement design was selected [5]:

40 mm	Stone mastic asphalt surfacing
80 mm	Asphalt base
300 mm	Cement stabilised subbase
150 mm	Upper selected gravel
150mm	Lower selected gravel

As covered in the section below on pavement construction some of the materials from the upper layers were salvaged and reused in the new pavement but it was necessary to import most of the layer works, including the subbase, from local commercial sources.

IV. SPECIFYING WARM MIX ASPHALT

The use of Warm Mix Asphalt (WMA) was prompted by the rapid increase in the use of this product in several countries that showed:

- The potential to reduce burner fuel consumption in the asphalt mixing plant, resulting in decreases in greenhouse gases
- Easier compaction, with the potential of reducing the cost of compacting the paved mix and improving workability for handwork
- The possibility of longer haulage distances, making it possible to utilise the asphalt mix further from an asphalt plant.

Similar benefits were found in the use of WMA during a succession of trials that were carried out in South Africa between 2008 and 2010, which culminated in the compilation of a best practice guideline [6]. Based on these findings, it was therefore decided to specify WMA containing at least 25% of RA for the approximately 20 000 tons of asphalt base required on this project. In essence WMA enables asphalt to be mixed and paved at temperatures of at least 20°C below those of similar conventional asphalt mixes while maintaining at least the same performance.

Several technologies may be used to produce WMA; these include chemical and rheological modifiers as well as "water technologies", which are based on the addition of zeolite or on the use of foamed bitumen. As discussed in more detail later in this paper, the asphalt supplier on this contract opted to use foamed bitumen technology.

Although not covered in more detail in this paper, it should be mentioned that the asphalt supplier chose to modify the bitumen used in the manufacture of the SMA surfacing with synthetic wax. The primary aim for adding 3% of F-T wax into the 50/70pen bitumen was to improve the ability of the mix to maintain a high film thickness without the risk of the binder draining from the aggregates during mixing, transportation and paving. Additionally, the thick binder films positively affect the fatigue and aging behaviour of the asphalt. The mix design showed that satisfactory drainage characteristics could be achieved with a binder content of 6.5% and film thicknesses around 12 microns.

The secondary reason for using the F-T wax in the SMA surfacing mix was its effectiveness as a warm mix agent, enabling lower mixing and paving temperatures.

V. PAVEMENT CONSTRUCTION

As already mentioned in the materials investigation of this paper, the existing two-lane carriageway was in a poor condition and the weak pavement required substantial strengthening. Due to its poor condition, as well as the need to widen the road to incorporate a new carriageway and turning lanes, it was necessary to reconstruct all the pavement layers in the existing pavement structure. While some of the materials from the upper layers were salvaged and reused in the new pavement, it was necessary to import most of the layer works materials from local commercial sources.

The subbase, which consisted of a blend of weathered granite gravel and graded crushed tillite rock, was stabilised with 2.5% cement, using a recycler. Due to the high moisture content of the subgrade along some sections, it was deemed necessary to undercut and to install a layer of crushed rock to produce a stable surface on which to construct the pavement layers.

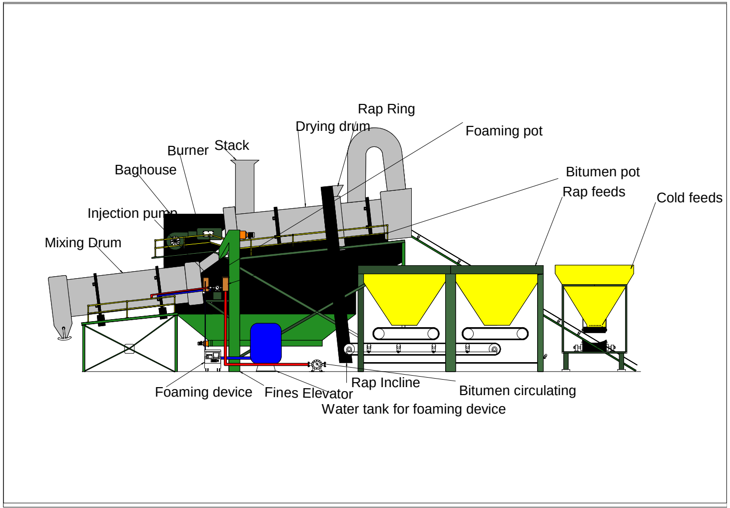

Fig. 1. *Diagram of a Twin Drum Asphalt Mixing Plant Showing the Foamed Bitumen Sytsem*

VI. THE DESIGN, MANUFACTURE & PAVING OF THE ASPHALT BASE

A. The use of Foamed Bitumen in The Asphalt Base

The asphalt supplier selected to use foamed bitumen in the manufacture of the Warm Mix Asphalt (WMA) base. The main reason for this was that previous trials had shown this technology to be the most cost-effective and reliable. Mixing was carried out at their Cliffdale asphalt plant that is located approximately 14 kilometres from the project. This plant is equipped with a specialised propriety foam generation system that produces the foamed bitumen which is fed into the mixing drum of their twin drum mixing plant as shown diagrammatically in Figure 1.

The basic principle of this process is to feed hot bitumen into a chamber where a relatively small quantity of water (normally between 1% and 3% by mass of the binder) is introduced under pressure. The water vaporises on contact with the hot bitumen causing it to expand approximately 16 times the original volume of the bitumen. The foamed bitumen is discharged directly into the asphalt plant's mixing drum where it mixes with the heated aggregate. The reduced viscosity of the foamed bitumen enables it to coat the aggregate particles at significantly lower temperatures than conventional bitumen; it continues to improve the compaction characteristics of the asphalt mix while maintaining its workability.

The two main properties of foamed bitumen that affect its performance are known as "expansion ratio" and "half-life" [7]. These properties can be examined using the plant's sampling system. The sample of foamed bitumen is collected in a steel container where its expansion ratio as well as its half-life can be measured. Altering the quantity of water that is injected into the hot bitumen tends to alter these properties. Increasing the quantity tends to increase the foamed bitumen's expansion ratio and decrease its half-life while a decrease in the quantity of water has the opposite effect.

B. The Inclusion of 25% RA in the Mix

A minimum of 25% of reclaimed asphalt (RA) was specified on this contract with its economic and environment benefits in mind, such as extracting the highest value from RA that may be sourced from other nearby rehabilitation contracts. It also reduces the quantity of new aggregates in the mix that have to be mined and crushed. An additional benefit is that the binder in the RA replaces some of the bitumen required in the mix.

The lower manufacturing and paving temperatures of the WMA are likely to reduce the inevitable hardening of the binder that takes place during manufacture and paving.

The preparation of the RA before use included crushing it using a vertical impact crusher to reduce aggregations and to then screen it into two fractions, minus 20 mm and minus 12 mm. The larger sized fraction contains around 1.6% binder while the smaller fraction contains approximately 4.8% binder.

This binder contributes to the total amount of binder required to obtain the mix's optimum binder content.

As can be seen in Figure 1, the plant used to produce the WMA consisted of a locally designed and manufactured twin drum mixing plant with separate drying and mixing drums. The drying drum has inner and outer barrels. The RA is introduced into the outer barrel via a calibrated cold feed bin and conveyor while the virgin aggregates are dried and heated in the inner barrel. The heated RA and virgin aggregate are mixed together in the mixing drum. The foamed bitumen is injected into the mixing drum where it is mixed together with the heated aggregate and RA.

As it was not found possible to accurately reproduce the mix on a laboratory scale using foamed bitumen, the initial mix design for the minus 28 mm continuous graded base mix was carried out using standard grade bitumen. The Bailey Method was used to optimise the gradation of the mix.

C. Full-scale mixing and Paving Trials

The second step was to manufacture the mix full-scale in the asphalt plant using the same aggregate proportions as those used in the laboratory mix but replacing the penetration grade bitumen with foamed bitumen. Four separate batches of asphalt were produced at different binder contents and the optimum binder content was established by analysing the test results of each batch.

A paving trial was then carried out to check the mixing and paving temperature limits applicable to mix, its compaction characteristics, as well as its mix properties. The opportunity was taken to establish the effect of two different grades of bitumen, 35/50 pen and 50/70 pen, in the mix. Rut resistance of both mixes, using MMLS3 accelerated wheel loading tests [8], were found to be similar and it was decided to continue with the more readily available 50/70 pen grade bitumen.

Pertinent details of the approved mix are summarised in Table II.

TABLE II. PERTINENT MIX DETAILS

Mix proportions:	
20 mm quartzite	22%
14 mm quartzite	12%
10 mm tillite	8%
Crusher dust tillite	20%
Washed quartzite dust	12%
Minus 20 mm RA	10%
Minus 12 mm RA	15%
Hydrated lime	1%
Manufacturing temperature	130 – 140°C
Compaction temperature for Marshall briquettes & Gyratory testing	105°C
Optimum binder content	4.0%
Air permeability ($x10^{-8}$ cm^2) @ 7% void content	0.3
Modified Lottman TSL	0.92
Void content after 300 gyrations @ 105ºC	3.9%

D. Quality Control

The asphalt supplier carried out testing for process control while the consultant was responsible for acceptance control testing in their site laboratory. The consultants also monitored the temperature of each load of asphalt delivered to the paver. Three of the parameters used for acceptance control including binder content, void content and relative compaction, were controlled using the specified statistical judgement plan [9].

Surface levels and layer thickness were also processed statistically, with levels being determined at exactly the same points before and after paving the layer. The thicknesses obtained through the level survey were verified by physical measurement of asphalt cores

Process control for the compaction of the 80 mm WMA base layer was undertaken using a thin surface nuclear gauge, taking frequent measurements as the compaction progressed [10]. Acceptance control in respect of compaction was carried out by determining the density of cores extracted from the layer after it had been fully compacted and had cooled.

E. Paving the Base

A total of just under 20 000 tons of WMA base was paved on this contract. Typical of this sort of project, where traffic has to be accommodated during construction, the asphalt base was paved as soon as a sufficient length of subbase had been approved, with traffic running on the base while the selected and subbase layers were being constructed on other sections. This resulted in short bursts of paving with pauses of a few weeks in between.

Besides a slightly shinier appearance, the WMA containing 25% RA was visually similar to that of conventional asphalt. There were however very noticeable reductions in the temperature at which the mix arrived at the paver. The normal mixing temperature for asphalt using 50/70pen bitumen is between 155°C and 165°C, however the average manufacturing temperature of the WMA base over the full term of this contract was found to be 132.5°C, a reduction in the order of 30°C.

Compaction was carried out using an 8-ton tandem steel-wheeled vibratory roller. A 21-ton pneumatic tyred roller followed this while a smaller 4.5-ton steel-wheeled roller completed the compaction and finishing processes. Typically, four roller passes of the 8-ton tandem roller and four passes of the pneumatic tyred roller were required to compact the mix; similar to the compaction that would be applied to a conventional asphalt mix.

Typical results of the routinely paved mix, together with those specified in the tender documentation, are summarised in Table III.

TABLE III. SUMMARY OF TYPICAL RESULTS

Sieve analysis Sieve size (mm)	Percentage Passing	Specification
28	100	100
20	97	87 - 96
14	84	73 - 85
10	70	64 - 79
5	52	43 - 61
2	33	28 - 44
1	23	20 - 35
0.6	18	15 - 30
0.3	13	11 - 24
0.15	8	8 - 19
0.075	5.7	5 - 12
Bitumen content (%)	4.2	3.7 - 4.3
Void content (%)	4.9	3.0 – 6.0
ITS (kPa)	1023	800 min.
Compaction (%)	94	92.1 min

As a means of checking the rut resistance of the mix, a series of cores were taken from the paved base and subjected to accelerated wheel load testing, using MMLS3 equipment. The results, which are included in Table IV show that the asphalt mix has satisfactory resistance to rutting; MMLS rut depths of 2 mm or less have been found to perform well regarding their rut resistance [8].

The properties of binder recovered from the mix are also shown in Table IV. This show that the mix has only decreased by one grade (from 50/70 pen. to 35 pen.) despite the fact that it contains 25% RA with a low penetration of between 13 and 18 (refer to Table I), these results suggest that the lower mixing temperature has contributed to less aging of the binder compared to conventional mixes manufactured at higher temperatures.

TABLE IV. SUMMARY OF MMLS RUT RESISTANCE TESTS

Average void content (%)	6.6
Average rut depth after 100 k repetitions (mm)	1.82
Penetration @ 25 ºC (1/10 mm)	35
Softening Point (ºC)	56.4

F. Summary of Experience with WMA

Approximately 20 000 tons of WMA base containing 25% of reclaimed asphalt was successfully used on this project. Very few problems were experienced in the use of foamed bitumen and compaction was successfully achieved at around 30ºC below the paving temperatures of similar conventional asphalt mixes. In fact, the paving crew and handwork team found that the mix behaved in much the same way as conventional mixes at higher temperatures.

Unfortunately, due to the stop-start nature of this project, it was not possible to assess the reduction in burner fuel consumption that is usually recorded when manufacturing WMA.

VII. UTILISING CONCRETE WASTE

Concrete waste that is generated during the upgrading of a road, such as old concrete side drains, kerbs and channelling, is normally disposed of in spoil dumps or landfills. However, on this contract it was decided to recycle the waste and to utilise it in the pavement layers. The equipment used to process the waste consisted of a large, mobile impact crusher and a mobile power screen.

Once the waste had been stockpiled, large pieces were broken down so that they could fit into the mouth of the crusher using a vibrating "pecker" type hammer fitted to a crawler-mounted excavator. The crushed material was fed onto the power screen where it was sieved into two sizes, with oversized fragments being returned to the crusher. Up to 5% of silty sand was added to the crushed concrete to improve the grading.

A typical grading of the blended material is illustrated in Table V. The CBR at 95% Modified AASHTO compaction was found to exceed 50 while the grading meets the specified requirement for cementitiously stabilised subbase [11]. This material was utilised in the subbase layer, where it was stabilised with 2.25% cement. It was also used in other areas, such as the base of the sidewalks.

TABLE V. SUMMARY OF MMLS RUT RESISTANCE TESTS

Sieve Size (mm)	Percentage Passing
37.5	100
20	80
5	47
0.425	15
0.075	5

Typical properties of the crushed concrete waste blend after stabilisation are shown in Table VI.

TABLE VI. TYPICAL RESULTS OF TESTS AFTER STABILISATION

Property	Typical Range	Specification
Unconfined compressive strength @ 100% Mod. AASHTO compaction (MPa)	2.0 to 3.3	Min. 1.5 MPa
Indirect tensile strength (@ 100% Mod. AASHTO compaction (kPa)	350 TO 385	Min 250 kPa

As can be seen from the above Table, the UCS and ITS results of the crushed concrete waste blend exceeded the specifications. In total, approximately 8 000 m^3 of the crushed concrete waste was successfully utilised on this project, with both economic as well as environmental benefits. Recycling of the waste meant that less material had to be imported for the pavement layers. In addition, the concrete waste could be utilised on site instead of having to dispose of it in a landfill, reducing haulage costs as well as improving the environmental friendliness of the process.

VIII. Conclusions

This paper illustrates the successful use of Warm Mix Asphalt (WMA) containing 25% of reclaimed asphalt (RA) on a Provincial Road contract in Kwa-Zulu Natal, South Africa. A reduction in the manufacturing and paving temperature of at least 20ºC was realised compared to that of similar conventional asphalt mixes.

The temperature reduction was achieved through the use of a specialised foamed bitumen system. The foamed bitumen enables the aggregate to be coated at significantly lower temperatures and its lower viscosity continues during the paving process to enable compaction at these lower temperatures.

The requirement for at least 25% of reclaimed asphalt to be used in the mix means that 25% less virgin aggregate has to be sourced from commercial quarries; this obvious results in economic and environmental benefits. The binder in the RA also contributes towards the total quantity of binder in the asphalt mix, reducing the use of "new" bitumen and resulting in further cost savings.

Results show that the qualities and characteristics of the WMA base mix being used on this project complies with the same standards as that of asphalt manufactured at conventional temperatures. Rut resistance testing carried out during the trial paving stage, as well as during routine paving, show satisfactory results.

Another feature of this project was the successful use of reclaimed waste concrete in the pavement layers. After crushing and screening the material was used in the stabilised subbase as well as for the base layer in the sidewalks. This resulted in both economic and environmental benefits; less material had to be imported from commercial sources, reducing costs, while the waste was reused instead of being disposed of in a landfill, saving haulage costs and enhancing environmental friendliness.

Based on the experience gathered on this project, the utilisation of innovative materials designs, such as the use of Warm Mix Asphalt with the addition of reclaimed asphalt, as well as the use of recycled concrete waste, has not negatively impacted the performance of the road structure; short-term performance of the pavement can be regarded as entirely satisfactory. The benefits, both economic and environmental, indicate that these technologies will contribute to more sustainable road construction practice and further assessment into the re-use of other, so called waste products, is recommended.

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