Premature Deformation Failure of an Asphalt Surfacing: Case Study on N 1 at Hex River Pass, South Africa

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ABSTRACT: An asphalt surfacing failed prematurely (rutting and bleeding) under heavy-duty conditions (steep uphill gradient, slow moving truck traffic and high temperatures) over a 4 km section on a major national route in South Africa. The original coarsely graded continuous surfacing mix design complied with the original strict performance based design criteria. The purpose of the failure investigation study was to define the reasons for this failure and to report back on the improvements in the performance based design criteria that were successfully used to design the repair mix. This failure was attributed to borderline mix compliance (marginally high binder and high filler) on a grading sensitive mix; in addition it is also concluded that the performance criteria (rut resistance) was not set high enough for the extreme loading conditions. The Model Mobile Load Simulator (MMLS) accelerated pavement testing (APT) deformation resistance test criteria, used in the industry at that time, did not effectively assess the mix resistance to deformation under extremely slow traffic (i.e. <5km/h). For the repair, revised MMLS testing parameters and rutting criteria were set which allow for these extreme slow design speeds; also deformation testing was done on the deformation "weak" side of the control limits (at upper binder content and 0.075 mm levels). Based on the revised performance specifications and tighter control limits, a similar aggregate grading with a 4.6% EVA modified binder and a higher VIM's target of 6.0% was successfully used.

KEY WORDS: Premature Asphalt Failure, Rutting, Bleeding, Performance Based Design Criteria, MMLS

1 INTRODUCTION

This purpose of the paper is to share the findings of an investigation into the premature failure (early fattening and deformation) under very severe heavy duty traffic conditions, i.e. steep uphill gradient in excess of 6%, high temperatures (>60°C in layer) and very slow moving traffic(<5 km/h).

The investigation involved extensive testing on field cores and slab samples from the failed and controlled areas, re-testing of asphalt production samples and testing of bitumen, both original and recovered. The study indicated the importance of proper mix control and the application of the appropriate performance test criteria which can simulate field conditions accurately (Pretorius 2007, Kandhall 1997).

The causes of the failure has been identified with a reasonable level of certainty given the limitations of test on field cores and resulting changes in mix properties (these limitations include that bleeding mixes tend to trap additional material passing the 0.075 mm and over-application of tack which can increases the bitumen content on deforming mixes).

A number of recommendations are presented including revised performance based MMLS criteria for asphalt layers at steep uphill gradients and under heavy axle, slow moving, traffic.

2 PROJECT BACKGROUND

The construction project involves a 40mm bitumen rubber asphalt overlay on the National Route 1, South Africa, between Kanetvlei and the Hex River Pass over a distance of 20.3 km. A design traffic volume of 23 million equivalent 80 kN axle loads (E80's) was used during the material and pavement design process. The summer daytime maximum average temperature is 30.4ºC in January with the average highest for the month record as 38.0ºC. The region has a mean annual (MAP) rainfall of 320 mm with the rainfall peaking between April and August.

Originally a BRASO layer (Bitumen Rubber Asphalt Semi Open graded mix) was recommended in the consultants design report, but this was changed to a BRA (Bitumen Rubber Asphalt, continuous graded) surfacing during the tender award as per the Contractors alternative offered. The motivation to accept this alternative was due to budget constraints and the high prices received due to the high workload in the market at that time.

Whilst the BRA is a highly durable mix, experience with this type of mix in heavy slow moving, trafficked areas (steep uphill gradients and intersections) indicated a relative low resistance to deformation not suited to this heavily loaded uphill slow section (over a distance of 4 km) with gradients ranging from 6.5% to 7.2%. The BRA type of mixes is also particularly sensitive to fuel and oil spillages which frequently appear on these slow trafficked areas.

Given the budget constraints of the projects, this slow uphill section (from ±km 44 to km 48) was instead overlaid with a 40 mm medium continuous graded surfacing mix instead, as to obtain the higher rut resistance on this heavy uphill section. Based on the use of performance based asphalt mix design criteria, as used successfully on various other high performance asphalt projects (Pretorius et al. 2003, Wright et al. 1984, Pretorius 2007), the following mix design and performance criteria was approved:

Table 1: Key properties of the approved production mix (continuously graded asphalt)

Mix Property		Value	Specification
Aggregate grading (sieve sizes in mm):	% Passing 13.2 mm	98	90 – 100
	% Passing 9.5 mm	89	82 – 100
	% Passing 6.7 mm	70	-
	% Passing 4.75 mm	55	54 – 75
	% Passing 2.36 mm	37	35 – 50
	% Passing 1.18 mm	26	26 – 42
	% Passing 0.300 mm	13	11 – 23
	% Passing 0.150 mm	9	7 – 16
	% Passing 0.075 mm	6.8	4 – 10
Combined aggregate density (BRD)		2.743	-
Bitumen content (60/70 Penetration grade)		4.8%[#]	-
Film thickness		7.8 µm	>6.5 km

Mix Property	Value	Specification
Voids in Mix (VIMs)	5.5%[#]	4.5 – 5.5%
Voids in Mineral Aggregate (VMA)	15.4%	>15%
Indirect tensile test (ITS)	1144 kN	>1 000 kN
Gyratory Refusal Void (300 repetitions)	3.8%	>3%
MMLS (100,000 reps, 50ºC)	1.67 mm	<2.0%

Note: [#] Lot based gradings were within general tolerances; binder content on average 4.9% and VIM ≈ 5.3%

Lot based mix properties, as tested on a statistical evaluated daily quality control bases, indicated that all lots were within specification (except for one marginal density lot).

After the first summer period during the (December 2007/January 2008), i.e. about one year after construction, the 4.0 km of the slow uphill lane shown fattening and deformation failures over ±50% of the total length of the section. The premature failures ranged in severity from mild fattening to excessive deformation (more than 10mm).

3 SCOPE OF INVESTIGATION

The study has assessed the following causes of the premature failures (fattening and bleeding):

- Mix production problems (grading or aggregate structure, measured in terms of overall performance simulation tests),
- Binder problems (out of specification binder contents, properties of the binder, influence of excessive tack applications)
- Mix specification and performance criteria not adequate for application (slow and uphill traffic).

During the failure investigation the following sampling methodology was used:

- Field sampling (extract field cores for the control section – good performance; extract field cores from five sections exhibiting premature failures),
- Production control mix sampling (limited loose material samples were stored),
- Binder retesting from stored binder samples.

The testing programme involved the following tests on field cores, retain and production samples and bitumen samples:

- Volumetric properties done on cores and retained productions samples (aggregate gradings, bitumen contents, voids and mix and field densities),
- Bitumen properties on extracted bitumen and original stored bitumen (i.e. penetration, softening point and viscosity at 60ºC),
- Performance based tests on extracted material from field cores (VIM's after Superpave gyratory refusal density, i.e. 300 gyrations; MMLS loading tests at original criteria, i.e. 100 000 repetitions/50ºC).

4 PRESENTATION OF ASPHALT AND BITUMEN TEST RESULTS

This section deals with the analysis of test results.

4.1 Field Samples Details

Testing of field samples has been carefully conducted and assessed due to changes in the material properties over time. Experience has indicated in sections where excessive bleeding occurs, that the material properties can differ to due to weathering, excessive tack application and due to windblown tyre-pressed-in fines in bleeding areas. For this reason some of the cores (extracted from road during investigation) have been split into top and bottom parts where indicated.

Table 1: Asphalt and binder test done on cores and material extracted from cores/slab

Test Parameter	**Fattening Area Section A (SV 45.293) (Lot No WC3)**	**Good Section B1 (SV 45.480) (Lot No WC3)**	**Poor Section C1/2 (SV 45.522 (Lot No WC3)**	**Poor Section D1 (SV46.026 (Lot No WC4)**	**Poor Section E1 (SV46.658 (Lot No WC4)**	**Poor Section F1 (SV47.016) (Lot No WC5)**	**Specification (Design Values)**
Asphalt Tests:							
Field Voids	1.4				0.7/1.1		
MMLS (on 150 mm Cores)	-	1.3 mm	1.4 mm		-	-	<2 (1.67)
Gyratory Refusal (Voids)		4.2	NT/0.6		1.5	0	>3 (3.8)
Binder content (%)	5.0	4.6	5.2/5.5	5.4	5.3/5.4/**5.2***	4.9	4.8
% passing $0.075^{\#}$ sieve	**8.0^{B}/9.5^{T}**	7.4	8.5/9.5	9.6	6.7/11/**9.9***	11.4	6.5 (**6.8****)
% passing 2.36 sieve	41	36	38/NT	40	34/40/**39***	43	(37)
Marshall VIMs (%) (remoulded)		6.7	2.7/NT		3.6/0.4	0.4	(5.5)
Binder Extr. Tests:							
Penetration		21	24	30	30		
R&B Soft Point		60	58.4	53.4	53.4		
Viscosity (60°C)		537	471	337	337		<300% initial

Note: # Split into top and bottom where indicated; B = Bottom section and T = Top section of core tested; NT = not tested

* Upper 10 to 15 mm removed from core before testing (average of four field cores)

** Set somewhat higher at 6.8% during production then in design (6.5%)

Some significant differences were noticed between the good control section and poor section as discussed in more detail in section 5. Initially it therefore appears that an out of specification mix (binder and 0.075 mm fraction) were to be blamed, however further investigation proved somewhat more complex causes.

4.2 Split Samples Testing and Comparison

The purpose of this serious of testing was to determine whether the original control and acceptance testing were done accurately and whether the failures can be attributed to “of target” mix production at the plant. The disadvantage of this control testing, sampled at the plant in this case, was that it is difficult to accurately correlate a specific test result back to a specific failure section on the road. Further detailed testing of extracted samples followed and the results are listed in Table 2.

Table 2: Sample retesting results

Test Parameter/Position Test	Spec (Ave. on Lots)	Lot No and Sample No on Retested/Extracted Samples					
		WC03: P38	**WC03: P39**	**WC04: P45**	**WC04: P46**	**WC05: P52**	**WC05: P52**
% Passing 2.36 original	37 (38)	39	37	35	41	35	35
% Passing 2.36 retested	37	35	35	34	34	37	36
% Passing 0.075 original	6.8 (6.8)	7.6	7.0	6.8	7.8	6.9	6.9
% Passing 0.075 retested	6.8	6	6.9	6.7	6.8	7.2	7.0
Binder content original	4.8 (4.9)	4.8	4.7	5.0	5.0	5.1	5.1
Binder content retested	4.8	4.8	4.7	5.1	4.9	5.3	5.1
Voids in mix original	5.5 (5.3)	5.0	6.2	4.9	4.8	4.6	4.6
Voids in mix retested	5.5	5.1	5.3	3.8	3.4	3.7	3.7

A meaningful difference was found in the Voids-in-mix (VIMs) results, where the re-tested samples indicated lower VIM's results of approximately 1%. Results that can be related to the good control section indicated VIM's mostly higher than 5%, while VIM's results attributed to the failed section was tested as significantly less than 5% (caused by binder/0.075 mm aggregate higher values).

Binder testing on original bitumen shown the following results:

Table 3: Results of bitumen testing on original stored bitumen

Binder	Specifications	Date and Lot No of Sample			Date and Lot No of Sample		
		B06: 18/04/07	**B07: 23/04/07**	**B08: 12/05/07**	**B522: 18/04/07**	**B533: 22/0407**	**B559: 11/05/07**
Penetration	60 – 70	69	68	66	-	-	-
R&B Soft Point	46 – 58	48	49	51	-	-	-
Viscosity at 60°C Pa.s	120 – 250	-	-	-	189	199	148
Viscosity at 135°C Pa.s	0.2 – 0.4	-	-	-	0.33	0.33	0.28

The bitumen fully complied with the relevant SANS307 specification, but indications are that the bitumen tends toward the "softer" side of the limits of the specification.

5 ANALYSIS AND DISCUSSION OF THE TEST RESULTS

The initial analysis regarding compliance of mix with original asphalt specification, indicate some discrepancies. A comparison between volumetric properties of the good section, the specifications and the poor sections are graphically illustrated in figures 1 and 2 below. These key properties are:

- Bitumen contents using material extracted from the cores,
- Material passing the 0.075mm sieve using material extracted from the cores,
- Marshall voids in mix using material extracted from the cores,
- Gyratory refusal voids using material extracted from field cores.

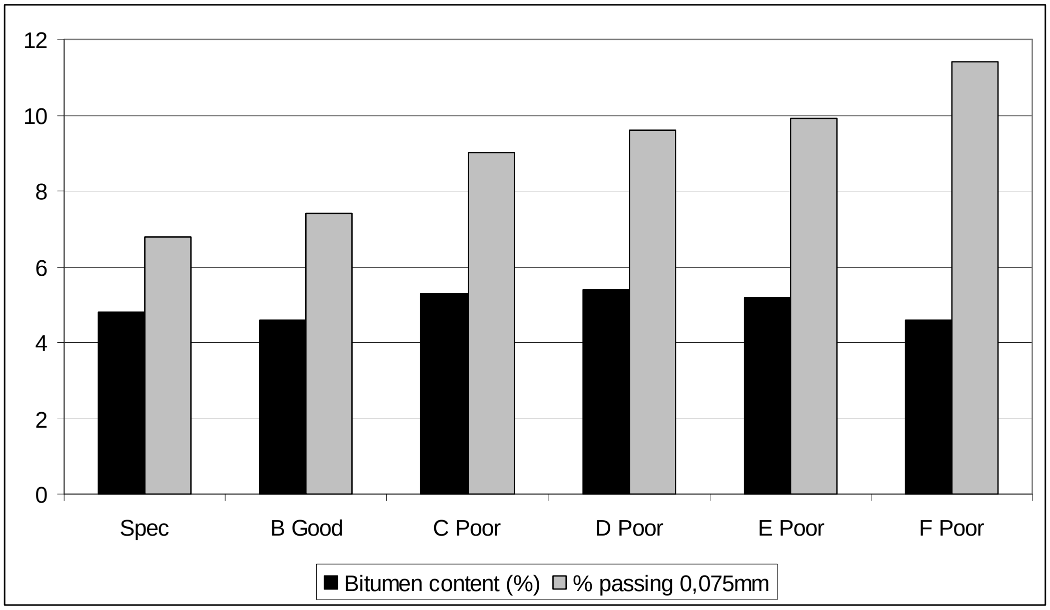

Figure 1: Comparison of bitumen and % Passing the 0.075 mm sieve contents of the good control section and poor sections against the specification.

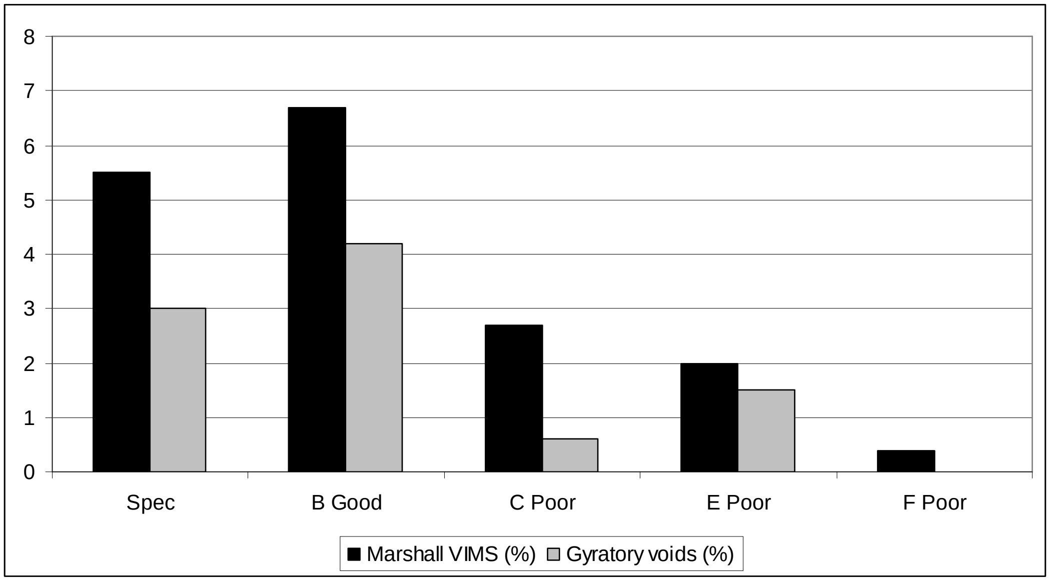

Figure 2: Comparison of the density voids in mix (VIM's) and Voids at Superpave Gyratory Compactor refusal density (300 repetitions) of the good control section and poor sections with the target specification.

5.1 First (Basic) Testing Results

From the initial testing data (see unbold values in Table 1) it at first seemed that:

- The relative good areas show binder and material passing the 0.075 mm sieve values in line with the mix target (including allowed tolerances). The Marshall VIMs (using material from extracted cores) and the gyratory values are in line with the approved mix in these areas.

- The poorly performed areas show binder and/or % P0.075 mm values exceeding the allowed tolerances. This corresponds with low Marshall VIMs (0.4% to 3%) and low Gyratory refusal voids (0.6/0.0/1.5% versus specification of >3%) on recompacted recovered material.

Based on the results of both the cores and retesting of retained asphalt samples, it was found that the grading somewhat fluctuate, but in general agree with the target specification (except for the material passing the 0,075 mm sieve which may have been from external packing onto fattening/bleeding).

It is also significant to note the density of the asphalt in the poor sections are very high (98.5% of MTRD) and is far higher than the initial construction density (93% to 94.5%). The deformation trigger can therefore not be attributed to initial over compaction during the paving process; it can rather be attributed to marginal mix properties allowing traffic compaction during the hot summer period.

Binder properties (see Table 3) of the stored samples are in line with specifications broadly. Extracted binder from field cores (see Table 1) also indicate binder properties are as expected for one year old field mixes.

Based on this initial test results, it was decided to check where these higher binder contents recorded originated from (be it tack contamination, production problems, etc), and whether the significant variation from the grading on the fine side of the envelope was accurately tested; also further whether the original test results, which did not pick this up, correspond with the retested samples.

5.2 Further in-depth testing and analysis of results

Cores taken in fatty areas (see values in bold in Table 1) were split and their gradings then tested in order to check whether the high % material passing the 0.075 mm sieve is a result of initial production or as due to windblown tyre-pressed-in fines into bleeding areas (see results in Table 1, Section A). It indicates marginally (±1.5%) higher % material passing the 0.075 mm in upper sections of cores (9.5% v 8.0% in lower sections). Also cores taken in Section E1 (*annotated in Table 1), of which the upper 10 to 15 mm were removed, were tested and they indicate the % material passing the 0.075mm of 9.9% on average.

Binder tests in all affected areas (except where obvious high % material passing the 0.075 mm prevail) shows 0.2% to 0.6% higher than the design. Retest of the stored samples however indicates no significant binder differences with both the average of initial six samples and the retested same six samples being ±5.0%. It seems that a combination of marginally high initial binder contents and possible high and/or fluctuating tack application may have resulted in these (site recovered) higher binder content areas.

5.3 Performance criteria assessment

The performance criteria used, i.e. MMLS deformation, gyratory refusal voids minimum values, volumetric parameters, gradings in accordance with sound packing principles, etc, was proven on other similar projects (Jenkins et al. 2001, Epps 2002, Pretorius et al. 2003).

Discussions with the MMLS specialist and developer, Prof Hugo of University of Stellenbosch Institute of Transport Technology (US – ITT), in April 2008 indicated that a process is currently in place to set updated industry norms completed to the MMLS criteria for various load conditions, instead of `informal’ criteria currently in use. He suggested for this specific extremely aggressive loadings (30 million E80’s design axles on steep grades up

Kanetvlei Pass), that a specification of 1.8 to 2.0 mm maximum rutting, to be applied at lower traffic simulation speeds (i.e. 1 800 – 2 400 loadings/h); this would be more applicable than the original 7 200 loadings/h simulation speed. The original MMLS criteria (of less than 2.0 mm as specified at 50°C and at a faster testing speed of 7 200 loadings/h) might probably have resulted in a marginally deformation resistant mix, which, if production variations on % material passing the 0.075mm and binder content is allowed for, can result in the VIM's to close up and the mix not to have the required stability and resistance to deformation under these harsh uphill conditions.

6 CONCLUSIONS

It was therefore concluded from the investigation that the early failures of this continuous graded surfacing mix, in the slow lane up the Hex River Pass, were caused by a combination of a marginal deformation resistant mix design (with respect to the harsh 30 million ES80's design loading, very slow, uphill conditions) which closed-up as a result of the production mix being mostly on or exceeding the higher tolerance side of both the binder content and % material passing the 0.075 mm, and therefore not being stable enough to carry the extremely demanding traffic loadings. This was confirmed in later field assessments (one year later) where even some of the control (good conditions, i.e. binder and fines at design targets) areas started to show fattening and signs of rutting.

7 RECOMMENDATIONS

It was recommended from this study that the following mix design criteria (for APT performance simulation testing), for the replacement asphalt mix and other similar layers, be used in future:

- MMLS rutting at 2 400 loadings/h; criteria of <1.8 mm rutting at 55°C (or other applicable temperature);
- Verify asphalt mix with second rut resistance (Hamburg rut tester or other) performance test by checking results against other heavy duty mix parameter norms;
- Use of high EVA modification, or other proven plastomer (or special binder grade) to be considered in order to obtain the high performance criteria;

In order to comply with the revised MMLS specification, an EVA modified binder (5.5% EVA with 60/70 Pen. Binder) was required for the replacement mixes. The performance of the replacement mix to date (18 months, two summers later) indicates satisfactory mix performance.

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