EXPERIMENTAL REHABILITATION OF A ROAD WITH INTRACTABLE SALT DAMAGE WITH A BITUMEN-RUBBER SINGLE SEAL

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ABSTRACT

Bituminous surfacings which have been blistered, cracked and potholed due to excess salt in the base course are notoriously difficult to rehabilitate by resurfacing with a seal or asphalt as the damage usually penetrates the new surfacing within one year. This paper describes an experiment laid in 1984 on the O'kiep-Steinkopf road (now the N7/8) in Namaqualand to rehabilitate with 7 mm bitumen-rubber single seals at application rates of 2,6 - 3,6 l/m^2. A length of 728 m of an extensively salt-damaged 19 mm Cape seal with two reseals which was still developing new salt damage more than 20 years after construction in 1961, and a very lightly trafficked dead-end remnant cut off from the 1961 road and resealed once was used. On both sections the damage on the existing surfacing consisted of patches of mostly 50 mm diameter craters and blisters averaging about 75 mm in diameter at a spacing of 0,5 - 2 m on the road (some 4 000 / km), and 300 mm on the remnant, together with 1 - 3 mm-wide cracking on a starburst to random pattern, closed blisters, and staining. Although within one year all the experimental reseals on both sections were also penetrated by salt damage, after five and eight years the bitumen-rubber seals on the lightly trafficked section (intended to simulate the worst-case scenario of surfaced shoulders and airports) were in a fair condition and remained so for 13 years whereas the unresealed control sections were severely and extensively potholed. After two years the unmaintained 12 half-width bitumen-rubber sections exhibited an average of 11 blisters (closed and cratered) / 100 m and 55 blisters plus stains (potential blisters) / 100 m in contrast to 47 blisters and 83 stains on the emulsion control section and 9 blisters, 5 stains and 178 patches (some prior to 1984) on the two untreated 1980 control sections. After five years before a routine reseal of the whole road in 1989 the bitumen-rubber exhibited negligible damage and no patching, whereas both were present on the emulsion and 1980 seal controls. Although after eight years in 1992 even the 1989 (the fourth) reseal had become slightly damaged, in 1997 after a further reseal no damage was visible except for a few stains on the emulsion-sealed section, and none at all after 20 years. It is concluded that an ordinary single reseal should not be used on a salt-damaged seal, that a bitumen-rubber single reseal at a minimum of 2,8 l/m^2 should be an acceptable although not a perfect solution, and that the sulphide as well as the salt content and pH should also probably be controlled in base courses.

1. INTRODUCTION

Many of the natural gravels and much of the water available for compaction in the drier parts of the country are contaminated with soluble salts. When present in amounts in excess of about 0,2 % in the completed base course these salts tend to disrupt the primed surface and/or to cause the bituminous surfacing to blister, crack and "pothole". Such damage has occurred on over 160 pavements of all kinds in southern Africa, including graded crushed stone bases made from gold or copper mine waste rock and quarried rock containing sulphides in all climates.

Pavements which have been blistered and cracked by salts can be extremely difficult to rehabilitate: the damage usually penetrates ordinary reseals and even asphalt overlays over 50 mm thick (Netterberg, 1979, 2015). Since its construction in 1961 the O'kiep-Steinkopf road was resealed at least twice up to 1984 and in every case the damage penetrated the reseal within a year. The damage to this road in 1962 appears to have been the first such case investigated and ascribed to salt in South Africa (HH Weinert, 1962, Unpubl. Rep.) was briefly described by Weinert and Clauss (1967) and in more detail by Clauss (1970).

It is the purpose of this paper to describe the performance of two full-scale road experiments constructed in 1984 in an attempt to rehabilitate this intractable problem using the then new bitumen-rubber.

2. PAVEMENT DESIGN

The road was completed in 1961 as the N11/9, later renamed TR11/9, and is currently the N 7/8. At the time of the experiment in 1984 it consisted of a surfacing of 7 mm and 13 mm single (S1) reseals on an S4 19 mm (granite) Cape seal with "koffiemoer" (crusher-dust asphalt) on a primed, 150 mm-thick G2 quality base with a 150 mm G5 subbase on two 150 mm G7 and G8 selected subgrade layers, with 2,5 m-wide gravel shoulders (according to the later TRH4:1996 and COLTO:1998 nomenclature).

The area has an arid climate with a mean annual rainfall of 162 mm falling mostly in winter, mean temperature of 17,7ºC, relative humidity of 38% at 14h00 (Weather Bureau, 1986), and a Thornthwaite Moisture Index of minus 48 (Emery, 1992). Weinert's (1980) N Value is 26 and the macroclimate is "Dry" for pavement design purposes (TRH4:1996).

"Crusher-run" made from a waste rock dump of the O'kiep copper mine was used for base course, apparently over the sections from km 0 to 3 and 7 to 32.

In 1969 a section up to km 11,1 between Springbok and O'kiep was reconstructed and realigned as part of the N7/7. In 1984 remnants of the old salt-damaged road remained as the main street through O'kiep village and as a very severely salt-damaged abandoned section to the north of the village and to the east of the present N7/8.

The section of the Springbok - Pofadder road as far as Carolusberg for which copper mine waste rock was also crushed for base course and also very severely damaged by salt was successfully rehabilitated with a crushed stone overlay in 1983 as part of the reconstruction of the then MR26, later TR 26/1 and now the N14/1 (Netterberg, 2015).

3. MAINTENANCE

The following maintenance was apparently carried out over the lengths in question:

km 8-11 (remnant of former N11 through O'kiep village)
Probable patching and possible reseal in places before 1965 reseal
Single seal (S1) in 1965: 7 mm chips and emulsion.

km 18 - 20 (present N7/8)
Probable patching and possible reseal in places before 1965 reseal
S1 in 1965: 7 mm chips and emulsion (km 10,9 - 21,7), four years after construction
S1 in 1980: Cationic 65% emulsion at 1,05 l/m^2, 13 mm granite chippings at 115 m^2/m^3, cationic 65% emulsion at 1,1 l/m^2, lightly sanded (km 12 - 32).

Sl in **1988 / 1989** (km 11,1 - 47): 65% Cationic emulsion at l,40 l/m^2 (hot), 9,5 mm gabbro chippings at 160 m^2/m^3, 65% (cationic emulsion diluted 1:1 with water at 1,0 l/m^2, lightly sanded after breaking.

In addition, prior to the 1965 reseal long sections totalling about 6 km of the worst damage about 200 mm wide along the centreline were cut out and patched from about the O'kiep Hotel (at about km 8) to at least km 25 and the reseal was designed to be as rich as possible (CJ Poole, 1983, Pers. Comm.). The digging out and patching of literally thousands of salt blisters and small "potholes" (the ganger's "vrot kolle") 25 - 50 mm deep containing "clay" was an ongoing maintenance operation, apparently from soon after construction until at least the 1988/9 reseal. It is understood that neither of the two experimental sections was maintained in any way between 1989 and 1992.

4. TRAFFIC

The traffic carried over the relevant section of the N7/8 is shown in Table 1.

Table 1: Traffic history

Year	AADT	% Heavy	E80/day
1979	433	25	-
1987	440	-	50
1991	276	-	52

Although no split counts were available it was understood that the traffic was approximately equal in both directions in both volume and loading.

The dead end remnant of the 1961 road opposite km 10 on the N7/8 carried almost no traffic – at most only a few cars and pickup trucks and one or two heavy vehicles per day.

5. BRIEF HISTORY OF PROBLEM

What would now be regarded as the first indications for future problems first appeared during construction. Fumes smelling of sulphuric acid were emitted when drying samples of the base course in the laboratory and white stains were noticed on the primed base course (which had stood for some time) after rain (CJ Poole and others, 1983, Pers. Comm.), but apparently no blistering or surface disintegration.

Damage in the form of blistering, cracking and white staining was noticed about five months after surfacing in i961 due to sulphate salts apparently already in the dumprock crusher-run at construction and not in the chips or the brack water used for compaction (HH Weinert, 1962, Unpubl. Rep.).

Chemical analyses of the base and the stockpiled crusher-run showed them both to contain about 1,5% of water-soluble salts. Chemical analyses of three dried water extracts showed the presence of about 20% Fe_20_3, 10% Ca0, 3% MgO, 2% K_2O, 7% Na_2O, 17% SO_4^{2-} and 3% Cl^-; with a loss of ignition of 30%, indicating the presence of mostly hydrated iron and sodium sulphate salts. In 1970 most of the road between km 6,5 and 19,0 was said to possess an average of about one blister or small (25 - 50 mm diameter) “pothole” /m^2 with some sections such as 6,8 - 7,6 and km 11,1 - 12,4 exhibiting as many as 10 blisters /m^2 (Clauss, 1970). Observations by the author between 1974 and 1983 confirmed these observations and in 1979 noted that the remnant section of the N11 as well as the trafficked MR 26 had deteriorated to a severely “potholed” state, with thousands of patches, blisters, small “potholes”, and cracks being evident (Figure 1). Clauss (1970) also made the important observation that, although the average percentage passing 0,075 mm (P075) of 8% over the damaged section on the N7/8 was well within the 4 - 12% required for a crushed stone base course, two trial holes showed that much of it was concentrated in the upper 25 mm.

Figure 1: Condition in May 1984 showing damage under little traffic before spraying

Blistering and “potholing” is understood to have penetrated all reseals within a year both as new damage and also on previously patched “potholes”. X-ray diffraction analysis showed the salt in one blister to be a mixture of pickeringite ($MgAl_2(SO_4)_4$•$22H_20$ and hexahydrite ($Mg.SO_4$•$6H_20$).

Although the term “pothole” was used for such damage at the time the term should be restricted to holes extending a significant depth into the base course and not holes due to salt damage (TMH 9:1992), which usually only penetrate the seal and for which the term “kratertjies” (small craters) was coined by EM de Villiers (1986, Pers. Comm.)

The inefficacy of simple (even rich) single reseals to contain the problem on this road and the poor performance of most other methods including thick asphalt on the Witwatersrand (Netterberg, 1979), but the promising early performance of a bitumen-rubber reseal on a large parking area in Boksburg (Netterberg and Bergh, 2019) led the author to recommend to the then Cape Provincial Roads Department (CPRD) that an experiment using bitumen-rubber be laid when the N7/7 was resealed.

6. BITUMEN-RUBBER RESEAL EXPERIMENTS

The sections for experimental rehabilitation with bitumen-rubber were selected by the CPRD and the author. The author was not present at the laying in l984, or at the inspections carried out during 1984. The single bitumen-rubber seal was laid as a stress-absorbing membrane in February 1984 with the following properties (T0SAS, 1984, Unpubl. Rep.):

Binder

Binder content	:	2,2 – 3,4%
Bitumen/rubber ratio	:	22% rubber of total blend (by mass)
Natural rubber/rubber ratio	:	≥ 30% natural rubber
Base bitumen	:	80/110 pen. (Caltex)
Cutter and/or extender oil	:	yes
Spraying viscosity	:	2 200 Cps at 195°C
Specified application temperature	:	200-210°C
Specified spray rate	:	2,8 l/m^2

The binder was prepared in Cape Town and transported to site by road tanker, primarily for the resealing of the N 7/7. The control on the spray rate was poor as the pressure gauge was dysfunctional.

Aggregate (not precoated)

Nominal size	:	6,7 mm
Actual grading	:	100% <9,5 mm, 96% < 6,7 mm, 68% < 4,75 mm, 30% <3,35 mm, 0,7% < 0,425 mm, 0,5% < 0,075 mm
Flakiness index	:	15,5%
Average least dimension	:	2,9 mm
Specified application rate	:	0,015 m^3/m^2

No rain fell in the area during February and only 15, 5, and 38 mm in March, April and May, respectively**,** and a total of a further 46 mm to the end of October, 1984.

6.1 Little-Used Remnant of N11 Opposite km 10 on the N7/8

The purpose of the bitumen-rubber reseal on this remnant of the old road with a dead end was to simulate the worst conditions, i.e. worse damage than on the N7/8 and very little traffic, such as on airports, surfaced shoulders and other lightly trafficked facilities.

Apart from numerous patches, in 1983 the surfacing was seen to consist of a single 7 mm reseal on the old-type 19 mm Cape seal with a total thickness of 20 - 25 mm. The damage consisted of mostly white-stained, cratered blisters averaging about 75 mm in diameter with 50 mm-wide, 20 mm-deep craters (Degree 1 - 2 in TMH 9: 1992 terms) on a varying but average spacing of about 300 mm together with 3 mm-wide cracking on a short starburst to random pattern (Figure 1).

Trial holes for sampling in 1983 showed the 150 mm-thick base to consist of a moist, yellow - or reddish brown, weathered, diorite, graded crushed stone then visually of at best G4 quality, and the 150 mm subbase and selected layers to be wet, reddish brown, clayey sand of G7 or G8 quality. Six samples of the base under intact surfacing yielded marginal P075s of 10 -13% in contrast to five samples under blisters, which had P075s of 27 - 34%, although the PIs of 1 - 5 were similar. One sample under a 30 mm-high blister yielded a paste electrolytic conductivity (EC) of 0,83 S/m and a pH of 3,0 with a strong reaction for sulfate when tested according to the NITRR Method CA21-74(1980) (the EC method later became TMH 1:1986 Method A21T) - far out of the COLTO:1998 specification of a maximum EC of 0,15 S/m and/or a minimum pH of 6,0.

In-situ air permeability tests according to ASTM D3637-84 of three intact areas of the surfacing showed it to be impermeable even at a head of 20 mm of water, whereas that on blisters was highly permeable.

The bitumen-rubber seal consisted of one 30 m-length of two lanes each 3,1 m wide applied at two different application rates given in Table 2. In the case of the left (north-bound) lane only, the blisters were rolled flat before spraying. After spraying, chippings of nominal size 6,7 mm were then applied at a rate of about 0,015 m^3/m^2 with a chip spreader and rolled with a 3 tonne steel-wheel roller and a 25 tonne pneumatic roller. Excess chippings were not removed.

Details of the treatments together with their condition compared with the adjacent sections of untreated road after eight years in February 1992 are shown in Table 2 and Figure 2.

Table 2: Performance of unmaintained bitumen-rubber reseals and unsealed controls on very lightly trafficked road after eight years in 1992

Lane / Attribute	Left	Right
Details of 30 m-length of 6,7 mm bitumen-rubber reseal applied on 1984-02-16 [1]		
Blisters rolled flat Binder application rate (l / m^2)	Yes 3,23	No 1,87
Condition of **bitumen-rubber reseal** on 1992-02-21 [2]		
Blisters (closed)	Average 75 mm diameter, 3 mm high, 300 mm spacing (i.e. ≈12 / m^2 ≈ 3600 / 100 m lane), both lanes similar	
Blisters (cracked) (no.)	16 (≈ 1/6 m^2)	17 (≈1/6 m^2)
(no. / 100 m)	53	57
Blisters (cratered) (no.)	34 (≈ 1/3 m^2)	57 (≈1/2 m^2)
(no. / 100 m)	113	190
Cracks (no.)	Few	Few
Stains (no.)	Rare	Rare
Blisters + craters (no. / 100 m)	3 766	3 847
Condition of adjacent 30 m-lengths of **untreated sections** on 1992-02-21 [2]		
Blisters (closed) (no.)	Rare	Rare
Blisters(cracked) (no.)	Rare	Rare
Blisters (cratered or potholed)	Average 75 mm diameter, 5 mm high, 300 mm spacing (i.e. ≈12 / m^2) ≈ 3 600 / 100 m lane) both lanes similar	
Cracks	Star-random, 3 - 5 mm wide, 200 mm long, 300 mm spacing, both lanes similar(≈ 12/m^2 ≈ 3 600/100 m lane	
Stains	Yes	Yes
Blisters + craters + cracks (no. / 100 m)	>7 200	>7 200

Notes:

[1] 6,7 mm Bitumen-rubber reseal applied at 08h15. Temperatures: road 30°C, air 29°C, binder 200°C. Viscosity 2 100 Cps at start. Speed 105 m/min, pump pressure 200 kPa. Design aggregate application rate 0,015 m^3/m^2. Observers: RH Renshaw and JBN Wahl

[2] Inspection panel: MI Pinard and F Netterberg

White surface stains and running over the whole width of the seal but no damage was noticed within three months of application on the 16th February 1984.

After two years in February 1986 both lanes exhibited only slight damage consisting of only one closed, 3 mm-high blister on a 3 m spacing instead of open, cratered blisters 20 mm high on a spacing of about 500 mm on the adjacent untreated sections at either end.

After five years in May 1989 the bitumen-rubber section exhibited 20 - 40 mm diameter craters or blisters about 5 mm in height at a spacing of 0,5 - 2,0 m in comparison with a diameter of 75 mm and spacing of 0,3 - 0,5m on the untreated sections, as well as salt stains on both sections and potholes on the untreated sections.

After 13 years in January 1997 there was no further significant increase in the salt damage on the bitumen-rubber section, whilst some of the holed blisters on the adjacent untreated sections were filled with soil or loose chips and went into the base, and as such are correctly called potholes.

When last inspected after 20 years in October 2004 only the cratered blistering in the right lane had increased to about 2 / m^2 and the cracking in both lanes from few in 1992 to many star to random cracks 3 - 5 mm wide, averaging about 300 mm in length at a spacing of 0,5 m in the left and 1,0 m in the right lane. The adjacent untreated sections exhibited little further change from 1992 and 1997 although the degree and extent of cracking, cratering and potholing had increased somewhat, especially in the outer 1 m.

Figure 2: Condition after 20 years in February 1992 after brooming, showing left and right lanes of bitumen-rubber reseal in comparison with unresealed section in foreground, with an ASTM D4580-type chain drag

Whilst both bitumen-rubber reseals had become damaged, they were in a far better condition than the untreated control sections. Most of the blisters were closed in comparison with the mostly cratered and potholed blisters on the untreated sections, whilst cracking was also much less. The higher binder application rate and probably also the prior rolling in the left lane yielded the better performance of the two lanes. Although no conventional reseal was applied as a control, previous experience on this road suggests that it would by then have been in little better condition than the untreated sections.

Figures 3 and 4 show the effect in 1992 of no maintenance together with little traffic since 1969 on the remnant section. Under conditions of almost no traffic at all the blistering and cracking had become very severe (Figure 3) whilst even very light traffic had led to even more severe cratering and potholing of the blisters (Figure 4).

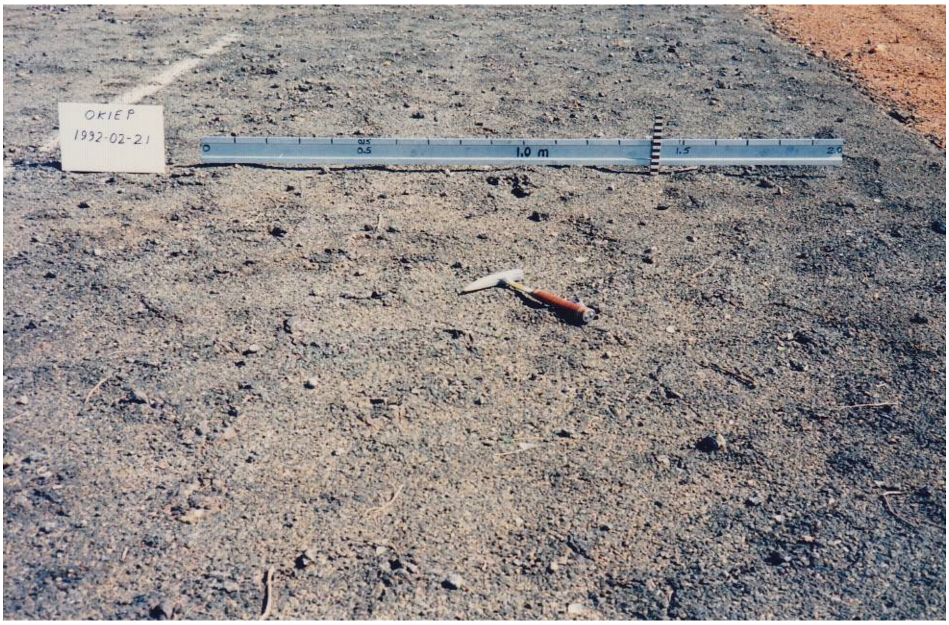

Figure 3: Lack of traffic led to blisters up to 30 mm high (but few potholes) on completely untrafficked section

Figure 4: Light traffic and no maintenance caused the blisters to progress to white-stained craters and potholes

The condition of the bitumen-rubber in 2004 was still bright and sticky (i.e. TMH 9:1992 Degree 1) and could be drawn out by about 2 mm before breaking. The 1965 reseal below was dull, black and brittle (i.e. Degree 3, but the original 1961 Cape seal was still bright, though brittle, and therefore also Degree 3).

Although samples of the base from good and bad areas were taken by the author for indicator, conductivity, pH, and mineralogical testing they were all inadvertently discarded by the roads authority without testing. Later samples taken in 2012 remain to be tested due to lack of funds.

Testing for delamination with an ASTM D4580 chain drag indicated that the surfacing on the bitumen-rubber sections was still generally adhering well to the base and this was confirmed at the sampling sites. However, a general lack of bond was indicated on the adjacent untreated sections, which were not sampled.

Although by no means a perfect solution, with prior flattening of blisters, digging out and prepatching of craters and potholes, and subsequent maintenance, a bitumen-rubber single seal at a binder application rate of about 3,0 l/m^2, can therefore be considered as an alternative to reconstruction for the rehabilitation of very severely salt-damaged surfacings on very lightly trafficked pavements

6.2 National Road N/8: km 18,35-20,00

Observations by the author in January and September 1983 between km 19 and 20 before the bitumen-rubber reseal in February 1984 showed the presence of areas of patches and mostly cratered blisters 25 mm deep and 25 - 100 mm in diameter, at a spacing of 0,5 - 2 m, equating to some 4 000 / km. The section km 18,90 - 18,95 was the worst, with an average between spacing of the damage in the right lane (i.e. O'kiep-bound) of about 0,5 m. Cracked and often cratered blisters up to about 5 mm high and 50 mm in diameter were observed to be penetrating the 1980 reseal, which was otherwise in a good condition. This section was therefore chosen for what became Sections 1 - 8 of bitumen rubber and km 19,3 - 19,5 was left as a maintained control section.

One sample each of the base from under intact surfacing and a crater at km 19,0 yielded ECs of 0,4 and 0,5 S/m respectively, with a pH of 3,4 both also far out of the COLTO:1998 specification, with a strong reaction for sulfate and chloride on both.

The positions of many old patches were visible as fatty spots on the reseal and some had again become cratered. The usual method of patching was to dig them out, fill with 6,7 mm chippings, penetrate with 60 % SS emulsion and to compact with a hand stamper. This was not always successful and addition of crusher dust to the chippings was ordered for further patching.

Observations recorded by TOSAS before sealing in 1984 also showed the damage to consist mostly of white-stained craters with an average diameter of 60 mm but ranging between 20 and 110 mm, depths of 20 mm (15 - 30) and a spacing of 800 mm (400 - 1 000) (Figure 5). Occasional blisters up to 12 mm in height at a spacing of 1,0 m (at km 19,879) and dark brown or green stains were also noted. However, no cracks were recorded.

The craters and potholes were prefilled with slurry and the blisters flattened with a steel-wheeled roller prior to resealing with bitumen-rubber (Figure 6).

Figure 5: Cratered blisters and brown staining on 1980 13 mm reseal at km 19,997: Average diameter 60 mm, depth 15 mm, spacing 400 mm (TOSAS photo)

Figure 6: Craters on 1980 13 mm reseal pre-patched with slurry and blisters flattened with steel-wheeled roller at km 19,540 (R) for bitumen-rubber Section 12: Average spacing 400 mm (TOSAS photo)

The layout of the experiment was as follows, sprayed as two 3,1 m-wide lanes:

km 18,350 - 18,750: 7 mm aggregate emulsion reseal (1984)

Applied at 13h00 - 14h00 on the 1984-02-16:

Binder

Type	:	65% Cationic emulsion
Specified application rate	:	1,10 1/m^2 (net bitumen)
Actual application rate	:	1,09 l/m^2 (left); 1,13 l/m^2 (right)
Temperature	:	60°C (road 34°C, air 41°C)
Speed	:	55 m/min
Pump pressure	:	135 kPa

Aggregate

Specified application rate	:	0,01 m^3/m^2
Actual application rate	:	0,01 m^3/m^2
Nominal size	:	6, 7 mm

Details of the bitumen-rubber reseal applied starting at 09h15 were as follows:

Binder

Specified application rate	:	2,75 l/m^2
Actual application rates	:	2,57 - 3,57 l/m^2
Temperature	:	200°C (road 30-41°C, air 29-34°C)
Speed	:	105 - 120 m/min
Pump pressure	:	200 kPa (approx.)
Viscosity	:	2 100 Cps (at start)

Aggregate

Specified application rate	:	0,015 m^3 /m^2
Actual application rate	:	0,011-0,014 m^3 /m^2
Nominal size	:	6,7 mm

During application it was noted that the aggregate was dusty and also that much of the finished product had a streaky finish, apparently due to blocked nozzles.

Both seals were rolled with a 3 tonne steel-wheel roller and a 25 tonne pneumatic roller and opened to traffic after about 1 hour.

The maintenance staff were informed that this was a road experiment and that no maintenance in the lanes was to be carried out without special permission, and notices were also erected to this effect.

The new 1984 7 mm emulsion seal between km 18,350 and 18,750 and the existing 13 mm 1980 seal between km 18,750 and 18,900 were to be kept as controls and also **not** to be maintained. However, patching of the other 1980 13 mm km 19,300 - 19,500 and 19,828 - 20,00 control sections was to continue.

Panel inspections were held after three months in May 1984 during which some salt damage was already visible, eight months in 0ctober 1984, two years in February 1986 and after eight years in February 1992. Occasional additional informal inspections with or without roads staff were also carried out by the author up to 2004.

The condition of the various seals after three months and two years and also in 1992 after the 1989 reseal is shown in Table 3. In order to allow for the different lengths of the sections the results for three months and two years have been “normalized” by expressing them all on a 100 m length basis. However, as they were so few, the eight-year results represent the actual number counted. Averages for the two bitumen-rubber sections are also shown in order to smooth out any discrepancies.

Table 3: Performance [1] of experimental reseals on N7/8 after three months in 1984 and two years in 1986 before the reseal in 1989 after five years [2], and after 8 years in 1992

Section No./km [3]	Binder		Blisters						Stains [5]			Patches [5]]			Total blisters [5]	Total blisters & stains [5]
	Type	Rate l/m^2 [4]	Closed [5]			Cratered [5]										
			No./100m		No.	No./100m		No.	No./100m		No.	No./100m		No.	No./100m	No./100m
			3m	2y	8y	3m	2y	8y	3m	2y	8y	3m	2y	8y	2 years	2 years
18,350 - 18,750 [6]	Emulsion (1984)	1,09 L	1	27	1	17	28	-	47	36	3	-	-	-	55	91
		1,13 R	1	18	5	9	21	-	49	36	-	-	-	-	39	75
18,750 - 18,900 [7]	Untreated control (1980)	2,15 L	-	-	1	-	-	1	-	-	-	-	154	-	-	--
		2,15 R	-	-	1	-	-	1	-	-	-	-	240	-	-	--
18,900 - 19,300 [6]	Bitumen- [8] rubber (1984)	3,30 L	1	6	0	1	1	-	30	43	-	0	0	1	7	50
		2,62 R	0	4	1	6	7	-	38	49	-	0	0	1	11	60
1		3,57 L	1	6	-	1	1	-	40	51	-	-	-	-	7	58
8		2,71 R	-	6	1	21	26	-	43	58	-	-	-	-	32	90
2		3,43 L	1	7	-	-	-	-	23	29	-	-	-	-	7	36
7		2,57 R	-	4	1	-	1	-	42	35	-	-	-	-	5	40
3		3,57 L	-	6	-	-	-	-	27	44	-	-	-	3	6	50
6		2,57 R	-	2	1	2	2	-	42	62	-	-	-	3	4	66
4		2,64 L	2	5	-	3	3	-	30	48	-	-	-	-	8	56
5		2,64 R	-	2	-	-	-	-	25	39	-	-	-	-	2	41
19,300 - 19,500 [7]	Untreated control (1980)	2,15 L	✓	10	-	✓	10	-	-	8	-	✓	150	-	20	28
		2,15 R	✓	4	-	✓	12	1	-	12	-	✓	206	-	16	28
19,500 - 19,828 [6]	Bitumen- [8] rubber (1984)	2,71 L	1	15	1	1	2	0	38	45	-	0	0	0	17	62
		2,76 R	1	10	3	1	2	1	27	36	-	0	0	0	12	48
9		2,66 L	-	19	2	1	2	-	44	56	-	-	-	-	21	77
12		2,76 R	-	8	-	-	1	-	24	38	-	-	-	-	9	47
10		2,76 L	1	11	-	1	1	-	31	34	-	-	-	-	12	46
11		2,76 R	1	12	6	1	2	1	30	34	-	-	-	-	14	48
19,828 - 20,00 [7]	Untreated control (1980)	2,15 L	✓	✓		✓	✓		✓	✓	-	✓	✓	-	✓	✓
		2,15 R	✓	✓		✓	✓		✓	✓	-	✓	✓	-	✓	✓

Notes:
[1] Inspection panels: May 1984: D Rose, G Els, RH Renshaw, JBN Wahl; Feb. 1986: EM de Villiers, IS Bakkes, HB Genade, F Netterberg; 1992: JP Nothnagel, IH Wiese, L Stark, MI Pinard, F Netterberg. [2] 9,5 mm Emulsion seal at 1,40 l/m^2 plus 1,0 1/m^2 diluted plus sand. [3] Sections 1 - 3 and 5 - 7 were 113 m, 4 and 5: 61 m and 9 - 12: 164 m in length. [4] Emulsion rates are net bitumen. Left = North (Steinkopf)-bound; Right = South (O'kiep)-bound. [5] Blank means not recorded, hyphen none, ✓ yes, but at the sampling sites. However, a general lack of bond was indicated on the adjacent untreated sections, which were not sampled.not counted. [6] Not maintained between 1984 and 1989 (also not before 1989 reseal). [7] Normal maintenance carried out between 1984 and 1989, but patching stopped between km19,300 and 19,500 as from late February 1986. Some craters prefilled with slurry. [8] Top two rows of rates and attributes are means for bitumen-rubber sections indicated.

Table 3 shows the three forms of salt damage observed: stains (largely cosmetic but likely precursors of blisters), closed blisters which are precursors of star-cracked blisters, which develop into craters and potholes. The last two columns show the totals of the then current damage (the closed and open blisters) and the current and potential (the stains) damaged.

After two years in February 1986 it was clear that **new** blisters, craters (holes not going into the base) and surface stains were still forming, both in the old and new reseals as well as the bitumen-rubber 25 years after construction in 1961, and in some of the old patches. However, apart from the salt damage the sections were all still in good overall condition and cracking was rare.

The whole experiment unfortunately received a 9,5 mm reseal after five years in 1989 along with the rest of the road. This destroyed both the experiment and obliterated the section markings and the sites marked to monitor the progress of the individual types of salt damage and the efficacy of the patching. Although no prior panel inspection was carried out, good photographs and notes were taken by Messrs IH Wiese and P Hougaard of the Department of Transport (DoT). No salt damage or craters were apparent in these photographs of the unmaintained bitumen-rubber sections except rare evidence of previous craters on bitumen-rubber Section 1 (3,6 l/m^2). However, areas of craters and blisters at a spacing of 0,5 - 1,0 m and evidence of previous patching could be seen on the unmaintained 1984 emulsion-treated section, recent patching on the km 18,75 - 18,9 1980 maintained control, patches and rare craters on a 0,5 - 2 m spacing on the km 19,3 - 19,5 1980 partly maintained control, and patches on a 0,3 - 2 m spacing on the maintained km 19,828 - 20,00 1980 control section.

In general, whilst some damage had also penetrated the 1989 reseal, this was limited to a few closed blisters and rare craters and in 1992 all sections were rated as in a good to very good general condition. Numerous small (75 mm diameter) dark patches seen on some sections especially km 18,750 - 18,900 represented patching done prior to the 1989 reseal. It is understood that as at February 1992 no patching had been carried out on these sections since the 1989 reseal.

In 1997 after a further reseal (the fourth) only a few stains were present on the emulsion section and none at all when last inspected by the author after 20 years in 2004.

7. DISCUSSION

In short, before resealing in 1989 the bitumen-rubber sections evinced no significant salt damage whereas the 1984 emulsion-treated and the 1980 untreated control section did.

On average, after two years the unmaintained bitumen rubber sections had far less salt damage especially in the form of closed or open (cratered) blisters than the unmaintained emulsion and the maintained untreated controls. However, the extent of staining (an indicator of future possible blistering, cracking and cratering) was much the same on the bitumen-rubber and emulsion, and least on the maintained control sections at km 18,75 and 19,30.

More importantly, the average number of potential patches in the form of craters on the two bitumen-rubber sections of only 6 / 100 m was significantly less than the 24 on the similarly unmaintained emulsion section and far less than the average of 188 patches / 100 m on the two untreated but maintained control sections.

The average higher application rates of the two lengths of bitumen rubber yielded both less current damage as well as potential damage in the form of stains. However, although among the best, even the two 3,6 l/m^2 Sections 1(L) and 3(L) exhibited some current and potential damage within two years, with similar scores of 7 / 100 m and 58 and 6 and 50, respectively.

On the basis of the then current damage after two years the **best** was Section 5(R) with 2,6 l/m^2 and the lowest (i.e. best) score of 2 / 100 m, closely followed by Section 6 (R) and 7 (R) (both 2,6 l/m^2) and the **worst** Section 8 (R) (2,7 l/m^2) and a score of 32, followed by Section 9(L), also with 2,7 l/m^2 and 21.

There seems to be little or no correlation between the then current damage and spray rate. For example, the **best** three current sections (Sections 5, 6 and 7 with scores of 2 - 5 / 100 m all had rates of 2,6, l/m, whereas the **worst** three (Sections 10, 11 and 9 with scores of 12 - 21 had rates of 2,8, 2,8 and 2,7 l/m^2.

Similarly, the **best** three with the lowest (i.e. best) current plus potential scores of 36 - 41 / 100 m (Sections 2, 7 and 5) had rates of 3,4, 2,6 and 2,6 l/m^2 respectively, whereas the **worst** three with scores of 66 - 90 (Sections 6, 9 and 8) had rates of 2,6, 2,7 and 2,7 l/m^2, respectively.

In short, there appears to be little correlation between the current plus potential performance and the binder application rate or whether it was in the left or the right lane. The reason for this probably lies in the varying degree and extent of prior damage between the sections - they were only broadly estimated and not counted. For example, Section 8(R) was on one of the worst areas of damage with a spacing of about 500 mm, and damage was often patchy.

However, it seems that a rate as high as 3,6 l/m^2 is unnecessary and that a minimum of 2,8 l/m^2 should ensure a probable maximum current damage score of about 12 (10 closed and 2 cratered blisters) / 100 m and a current plus potential maximum damage score of 50 blisters and craters / 100 m, which probably represent just acceptable maintenance loads.

The reason for the damage being so virulent and long-lasting is probably due to the ongoing oxidation of a high content of iron sulphide minerals such as pyrite (indicated by the brown and white stains) to sulphuric acid and soluble sulfate salts in the base course. However, the green stains indicate that copper sulphide was also present. The low pHs and the sulfate salts found indicate that such material should be amenable to treatment with lime.

8. CONCLUSIONS

- This was the first reported case of salt damage in South Africa due to the use of a graded crushed stone base course made from copper mine waste rock and could not then have been predicted.
- This is also the first reported case in which **new** salt damage was still being generated even 25 years after construction, probably due to ongoing oxidation of sulphides in the base to sulphuric acid and soluble sulfate salts.
- Although they all became damaged, the performance of the 7 mm bitumen-rubber reseals at application rates of 2,6 to 3,6 l/m^2 was far superior to that of an ordinary emulsion seal at 1,1 l/m^2 and preferable to that of maintaining the existing 13 mm 2,15 l/m^2 seal.

- Bitumen-rubber single reseals can be recommended for both trafficked and relatively untrafficked salt-damaged pavements at a minimum rate of about 2,8 l/m^2.
- Ordinary single reseals should not be used on salt-damaged pavements.
- Sulphides can apparently continue to oxidise sufficiently in road bases to cause long-term salt damage and should therefore be controlled in addition to conductivity and pH.
- Such materials should probably be pretreated with lime before use.

9. ACKNOWLEDGEMENTS

The author has freely drawn upon a TOSAS laying report and other information made available to him by TOSAS, the former Cape Provincial Roads Department and the Department of Transport. Many persons too numerous to mention participated or assisted this work in some way over many years, but especially Drs HH Weinert and KA Clauss then of the NITRR of the CSIR and Messrs EM de Villiers and D Rose of the CPRD, RH Renshaw of TOSAS, and IH Wiese of DoT. The experiment was started when the author was in the employ of the NITRR and the monitoring subsequently continued by him with the assistance of the Northern Cape Department of Transport and the DoT. However, the opinions expressed are those of the author and not necessarily any of the above.

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