FAILURE OF A CAPE SEAL IN KAROO CONDITIONS AND REHABILITATION THEREOF

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1. INTRODUCTION

This paper reports on the investigation by Messrs Potgieter, Hattingh & Raspi into the structural and functional condition of National route N1-11 between Hanover and Colesberg. This section of road is situated in the Karoo semi-desert region where summer and winter temperatures are extreme and the Weinert-N volume is above 10.

The existing pavement was found to be structurally adequate with sufficient structural capacity for the next 10 – 15 years. However, the functional aspects of smoothing of the surface have deteriorated to unacceptable levels. The smoothing of the surfacing was found too severe and extensive. Over 88 % of the length of the old Cape Seal surfacing were smooth and bleeding. Aquaplaning and skidding because of substandard macro and micro surface texture depth has become a real problem. This deficiency of the road was classified as a surface only problem, normally rectified through the construction of a reseal.

Several reseal designs were performed and the best product selected. This paper discusses the failure mechanism, design models as well as the construction of the reseal.

2. TRAFFIC AND AXLE LOADINGS

National route N1-11 is halfway between Cape Town and Johannesburg and extremely important in the national road hierarchy in the RSA. The more important 1999 traffic data are listed below:

- % of trucks = 37,3 %
- traffic split (north / south bound) = 46 : 54
- Average annual daily traffic = 2 457 vehicles per day
- Average annual daily truck traffic = 917 trucks per day (south bound)
- Average daily E80 in worst lane = 1 916 E80 per lane (southbound)
- Estimated E80 per truck = 1,9 E80 per truck
- Number of trucks in southerly direction = 496 trucks per day

The equivalent light vehicles (ELV) for seal design purposes in the worst lane was calculated from the formula ELV = (H x 40) + L

where L = Number of light vehicles in busiest lane per day
H = Number of heavy vehicles in busiest lane per day
40 = New equivalency factor for trucks in new TRH3
∴ ELV = 831 + (40 x 496) ≈ 21 000 ELV per day

21st Annual South African Transport Conference
'Towards Building Capacity and Accelerating Delivery'
ISBN: 0-620-28855-8

South Africa, 15 - 19 July 2002
Conference organised by: Conference Planners
CD-ROM produced by: Document Transformation Technologies

3. PAVEMENT CONDITION

The various pavement inspections, surveys and tests for this rehabilitation design are discussed in this section. The pavement consisted of:

- 19 mm Cape Seal (S4 – 19)
- 150 mm Crushed stone base (G1)
- 150 mm Stabilised sub-base (C3)
- 250 mm Gravel layers

3.1 VISUAL INSPECTION

A detailed visual inspection was carried out in September 1998, the results are furnished in table 1 below:

Type of distress	% of road in category			Total % in warning and severe
	Sound (%)	Warning (%)	Severe (%)	
Smoothing of surface	12	8	80	88
Ravelling & surface failures	100	0	0	0
Edge breaking	97	3	0	3
Cracking	97	3	0	3
Deformations	100	0	0	0
Structural failures	99	1	0	1

TABLE 1: Summary of visual survey

3.1.1 Smoothing of the surface

It is clear from the summary of the visual inspection in Table 1 that bleeding was the single largest deficiency of this road. This was confirmed by the pavement management system as well as the various laboratory measurements. The length of road within the severe category of bleeding distress was 80%. A further 8% of the road was in the warning stage. Only 12% of the road was considered sound with regard to smoothing of the surface.

The bleeding was most noticeable in the wheel path inside the traffic lanes and within the wheel tracks of the surfaced shoulders where these were used as climbing lanes.

Close-up investigations revealed that the smoothing of surfacing was due to the wearing and polishing of the chip pinnacles as well as the punching in of the large aggregate into the base. The reduction of this texture depth between the high points of the stone and the slurry surface triggered a secondary mechanism of bleeding where the wheels ride directly on the slurry.

The very high contact stresses were considered too severe to be carried by any slurry, especially on hot days. In this very hot climate with road temperatures measured above 65°C the softening point of conventional bitumen (48°C) is frequently exceeded and the binder then operates within its liquid phase.

The fattening up of the surface was due to the squeezing out of the liquid binder from the slurry. The binder possibly also originates from the tack coat which migrates upwards under the squeezing-out action of the heavy wheels. This bleeding bitumen on the road surface is then smeared along the wheel path on hot days. Imprinting of the heavy traffic tyres occurs on hot days when the tyres tread patterns are imprinted in the soft bleeding surface of the Cape Seal.

It also appears that very low surface texture was built in originally. Inspections and laboratory testing revealed that even untrafficked areas of surfacing are smooth and well below the preferred/required minimum of 0,7mm (cf. TRH3). This is possibly due to the overfilling of voids with slurry during construction of the Cape Seal.

The bleeding and fattening up resulted in a very smooth surface. The macro texture which relates to high speed braking was too smooth to allow water to escape from between the tyre and road surface and aquaplaning was a real danger. The micro texture was equally non-existent on the bleeding patches – here braking at low speeds was equally poor. It was therefore recommended that this road be resealed as soon as possible to reinstate a proper texture depth to provide the required skid resistance in wet conditions.

3.1.2 Ravelling and surface failures

Ravelling and surface failures were absent on this section of road.

The high incidence of smoothing of the surface as discussed in section 3.1.1, resulted in an over-supply of bitumen on the road surface. This excess binder was sufficient to counter ageing and deterioration of the bitumen thus preventing loss of surfacing material in the short term.

3.1.3 Cracking

The absence of cracks over this length of road indicates that there were substantial remaining structural capacity left in this pavement.

3.1.4 Deformations and structural failures

Structural failures were found to be negligible for this road. The excellent structural condition of this pavement was considered due to the Cape seal providing an adequate riding surface with sufficient cover over the base. The bleeding seal helped to keep the base layer dry albeit at the cost of skid resistance.

3.2 MECHANICAL SURVEYS

3.2.1 Riding quality

The HRI (half car roughness index) values for this section of road vary between 0,9 and 1,2mm/m and the total length of road was sound with regard to riding quality.

3.2.2 Deflections

Deflection testing using the falling weight deflectometer was performed. The total section of road was sound with regard to deflections.

3.3 LABORATORY TESTING

3.3.1 Texture depth

The visual survey revealed that the single highest deficiency of this road was smoothing of the surface with a resulting loss of skid resistance. Hence it was necessary to quantify the poor skid resistance by measuring the surface texture depth using the sand patch tests. These tests were performed in accordance with TMH6 method ST1. The results are furnished in Table 2 below.

Chainage	Texture depth (mm)		
	Shoulder		Lane
	In wheel path	Outside wheel path	In wheel path
km 26,4 LHS	0,57	0,64	< 0,4
km 31,6 RHS	0,60	0,69	< 0,4
km 34,0 RHS	0,56	-	< 0,4
km 36,8 RHS	0,60	0,66	< 0,4
km 39,0 LHS	0,64	-	< 0,4
km 41,2 LHS	0,60	0,69	< 0,4
km 43,4 RHS	0,64	0,63	< 0,4
Average	0,60	0,66	< 0,4

TABLE 2: Texture depth

The latest TRH3 states that the minimum required texture depth to provide adequate skid resistance is 0,7mm. None of the surface texture measurements met this requirement.

All the texture depth tests in the untrafficked areas of the shoulders were below 0,7mm. This indicates that low texture depths were originally built into this pavement, possibly the overfilling of the voids with slurry whilst constructing the Cape seal.

The proposed mechanism of bleeding is described in section 3.1.1. Suffice it to repeat here that the macro and micro surface texture which is so important for braking was at a minimum. Resealing for the sole purpose of providing texture depth for skid resistance in wet conditions was urgently required.

3.3.2 Ball penetration

The visual survey together with the sand patch tests indicated that the surface was smooth and fatty. The imprinting of tyre tread patterns into the fatty surface on hot days confirmed that the surface becomes soft on hot days. It was imperative that the magnitude of surface softening be determined during the design phase so that a workable solution can be allowed for in the project specification. The ball penetration method was used to assess the punching in of chips. The results are furnished in Table 3.

Chainage	Corrected ball penetration (mm)	
	In wheel path (@ 40°C)	In between wheel path (@ 40°C)
km 26,4 LHS	4,1	3,6
km 31,6 RHS	4,6	3,6
km 34,0 RHS	3,6	-
km 36,8 RHS	4,1	3,1
km 39,0 LHS	3,1	-
km 41,2 LHS	4,6	4,1
km 43,4 RHS	4,1	3,9
Average	4,0	3,7

TABLE 3: Ball penetration

All the ball penetration results, whether inside or in between the wheel paths, are high. The substrata on which the reseal was to be constructed was very soft. In fact it equals the highest penetration which the design curves in the latest TRH3 allow for.

With this high penetration and heavy traffic loading over 20 different seal designs were performed to assess the most suitable reseals for this project. The seal designs are discussed further in section 5.

3.4 SUMMARY OF MECHANISM OF FAILURE

The mechanisms of failure which give rise to the extensive smoothing of the surface are:

- Wear and tear of the chips (polishing).
- Overfilling of the voids with slurry initially.
- Punching in of the 19mm aggregate into the base.
- Because of the abovementioned 3 aspects the heavy wheels are now carried directly on the slurry.
- The bitumen from the original tack coat and slurry binder is migrating to the surface under the squeezing out action of the heavy wheel loading.
- The excess binder is smeared along the wheel path.

The slurry was found to be very soft and aggregate embedment as high as 4mm should be allowed for in the reseal design.

4. SURFACING SEAL DESIGN

4.1 HOT CLIMATE EFFECTS

This pavement is situated in a region with extreme summer and winter temperatures. The highest ambient temperature recorded was 40^{o}C and the lowest – 8^{o}C over the last 28 years. It was estimated that the average annual number of hours which the road temperatures is above 50^{o}C is 1 000 hours and above 60^{o}C is 120 hours i.e. almost 83% increase.

What makes this temperature scale significant is that conventional bitumens have a softening point around 48^{o}C. These bitumens will then be in the liquid phase for much longer than (say) a bitumen-rubber with a softening point of above 60^{o}C. Similarly will all the modified binders operate within its liquid phase for a much longer period, all depending on its softening point. This will largely influence the performance of a seal, should the bitumen be in a liquid phase, as the aggregate will act unpredictable when subjected to heavy wheel loads. If in a solid state, the bitumen will make the seal behave like a plane with much better load distribution characteristics and resistance to punching.

There is a similar performance correlation between road temperature, softening point and durability. If in a liquid stage the volatiles evaporate under vehicular wind action. The loss of volatiles after many such hot hours results in a bitumen that has aged prematurely, normally glossy with a lack of adhesion and workability.

4.2 MODIFIED BINDERS

Various modified binders were available for this project including non-homogenous binders like bitumen rubber and homogenous binder such as Styrene-butadiene-styrene (SBS), Styrene-butadiene-rubber (SBR), Ethylene vinyl-acetate (EVA), etc. From the available range of modifiers, a modifier had to be selected that would be able to cope with the heavy traffic conditions of national route N1-11 and the extreme temperature conditions of the Karoo. Cognisance was taken of the following advantages of modified binders:

- The load carrying capacity of modified binders is much higher and high traffic volumes can be catered for.
- The aggregates, when strewn on the stiffer modified binder, stand more erect and offer a higher effective ALD (+ 10%). With higher softening points the stiffer modified binder will cause the chips to lie as they fall. This lesser orientation creates a thicker effective layer of stone.
- The latest TRH3 advises that the modified binder seal acts more like a stiff mat and punching in of individual aggregates is reduced (± 50% but this is debatable).
- With higher softening points the modified binders will be in the liquid phase for a much shorter time resulting in less opportunities for punching (± 50% less punching).
- With higher softening points and shorter time in the liquid phase there will be a smaller loss of volatiles from the binder, i.e. a much better resistance to ageing and an increased durability.
- Modified binders have superior adhesion/adhesive qualities and existing surfacings with much higher surface textures can be overlaid (up to 1,0mm instead of 0,63mm). This saves on pre-treatment costs.
- Modified binders, to a large extent, can withstand the 3 main reasons for stripping, e.g. lack of adhesion, brittleness and stripping under the influence of water.
- Modified binders, in general but especially bitumen-rubber, offer high resistance against oxidation, ageing and deterioration.

4.3 RESEALS

The main functions of a surfacing seal are to:

- provide a waterproof cover to the underlying pavement;
- provide a safe all-weather dust-free riding surface and with adequate skid resistance for the public traffic; and
- protect the underlying layer from the abrasive and destructive forces of traffic and the environment.

In its simplest form a seal consists of a coat of bituminous binder which is then covered with a layer of aggregate and rolled. More layers of bitumen and/or aggregate may be added thereafter. There are a number of seals commonly in use which we considered suitable for this project. The three most likely candidates investigated were:

- Cape seal
- Single seal
- Double seal

Other surfacings such as pure slurry seals, sand seals, etc. were structurally too weak for this traffic situation. At the other extreme is asphalt surfacings, but these are too expensive and not justifiable for the existing traffic situation.

4.3.1 Cape seal

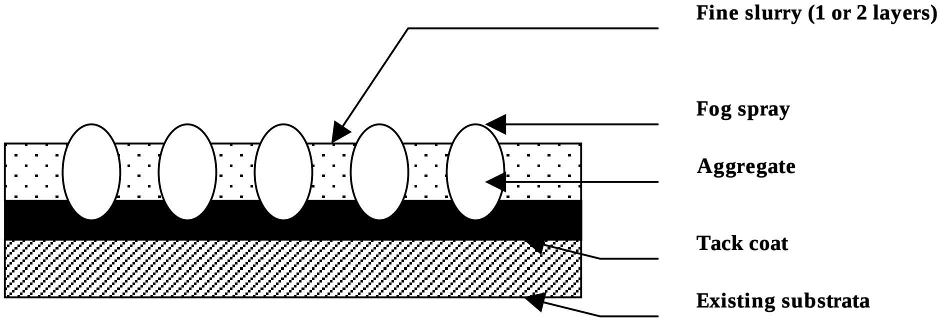

Figure 1: Cape Seal

Resurfacing using a Cape seal consisting of either a 13,2mm or 19,0mm aggregate tacked to the substrata with a bitumen was considered.

A 13,2mm and 19,0mm with an ALD of 8mm and 12mm respectively was designed for. Embedment, chip wear, future texture depth allowances, existing surface texture treatment, etc. was allowed for in the design. The equivalent void height left over to be filled with tack coat and slurry for the 13,2mm and 19,0mm aggregate is 2mm and 6mm respectively. The 13,2mm Cape seal offers insufficient space for the slurry after punching, chip wear, etc. and only the 19,0mm Cape seal is therefore a viable proposition.

The tack coat binder should be hot applied straight penetration binder. This is normally more economical. Also, it will heat up the existing fatty surface to increase the initial embedment and so decrease the unwanted post-construction punching by public traffic. The slurry seal must be struck off by hand squeegees and to a predetermined distance below the tip of chips. The slurry will flow between the large aggregates irrespective of the shape of the road, differential punching, existing texture variations and other cross-sectional differences. Thus this Cape seal can be struck off at the required texture depth.

The disadvantage of the Cape seal overlaying an old bleeding surface is that the wheels will again be touching the slurry and so cause upward migration when the old fatty bitumens are squeezed out. There is a real danger that the existing bleeding may repeat itself on the new Cape seal. The resurfacing of an old bleeding Cape seal by another Cape

4.3.2 Single seals

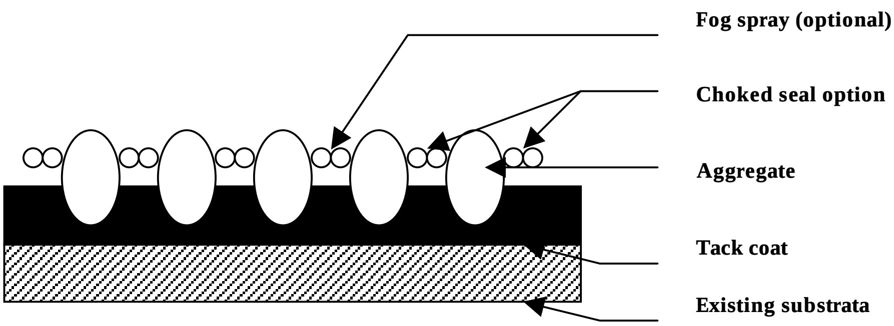

Figure 2: Single Seals

The use of single seals using 13,2mm, 16,0mm and 19,0mm aggregate and tacked to the substrata with a conventional or modified binder was evaluated for this project. A fog spray or pre-coating could be added as an optional extra. The use of a single seal, choked with a smaller aggregate could render excellent results but it requires a high level of skills which was not readily available from all contractors.

The use of 19,0mm single stone, although it offers a deep ALD and superior punching resistance, was not recommended for use because of tyre noise and heated tyre pressure bursts. The next size of 16,0mm aggregate is scarce but was available locally, an ALD of 10,5mm was expected. The 13,2mm aggregate was readily available commercially and with an ALD of around 8mm. Single seal design for both the 13,2mm and 16,0mm aggregate utilising straight penetration as well as modified binders was performed. These results appear in Table 4 where minimum and maximum envelopes for binder applications are furnished for 0,7mm minimum and 1,0mm maximum texture depths.

Nominal aggregate (mm)	ALD (mm)	Aggregate spread rate (m^3/m^2)	80/100 pen. bitumen (l/m^2)		Homogenous modified binders: Cold applied (SBS or SBR) (Note 1,2,3,5) (l/m^2)		Homogenous modified binders: Hot applied (SBS or SBR) (Note 1,2,3,5) (l/m^2)		Bitumen-rubber (Note 1,2,3,4,5) (l/m^2)	
			Min	Max	Min	Max	Min	Max	Min	Max
13,2	8,5	0,010	Too low		0,88	1,15	0,93	1,14	0,95	1,24
16,0	10,5	0,13	0,83	1,34	1,18	1,68	1,17	1,54	1,27	1,18

TABLE 4: Single seal design: Bitumen spray rate

Note: ⬭ can not be sprayed, binder is below minimum hot spray rate. The minimum spray rates are 0,8 for penetration bitumen, 1,1 for homogenous modified binder and 1,8 l/m^2 for rubber modified binders.

Spray rates that are circled in Table 4 indicate seals with spray rates below what can practically be sprayed. It is clear from Table 4 that only the 16,0mm aggregates could be used. The lesser ALD, punching, etc. prevented the use of a 13,2mm single seal on this project. All the bitumen-rubber seals were not suitable because of too little voids for this high minimum spray rate. If bitumen-rubber is sprayed below 1,8 l/m^2 then aggregate whip-off is likely to occur, especially if cold weather is experienced within the first 14 days.

The 16,0mm aggregate is suitable if used in conjunction with the homogenous binders such as cold or hot applied modified binders (SBS or SBR). The cold applied emulsions manufactured by emulsifying proper hot applied SBS or SBR was relatively new in South Africa and experimental to a certain extent (cold applied emulsified SBS or SBR is not to be confused with conventional emulsion to which SBS or SBR latex is added).

The 16,0mm aggregate with hot applied SBR was therefore preferred for this project. The hot applied SBR would heat up and soften the existing surfacing to increase embedment during construction and so reduce unwanted post-construction embedment. However, the 16,0mm aggregate seal has a coarse texture with a poor appearance because of the many micro undulations caused by the uneven existing Cape seal, differential punching, ALD variations, etc. The untidy wavy surface appearance, tyre noise and tyre heat build-up makes this seal an unattractive proposition. However, a double seal where the first layer of aggregate is struck level on top with a heavy steel drum roller before the final layer of small aggregate is overlaid offers a superior appearance with better riding quality and less tyre flexing.

4.3.3 Double Seals

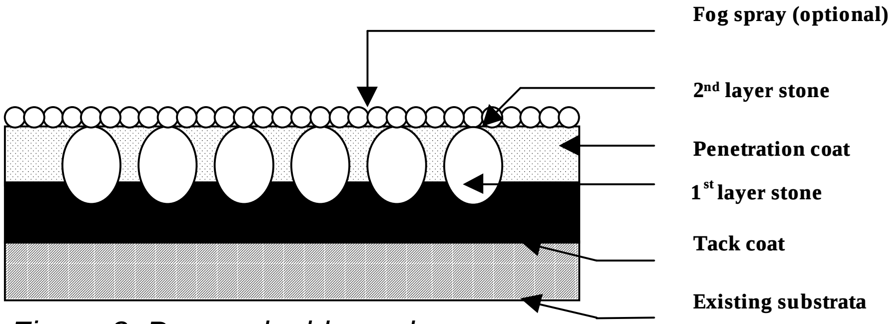

Figure 3: Proper double seal

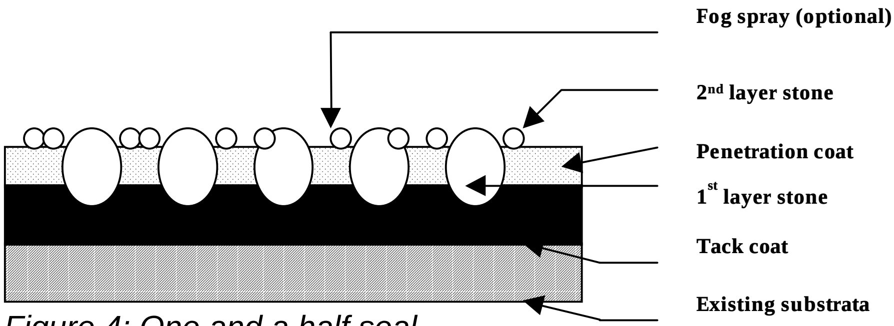

Figure 4: One and a half seal

The double seal in Figure 3 is most commonly used, a slight derivative is the one and a half seal shown in Figure 4. The latter seal comprises a slightly open seal to allow for the next layer of keystones.

Standard aggregate sizes are 19,0mm, 13,2mm, 9,5mm and 6,7mm. De Aar Crushers could also produce a 16,0mm chip although it is seldom used in road construction. Normal combinations are the 19,0mm or 13,2mm chip in the first application followed by a second layer of 9,5mm or 6,7mm. An alternative is the thinner 13,2mm and 6,7mm double seal.

It is good practice to roll the first layer of stone with a heavy smooth steel drum roller until a tight and flat surface has been obtained. A certain amount of crushing/splitting of the coarse aggregate will result, but the final finish should be tight, uniform and flat with the top of all chips in one flat plane. The broken points will lock the lower layer not unlike the choke or one and a half seal. The second layer of aggregate will lie evenly on top of the smoothed out first application. The smaller the aggregate in the final layer of chips (e.g. 6,7mm) the smoother and neater the final appearance.

The bitumen used should be a hot applied straight penetration bitumen or a hot applied modified bitumen. The transport costs of the emulsions are normally expensive because of the high water content. Cut back bitumens with solvents should not be used. Modified binders will have definite advantages in this heavy vehicle situation where extreme hot weather prevails during the peak summer months. Double seal designs for modified and unmodified binders were performed. These results appear in Table 5 where minimum and maximum envelopes for binder applications are furnished for 0,7mm and 1,0mm maximum texture depths.

Nominal aggregate (mm)	ALD (mm)	Aggregate spread rate (m³/m²)	80/100 pen bitumen (l/m²)		Homogenous modified binders: Cold applied (SBS or SBR) (Note 1,2,3,5) (l/m²)		Homogenous modified binders: Hot applied (SBS or SBR) (Note 1,2,3,5) (l/m²)		Bitumen-rubber (Note 1,2,3,4,5) (l/m²)	
			Min	Max	Min	Max	Min	Max	Min	Max
19+9,5	12+6=18	0,014+0,0065	2,28	3,02	2,83	3,77	2,86	3,80	3,06	4,07
19+6,7	12+4=16	0,014+0,005	2,05	2,50	2,51	3,18	2,53	3,21	2,71	3,43
13+6,7	8+4=12	0,014+0,005	Too low		1,94	2,32	1,96	2,33	2,10	2,51

TABLE 5: Double seal design: Bitumen spray rate

Note: can not be sprayed, binder is below minimum hot spray rate. The minimum spray rates are 0,8 for penetration bitumen, 1,1 for homogenous modified binder and 1,8 l/m² for rubber modified binders.

Spray rates that are circled in Table 5 indicate seals with spray rates below what can practically be sprayed. It is clear from Table 5 that none of the 13,2mm and 6,7mm and none of the bitumen-rubber seals were suitable for this road because of either too low voids or too high minimum spray rates.

Of the 19,0mm + 9,5mm or, alternatively, 19,0mm + 6,7mm double seals was the latter more suitable for this project because of its lower consumption of bitumen and thus less costly. The recommended 19,0mm + 6,7mm can either be constructed with a 80/100 conventional penetration binder or a homogenous modified binder emulsion or a hot applied modified binder. The cold applied homogenous emulsion which is manufactured by emulsifying a proper SBS or SBR bitumen was relatively new in South Africa and is not be confused with the lesser quality standard emulsion to which SBS or SBR latex is added. For this reason and because no water is transported in the case of the hot binder, the hot applied SBS or SBR is the preferred option. Both SBS and SBR have been used successfully to date but because of the uncertain behaviour of SBS during cold weather construction, the SBR was preferred. The conventional 80/100 penetration bitumen would also function satisfactorily in this 19,0mm and 6,7mm double seal but superior durability was looked for in this extreme climate and heavy traffic loading. Also, the conventional bitumen double seal requires pre-treatment of the existing surfacing which would adversely affect traffic accommodation.

Although uncoated stone could be used, pre-coating would greatly enhance the adhesion between the bitumen and aggregate. Adhesion is at its most critical when the road is freshly sealed and the adhesive bonds are still in the process of developing. Preferably all aggregate should be pre-coated but if funds are limited then at least the second aggregate layer should be pre-coated. Should the aggregate be pre-coated then bitumen split between the 1st and 2nd spray applications should be 50:50. No fog spray is then required.

If the aggregate is not pre-coated then the split should be 35:35:30 between the 1^{st} and 2^{nd} layers and fog spray. In the latter case the fog spray application should be increased since at least half of the fog spray will remain on the aggregate tops. A final design check should be made to see that at least the minimum sprays (refer to end of Table 5) are applied to prevent initial whip-off.

A smooth surface finish with good rideability is expected if a steel drum roller is used to iron out the pinnacles of the chips on the first layer, followed by the small 6,7mm finishing layer rolled with a rubber tyred roller.

The double seal with 19,0mm and 6,7 mm aggregate was accepted for this project and constructed as such.

5. CONSTRUCTION ASPECTS

The double seal was constructed during the first half of 2000. Frequent inspections after construction, during and after the defects liability period has shown that the seal is performing well.

The 19mm and 6,7mm aggregate sizes were crushed dolorite obtained from De Aar Crushers. The aggregates were extensively tested and conformed to all requirements of the COLTO specification.

The binder used for the construction of the double seal was a homogenous hot applied modified binder consisting of a 60/70 penetration grade base bitumen modified with 3,2% by mass styrene-butadiene rubber (SBR). The specification for the softening point of the binder was adjusted in the project specification from the standard 47^{o}C to 50^{o}C. This was done to accommodate the very high summer road temperatures. (In hindsight, a 60^{o}C softening point would have been better.)

The document also made provision that the 3% of SBR can be adjusted on site to achieve the specified characteristics. The percentage SBR was thus adjusted upward on site to 3,2%.

Some investigation was also done in the site laboratory on the degrading properties of the SBR binder at extremely high temperatures. Samples of the binder were kept at very high temperatures in the site laboratory and the softening point of the samples were then measured at regular intervals. The results indicate that rapid degrading of the binder occurs at spray temperatures between 210^{o}C and 230^{o}C. This could be seen as the softening point of the binder dropping from approximately 53^{o}C to approximately 48^{o}C in less than four hours of exposure to the very high temperatures. After the four hours the softening point starts to increase again as the base binder harden. A similar tendency was also seen on site when delays occurred during the binder application process and the binder was kept at high temperatures for an extended period.

The 19mm aggregate was placed on a 1,3 ℓ / m^2 SBR tack coat. The aggregate was spread with the latest generation Wirtgen chip spreader imported from Germany by Haw and Inglis (Pty) Ltd. The Wirtgen chip spreader was fitted with a telescopic spreader roller and electronic controls to adjust the aggregate application rates. After the initial rolling and brooming the 19mm stone was rolled with a smooth steel drum roller to achieve pre-punching into the soft slurry of the cape seal underneath. The final rolling of the 19 mm aggregate as well as the top 6,7 mm layer was with heavy pneumatic rollers.

6. REFERENCES

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