

INVESTIGATION OF THE EARLY PERFORMANCE PROPERTIES OF A PAVEMENT, RECYCLED WITH FOAMED BITUMEN AND EMULSION THROUGH FIELD TESTING

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ABSTRACT

The use of foamed bitumen for the modification and improvement of roadbuilding materials is increasing globally. This is mainly due to the increased commercial availability of static and mobile plants with the capacity to produce foamed bitumen following the lapse in patents on the foam nozzle system. As new rehabilitation procedures for maintenance and upgrading of the South African road network such as “In place cold recycling with foamed bitumen” emerge, so a level suitable level of understanding of these processes and reliability in the products requires development.

The primary objective of the research was to further the understanding of foamed bitumen treatment. This was carried out by characterising the foamed materials with the same tests as the equivalent emulsion treated materials, which is a better-understood product. In addition to the standard tests, triaxial testing was also carried out on the foamed mix only, as part of a research investigation.

Accelerated Pavement Testing (APT) was performed as part of the rutting potential investigation during early strength conditions. It also provided insight into ravelling of foamed bitumen and emulsion treated layers under traffic. The influence of slushing with water or diluted emulsion were investigated and reported.

The comparisons between foamed bitumen and bitumen emulsion treated mixes have highlighted the differences between these mixes. Foamed bitumen has provided higher tensile strengths than the equivalent emulsion mix, but higher field compaction results and consequently better rut resistance was achieved for the emulsion treated materials, probably due to a more favourable moisture regime during compaction. The influence of the cement content was not investigated.

INTRODUCTION

In collaboration with Messrs Stewart Scott Inc. and the Cape Town City Council, an investigation was undertaken by the University of Stellenbosch into the properties of a base layer recycled with bitumen emulsion and foamed bitumen. The investigation was carried out by means of accelerated pavement testing on site using a MMLS Mk 3, and mechanical (including static and dynamic triaxial testing) testing of specimens in the laboratory.

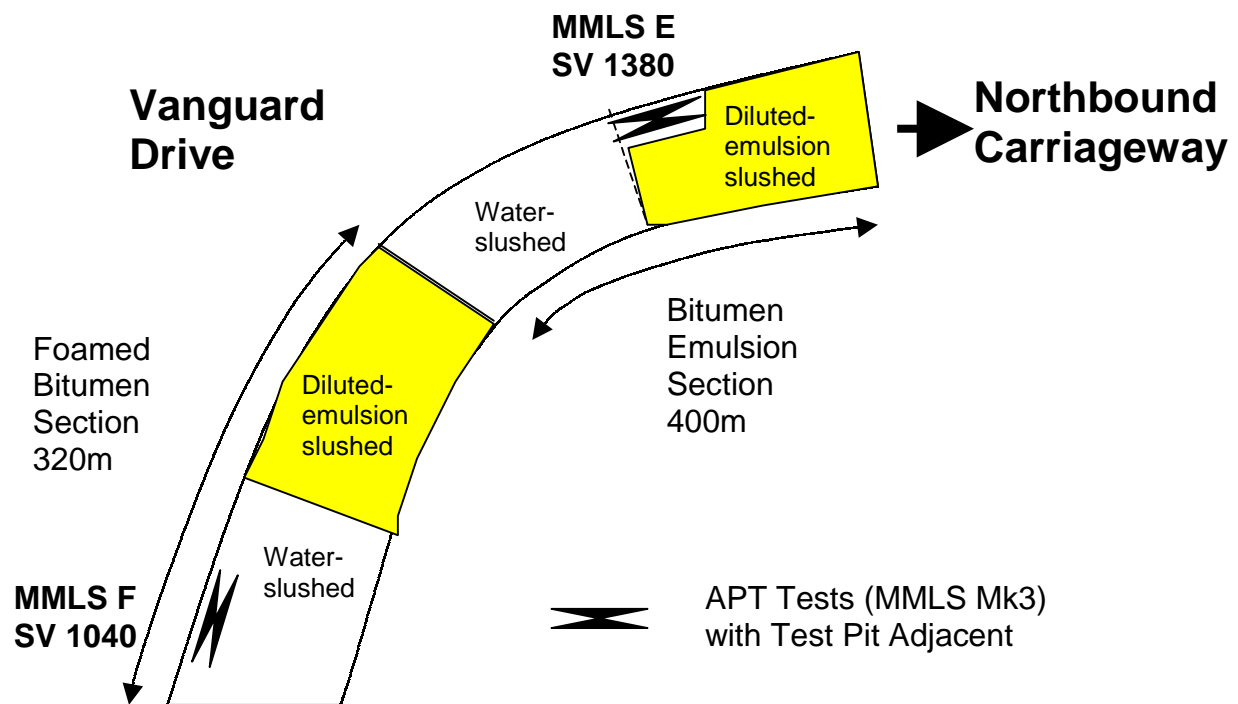


Figure 1. Layout of trial section

The project was initiated as part of a contract for the rehabilitation of Vanguard Drive south of National Route N1, between Frans Conradie and Voortrekker Roads. The project was initiated after this section of road was identified from the City of Cape Town's (CCT) pavement management system as a high priority for rehabilitation. The high rating being due to its very poor condition and its classification as an ES100 pavement class and a category A road. This section of road is a dual carriageway with two lanes in each direction. The pavement manifested extensive crocodile cracking, pumping and rutting in the wheel path. Some of the crocodile cracking had deteriorated to form potholes. A detailed rehabilitation investigation, including deflection measurements identified base failure as the mode of failure and the cold In-situ recycling of the in-situ surfacing was adopted because:

- Speed of construction (6 weeks vs 12 months of reconstruction)
- Project cost of R5m vs R20m for conventional reworking
- Less excess road user cost. Recycled layer can be trafficked during peak hours

A new asphalt surfacing layer was paved on the recycled layer, but early traffic had to be accommodated on the recycled layers itself. An overview of the test site for the accelerated pavement testing is given in figure 1.

The recycled materials utilised in the investigation included a composite blend of:

- 50 to 110 mm of asphalt wearing course,
- 90 to 220 mm of crushed Hornfels Base, and
- Ferricrete to at least 300 mm depth.

The objective of the investigation was to obtain more information on road recycling using two different binders i.e. foamed bitumen and bitumen emulsion on adjacent sections. In this paper the focus is on field testing and early performance, and to carry out comparisons with respect to:

- Field compaction,
- The efficacy of diluted emulsion when used as a surface enrichment to retard ravelling, and
- Rutting potential of the mixes when exposed to early traffic.

For detailed information of the whole project it is referred to reference 9.

TEST PROGRAMME

A mix design for the emulsion treated material had been carried out prior to the commencement of the foamed bitumen project. An emulsion content of 2% with 2% cement had been selected as the binder for the recycled layer following the results of Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS) tests. For comparative results, a binder content of 1,5% of foamed bitumen with 2% of cement was selected for the equivalent foamed bitumen section. The whole test programme is described in reference 9.

A separate test programme was established for the trial sections on Vanguard Drive. In order to investigate the ravelling effects of traffic on different surfaces, each of the test sections i.e. foamed bitumen and emulsion treated materials, was subdivided into two, one with and the other without applying a diluted emulsion to the surfacing. Evaluation of the ravelling was carried out by means of a visual assessment.

TESTING METHODOLOGY

Determination of Material Properties

Test pit excavated in the existing Vanguard Drive enabled representative samples to be retrieved from the layer profiles for laboratory testing at the mix design stage. The four test pits excavated in the northbound carriageway, at chainages SV 580 left, SV 900 right, SV 1200 left and SV 1500 right, were profiled in accordance with standard procedures.

Mix Design Properties

As part of the verification procedure for determining whether the foamed treated material would at least match the material properties of the bitumen emulsion stabilised layer at the equivalent residual binder content, various mix design tests were carried out. These included Californian Bearing Ratio tests (CBR), Indirect Tensile Strength tests (ITS), Unconfined Compressive Strength tests (UCS) and Indirect Tensile Stiffness Tests (ITT).

Foamed bitumen samples manufactured as part of the mix design process were prepared in a Hobart mixer with the foam supplied by a Wirtgen WLB 10. The mixes were compacted for 200 gyrations in a Troxler Gyrotory Compactor. Thereafter the specimens were subjected to 72 hours of curing at 50°C in a sealed container, after compaction. This is in line with recommended curing procedures as outlined by Jenkins² to simulate medium term curing in the road.

For the results of these testing it is referred to reference 9.

Triaxial Tests

Dynamic, static and repeated load triaxial tests were performed. The procedure used to manufacture and condition specimens is given in reference 9.

For the static triaxial test specimens were loaded at a constant displacement rate of 6.25 mm/min in the static triaxial tests. Tests were carried out at selected cell pressures of 50, 100 and 200 kPa and the load and vertical displacements were monitored directly from the MTS.

In order to investigate the resistance to permanent deformation of the foamed bitumen stabilised recycled layer, repeated load triaxial testing was engaged upon. The curing of these specimens was also limited to 1 day in mould at ambient temperatures to simulate field cure.

For the results of the triaxial testing it is referred to reference 9.

Accelerated Pavement Testing : MMLS Mk3

The influences of traffic on foamed bitumen and emulsion treated recycled layers were investigated using the Model Mobile Load Simulator (MMLS Mk3). The stations at which these tests were carried out, are illustrated in Figure 1.

The MMLS Mk3 is an accelerated pavement testing tool that includes four pneumatic-tyred wheels that cycle in a closed loop. The wheels are 300 mm in diameter and 70 mm wide. A general layout of the MMLS Mk3 is provided in figure 2.

The most applicable settings of the MMLS Mk3 for the APT test programme for Vanguard Drive were selected as:

- Tyre pressures of 600 kPa,
- Axle loads of 2,1 kN for each of the four wheels,
- Average rotations of approximately 30 rpm or 120 axle loads per minute, and
- Lateral wander of 150 mm total in a triangular distribution about the centre-line.

Each test was carried out to between 100 000 and 150 000 axle repetitions. Where ravelling was experienced, this was measured through collection of the material loosened during trafficking and weighing of this material. This enabled differentiation to be made between rutting as a result of material loss and permanent deformation.



Figure 2. General Configuration of MMLS Mk3 APT device

TEST RESULTS : ANALYSIS AND INTERPRETATION

Properties of Natural Recycled Layer

The gradation and indicator tests on the materials indicated that the existing base layer comprising crushed hornfels is generally G2 quality in terms of TRH4, but has deteriorated to G5 quality in places due to linear shrinkage criteria. The underlying Ferricrete layer is of G5 quality, although the CBR classification was not included in the testing procedure.

The Dynamic Cone Penetrometer (DCP) Probes carried out at various points along the trial section before rehabilitation, indicate primarily a lack in bearing capacity between a depth of 100 and 200mm. Some local weaknesses between depths of 50 and 100mm as well as, 200 to 300mm are also prevalent.

As part of the preliminary material characterisation, a moisture density relationship was determined using Modified AASHTO compaction. A representative material sample from the trial section was found to have the optimum compaction properties as shown in Table 1.

Table 1. Compaction Properties using Modified AASHTO

Carriageway	MDD (kg/m ³)	OMC (%)
Trial NBC	2160	6.8

Note : MDD = Maximum Dry Density

OMC = Optimum Moisture Content

Crushed Sandstone River Gravel alternative graded granular base

Mix Design Testing and mechanical testing for trial section

Considering the quality of the composite material and the level of traffic in Vanguard Drive, SABITA' s GEMS Manual³ recommends a CBR of at least 140% at 100% of Modified AASHTO compaction. The CBR value of 136% obtained for the composite recycled material with 1,5% residual bitumen from emulsion, does not quite meet this recommendation, but increasing the residual binder content to 1,7% does satisfy it.

It should be noted that a lack of sensitivity of CBR to residual binder content is prevalent. The compaction level had a far greater influence on CBR than the residual binder content (RBC). The Unconfined Compressive Strength (UCS) recommended for the given material, also in accordance with the GEMS Manual³, is 1200 kPa. The recycled layer treated with bitumen emulsion yields values in excess of 1550 kPa at all binder contents and adequately surpasses this criterion. A decrease in UCS is observed with increasing binder content

Mechanical Testing for Trial Section

In order to monitor the quality of the recycled mixes produced for the trial section in comparison to the mixes manufactured for mix design purposes, samples were taken from the recycled pavement before compaction and tested. Specimens were fabricated from samples in laboratory conditions using the same procedures as the mix design testing and mechanical testing was carried out.

Unconfined Compressive Strength obtained for the site mixes were found to be substantially higher than the UCS values obtained from the mix design testing. The average UCS obtained for the eighteen tests performed on the trial section foamed mixes was 2409,2 kPa with a standard deviation of 385,5 kPa. The average is substantially higher than the value of 1870,6 kPa obtained during mix design testing.

The results of the ITS tests carried out on the trial section foamed mix was found to be lower than the equivalent tests carried out during the mix design phase. The trial section foamed mix proved an average ITS (unsoaked) of 222,9 kPa with a standard deviation of 24,7 kPa for twelve tests. This is substantially lower than the mix design value for the ITS (unsoaked) of 445 kPa. The density of the two mixes varied by only 0,09% and cannot be considered as a contributing factor to this discrepancy. One factor that could have influenced the results is the delay time between retrieving the sample from the field and compacting the specimen. Although it remains unconfirmed, this is likely to have contributed to the difference.

Binder and Moisture Regime of Trial Section

Samples monitored for moisture content after stabilisation with foamed bitumen yielded an average MC = 3,2% with a standard deviation of 0,7%. Owing to the high energy rolling of the recycled layer, the MC on site was deliberately selected to be lower than the 4,8% moisture content aimed for in the mix design in order to achieve optimal compaction.

The binder content values obtained from extraction tests carried out on the trial section, yielded variable values. The average value of 1,6% foamed bitumen is slightly lower than the targeted binder content taking into account the binder in the RAP. The standard deviation of 0,7% for the foamed bitumen content is a point of concern however as it highlights the need for reliable procedures for the monitoring of binder content in recycling projects. The nature of recycled materials with filler contents that are often higher than average, can introduce inaccuracies to standard extraction techniques.

Field Compaction of Trial Section

The field compaction of the foamed bitumen and bitumen emulsion trial section was evaluated using nuclear density gauge and sand replacement tests. A summary is provided in Table 2. It is apparent from the results that densities in excess of 97% of Mod.AASHTO are readily achievable provided that the fluids content is optimised.

Table 2. Densities and Moisture Contents measured in Foamed Bitumen and Emulsion Trials

Section	Troxler			Sand Replacement		
	% Mod. AASHTO	Std. Deviation	Moisture (%)	% Mod. AASHTO	Moisture (%)	
Foam Trial (6 tests)	100.28	0.74	4.5	-	-	
Foam SV 1040	97.2	-	7.1	98.1	4.4	
Emulsion SV 1380	101.0	-	5.8	100.9	4.2	

Using the nuclear density gauge (Troxler), the density profile in the 300 mm deep recycled layer was investigated. Measurements at 50 mm intervals through the depth of the layer were carried out which enabled the densities in the individual inter-layers to be determined. Although it would be expected that the density profiles decreased with depth, as the stresses imparted on the surface dissipate, but this is not the case. As shown in Figure 3 and Figure 4 the density profiles appear variable.

The foamed bitumen treated layer shows no particular trend with depth whilst the emulsion treated layer decreases steadily with depth and then increases. The limited data available does not make it possible to draw conclusions from the results other than to observe that the preferable moisture regime that was prevalent in the emulsion treated layer probably had the most significant influence on the improved overall densities.

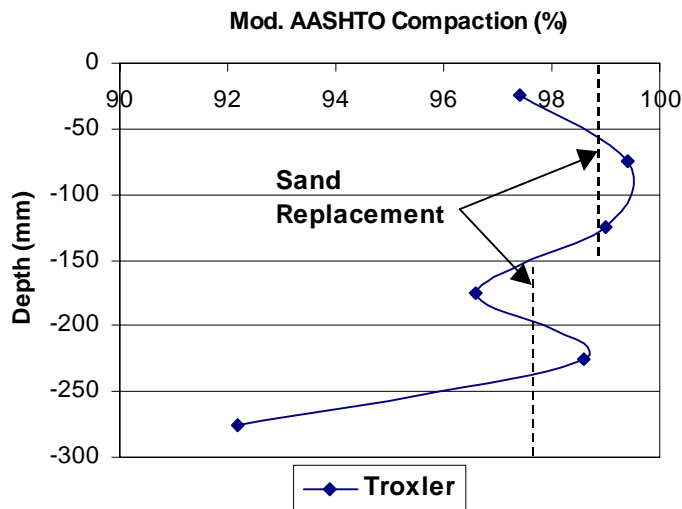


Figure 3. Compaction Profile for 300 mm deep Recycled Layer treated with Foamed Bitumen
 Sand replacement tests provide good agreement with the nuclear gauge results on average, and highlight the need to use at least 100 mm intervals (but not more than 150 mm) with the nuclear gauge to eliminate the profound effect of local influences (or spiking) in the readings.

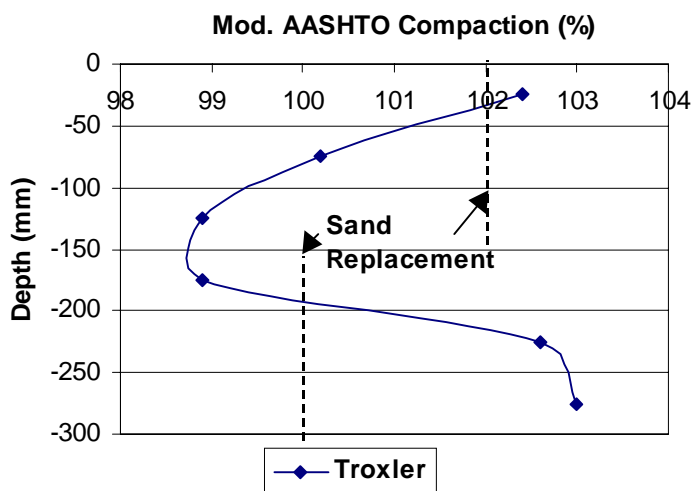


Figure 4. Compaction Profile for 300 mm deep Recycled Layer treated with Bitumen Emulsion

Accelerated Pavement Testing

Initial plans for the APT included testing of the recycled layer directly after compaction. However, after slushing of the surface of the recycled layer, immediate commencement was impossible as the MMLS Mk3 deformed the wet surface significantly. For this reason, at least a half-day cure period was allowed in order to create a stable platform for the APT.

The results of the accelerated tests in terms of rut depth have been averaged across the width of the wheel-path that experienced lateral wander. As is to be expected with a triangular lateral wander distribution, the rutting follows a similar triangular profile, see Figure 5 which shows a typical rutting profile. The wheel-trafficking profile is symmetrical about the centre of the offsets i.e. 15cm offset lies on the longitudinal axis of symmetry. The rutting profile is calculated for the average rut depth from 7,5 mm to 22,5mm offsets. As seen in the figure, some shoving is prevalent at the edges of the wheel path indicating shearing action in the fresh foamed bitumen mix (less than 24 hours after compaction). This material above the original level of the road surface was not loose otherwise it would have been considered as ravelled material.

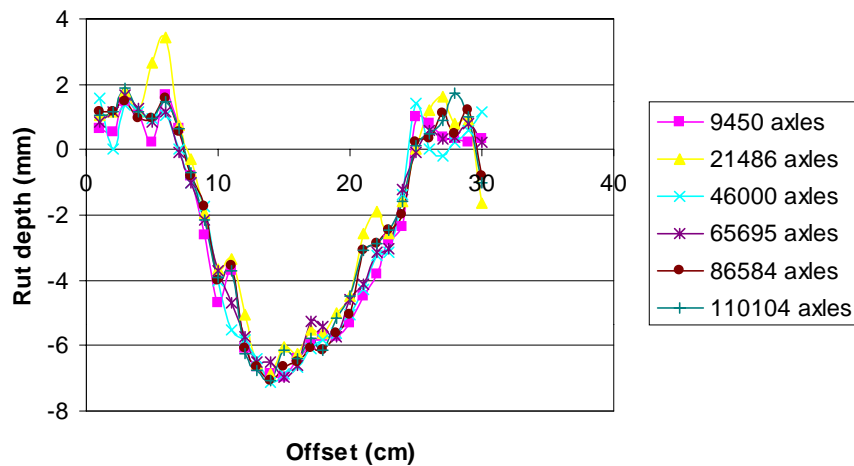


Figure 5. Profilometer Readings for Cross-section CD at Foamed Bitumen Station trafficked with MMLS Mk3 1/2 day after Recycling of Layer

The transverse profiles of the vertical change in elevation only incorporated a ravelling factor if loosening of the material occurred during the accelerated pavement testing. This was the case with the foamed bitumen treated layer that was cured for 3 days before trafficking, but not with the other two APT tests. The reason for the ravelling of the foamed treated layer was attributed to two predominant factors (that were identified through visual observation):

- *Surface finish:* Although the same material was utilised for the foamed bitumen and the emulsion trial section, the surface finish obtained was found to be variable. This variability of surface finish did not appear to be influenced by the type of binder utilised but rather by local influences during placement and rolling. It would appear that the type of finish achieved on a recycled layer would depend to a large degree on the respective operators of the plant constructing that layer.
- *Moisture content:* During the accelerated testing, the recycled layer was allowed to dry out to some degree. This results from both curing of the layer and mechanical drying through trafficking of the layer (especially at the surface). Moisture content tests carried out in the top 120 mm of the recycled layer before APT yielded the results shown in Table 3. As a result of the differences in initial moisture content, variations in density were prevalent in the recycled layer. In addition, the dryness of the foamed bitumen layer at 3 days after compaction encouraged ravelling.

Table 3. Moisture Content (%) of top 120 mm of Recycled Layer at APT set-ups, at different times after compaction.

Foamed bitumen mix (0.5 days)	Foamed bitumen mix (3 days)	Bitumen emulsion mix (0.5 days)
4,4	3,3	4,2

The proportion of ravelling that contributed to the overall rutting of the recycled layer is shown in Figure 6. As with the permanent deformation, the ravelling appears to increase rapidly in the beginning and level off with time. Similar observations were made on the recycled layer that was opened to the public during construction. This is discussed in the next section.

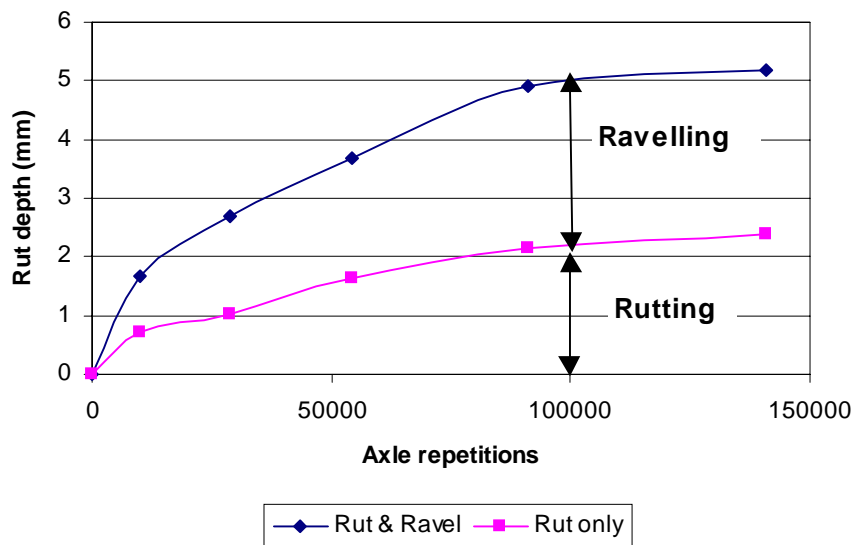


Figure 6. Deformation Profile for the Foamed Bitumen Section tested 3 days after Compaction with MMLS Mk3

A comparison between the different accelerated pavement testing sections may be made by superimposing the results of the rutting profiles on a time scale, see Figure 7. The differences in the rut depths between equivalent emulsion treated and foamed bitumen treated material should be viewed with due consideration to the density and moisture content of the layer.

The improvement in the rutting potential of the foam treated layer with increase in curing time is evident from these results, highlighting the benefit of delaying the opening of a recycled layer. This phenomenon is mainly influenced by curing effects as the density of the foam treated layer was not variable for the two test sections and the curing time was the only factor that varied. With all the materials, the initial deformation of the recycled layer in the first 30 000 axle load repetitions outweighs the subsequent deformation significantly. Densification of the recycled layer by the traffic appears to improve the resistance to rutting rapidly.

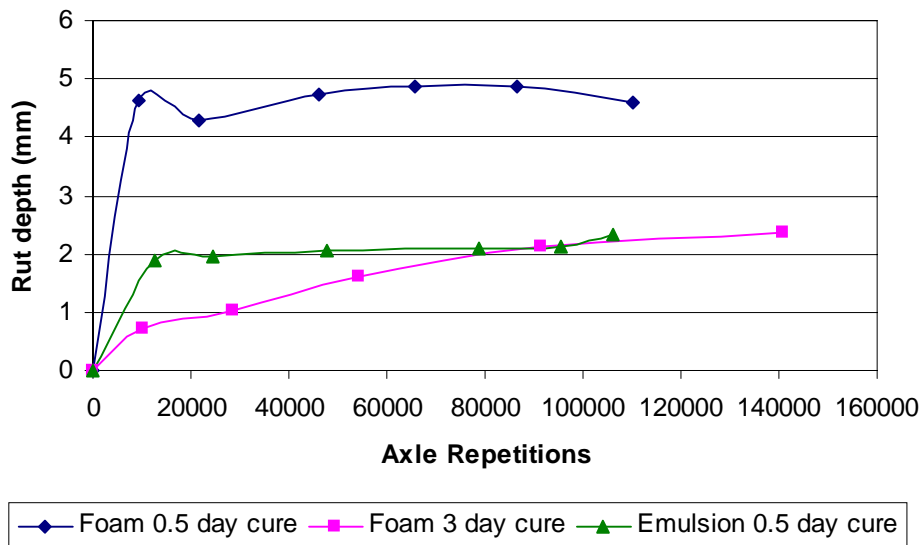


Figure 7. Rutting in Recycled Layer after APT with MMLS Mk3, tested with different binders and curing times

Ravelling

The trial sections with foamed bitumen or emulsion as binders and different surface treatments i.e. slushing with water or diluted emulsion, were inspected during opening to traffic. From the observations, ideas could be developed as to the preferable method of finishing of the surface to minimise damage after the layer is opened to accommodate traffic. The following points of interest were noted:

- Slushing leaves the surface of the recycled layer saturated and, if opened immediately to traffic, severe rutting would result. Slushing in late afternoon or in overcast conditions immediately before opening to traffic is not advised, therefore, and should be postponed until a more appropriate time
- The use of water for slushing of coarse, cohesionless, recycled material with 1,5% residual binder, so long as the material is well graded on the surface, results in little ravelling. Localised coarse patches, however, ravel significantly.
- Surface enrichment carried out by slushing the recycled layer with diluted emulsion, reduces raveling potential and dust generation significantly. The application rate needs to be accurately controlled (generally 0,4 to 0,5 l/m² of 50:50 emulsion:water mix). Over-application of diluted emulsion results in extended breaking time of the emulsion and stripping of it from the surface by tyres, exposing the underlying layer to ravelling. Sufficient breaking time before opening to traffic is an important consideration (to avoid dirty cars and windscreen damage).
- If significant ravelling does occur, it not only results in increased asphalt demand but also reduces the pavement quality. Ravelled sections are difficult to sweep with a mechanical broom as the finer fraction is swept into the undulations. This can result in debonding of the surfacing layer at a later stage.
- Experience plays an important role in maintaining lightly bound layers that are used to accommodate traffic. Achievement of a well-knit surface free from segregation and selection of application rates and timing of intervals, overwhelmingly influence the reduction in ravelling.

CONCLUSIONS

Field Compaction

- Results obtained from nuclear gauge testing compare favourably with the sand replacement tests on the same foamed bitumen stabilised material. This nuclear method of density control is suitable for use with cold bituminous mixes, however, oven dried samples should always be used for moisture analysis.
- Measurements of density with depth using the nuclear gauge proved to be sensitive to local influences. The back calculation of density of inter-layers of 50mm from the cumulative readings is considered too variable to be considered for specification purposes. Depths of a minimum of 100mm should be utilised for inter-layer density specifications.

Accelerated Pavement Testing

The MMLS Mk3 testing carried out on the foamed bitumen stabilised and the emulsion stabilised recycled material, highlighted the following points:

- As with the triaxial testing, the APT yielded high initial rate of permanent deformation decreasing with time. This holds true for both the binders i.e. foamed bitumen and emulsion.
- The overall permanent deformation of the recycled layer as a result of early trafficking appears to depend predominantly on compaction and moisture content, rather than the type of binder. In the trials, the bitumen emulsion treated layer, contrary to expectations, had a similar total moisture content than the foam treated layer after 05 days (see Table 3), which together with the higher compaction level (see figures 3 and 4) assists in explaining the superior rut resistance produced by the former.
- Ravelling of foam treated material caused by early traffic is largely dependent on surface finish and moisture content. An upper and lower limit of moisture content is required to reduce ravelling. The kneading action of traffic on a foamed bitumen treated layer does appear to reduce the rate of ravelling with time.
- Models that link the performance of foamed bitumen material in the laboratory to the field could possibly be developed using the information obtained from these trials. The triaxial results on the recycled material correlate well with a permanent deformation template for other triaxial investigations into foamed mixes. The linking of models will probably form part of the research of Jenkins².

General

The influence of the cement content has not been investigated. In this case the cement content was relatively high and definitively has influenced the behaviour .

Ravelling can be reduced by slushing with water or diluted emulsion, but experience plays an important role in maintaining lightly bound layers that are used to accommodate traffic immediately.

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Martin van de Ven did his Doctoral examination in Civil Engineering at Delft University in 1975. Since that time his activities were directly related to pavement Engineering, mostly as a Materials specialist.

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Since 1995 he is incumbent of the Sabita Chair at the University of Stellenbosch. Primary task: to promote education and research in Asphalt Technology at graduate and post-graduate level in order to provide the society and industry with high quality human resources. Professionally he actually holds the titles Prof Ir Ing.