BITUMEN RUBBER CHIP AND SPRAY SEALS IN SOUTH AFRICA

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ABSTRACT

Bitumen rubber chip and spray seals have been used successfully in South Africa since 1982 and mostly on road rehabilitation projects.

The main advantage of bitumen rubber seals extra over a standard binder is its superior waterproofing as well as its ability to prevent reflective cracks breaking through the newly placed chip seals or asphalt overlays and its longevity. The higher spray rates together with the better rheological properties of bitumen rubber modified binders provide the following additional benefits.

- Widening of working temperature range (Fraass freezing point up to softening point).
- Reducing temperature sensitivity.
- Longevity due to anti-oxidants in tyre buffings.
- Better adhesion.
- Stress absorbing qualities.
- Better Average Least Dimension (ALD) aggregate stands because of high B-R stiffness.
- Lesser stone embedment because of higher softening point.
- Resistance to binder absorption.
- Lesser pre-treatments.
- Superior elasticity and fatigue.

The aim of this paper is to present the South African design and construction procedures which have had widespread success. This paper describes the latest design methods as well as construction procedures of bitumen rubber chip and spray seals. Case studies are presented to describe the performance history. It is concluded that bitumen rubber chip seals are a viable and successful option on especially badly deteriorated roads where normal binders are ineffective.

1. INTRODUCTION

Seal work in South Africa in its elementary form consists of a coat of bituminous binder sprayed on by a special bitumen distributor followed by a layer of stone. The stone or aggregate is applied immediately after the binder and then rolled whilst the binder is still in its hot fluid state. A second coat of bitumen together with a second layer of stone may then be applied if a double seal is required. Both single and double seals may be finished off with a fog spray. The aim being to achieve a dense impermeable surfacing.

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In South Africa, as in general, the main function of a surfacing seal is to:

- Provide a waterproof cover to the underlying pavement.
- Provide a safe all weather, dust free riding surface for traffic with adequate skid resistance.
- Protect the underlying layer from the abrasive and destructive forces of traffic and the environment.
- Provide a Stress Absorbing Membrane Interlayer (SAMI) to prevent cracks from the underlying pavement reflecting through the new surfacing / overlays.

Whereas the bitumen provides the waterproofing membrane, it cannot support the wheel loads. The latter is carried by the aggregate, which acts as stepping-stones.

Bitumen Rubber (B-R) has come to the fore in South Africa (SA) as the preferred modified binder for chip and spray applications during pavement rehabilitation for heavy traffic situations. Furthermore, its high elasticity also helps to provide a waterproof layer over new construction of cement stabilized bases with shrinkage cracking. The excellent long-term performance over the past 20 years largely contributed to the good standing of B-R binder in South Africa. Different B-R chip seal projects from the past were revisited by the authors to assess the quality and long-term behavior of this product in South Africa.

The primarily thin surfacings used on unstabilized bases in South Africa makes the pavement sensitive to moisture ingress and waterproofing is vital. With the advent of stress absorbing membrane high levels of waterproofing as well as crack retardation is possible. The Stress Absorbing Membrane (SAM) is laid on top of the existing surfacing. The Stress Absorbing Membrane Interlayer (SAMI) in turn is constructed in between the old surfacing and asphalt overlay. Apart from the waterproofing the SAMI also provide an excellent method to prevent crack reflection through the asphalt overlay.

In practice the SAM and SAMI in South Africa is constructed as a B-R chip and spray seal[2]. The aggregate range from 26.5mm, 19.0mm, 13.2mm to 9.5mm, for single size aggregate. Double seals consist of 19.0mm plus 9.5mm. Single or double seals with aggregates less than 9.5mm are normally not used for B-R since the voids are small and the B-R binder can only be sprayed at high application rate (>1.8 ℓ / m^2) to obtain uniformity of the spray.

The aim of this paper is to present the South African design and construction procedures for B-R chip seals which have had widespread success. This paper covers the following aspects:

- Justifications for the use of B-R modified binder.
- Construction of B-R chip seals.
- Design procedures for B-R chip sprays.
- Summary.

It is concluded in this paper that B-R chip seals outperformed conventional chip seals (penetration grade bitumen) and other modified binder seals (SBS, SBR, EVA, etc.) and is the more economical chip seal when assessed over its full life cycle. B-R is especially suited to highly cracked pavements where it must be sealed and overlaid to prevent ingress of water, retard crack propagation and to provide additional structural capacity in heavy traffic situations.

2. BITUMEN RUBBER JUSTIFICATION

Bitumen-Rubber binder in South Africa costs approximately 30% more than an unmodified binder resulting in a chip seal that is about 10% more expensive than a conventional seal. Road authorities therefore expect a full justification of the use of B-R. The following paragraphs deal shortly with the topic.

2.1 Increasing the working temperature range

Practitioners in SA assume the working temperature range to be that band of ambient temperatures between freezing on the lowest end and the upper extreme where the binder is in the liquid state. The Fraass freezing point (less than –10^{o}C) is considered the limit below which a conventional bitumen tends to brittle fracture i.e. the lower end of ductility. The upper limit of the binder at which it can be considered an elastic solid is taken as the softening point (+48^{o}C for standard bitumen) i.e. above this it is in the liquid phase. Manufacturers of homogenous binders often claim that they can increase the softening point so that the binder remains a solid at elevated temperatures. However, this is mostly accompanied by raising the Fraass brittle fracture temperature as well. In such cases the total working temperature range is merely lifted and not widened, this is not the case with B-R binder.

2.2 Reducing temperature sensitivity

Conventional bitumen binders have softening points around +48^{o}C. Above this temperature, the bitumen enters the liquid phase where volatiles are lost with evaporation especially when vehicles generate hot winds in their slipstreams. When the bitumen cools down in the afternoons the binder returns to its solid state but minus the lost volatiles; the loss of volatiles is linked with the ageing of a binder i.e. the more volatiles lost the quicker the ageing of the binder. In SA some arid zones have road temperatures above 48^{o}C for as much as 1 500 hours per year and above 60^{o}C for about 100 hours per year. The use of B-R binder with a softening point above 60^{o}C is recommended in such hot climates since this ageing mechanism will be reduced from 1 500 to 100 hours per year[3]. This reduction in exposure to the liquid phase and conservation of volatiles largely contributes to the longevity of B-R binder. Furthermore, with the B-R good Fraass brittle fracture temperature it will rather flow plastically at temperatures as low as –20^{o}C without brittle fracturing.

2.3 Longevity

Because of the high softening point of B-R there is a largely reduced hardening / brittleness mechanisms and as described in 2.2 above. Further, the carbon-black chemical compounds used in the manufacture of tyres are excellent anti oxidants. The combined anti-evaporation and anti-oxidants in B-R is largely responsible for the B-R binder's superior longevity (up to 50% longer life time).

The main reason for the introduction of B-R modified binder to South Africa in 1982 was to make available a superior B-R chip and spray that would successfully reduce reflection cracking and retard ageing. Several road sections were paved in 1982 to evaluate the performance. The first roads were road P1-6 (Potgietersrus), road 343 (Brits), road MR27 (Stellenbosch), National Road N2 (Somerset-West) and National Road N2 (Umdloti). Roads P1-6, 343 and MR27 were revisited the past years. We concluded that the B-R seals performed admirably over the last 20 years. Although some of the base defects have reflected through, the anti-ageing and longevity performed way above that of a conventional binder.

2.4 Better adhesion

The modified Vialit adhesion test[5] is the specified test and comprises of sticking chips onto a plate, heating the plate (two tests at 5°C and 50°C respectively), the plate is then turned around and a steel ball dropped on the plate. The number of chips remaining on the plate after impact is expressed as a percentage of the original number applied. For conventional and homogenous binders the minimum percentage remaining is 95% (at 5°C) and 100% (at 50 °C), but for B-R binder these minimums are lifted to 100% for both tests since it is so easy to achieve this with B-R.

2.5 Stress absorbing membrane

Pavement structures are normally analysed by using multi layered models assuming homogenous isotropic linear elastic models. Whenever cracking occurs, these assumptions do not hold as there are sharp discontinuities. There have been a number of attempts to examine the problem of minimizing reflective cracking in asphalt overlays. One such study focused on the use of Stress Absorbing Membrane Interlayers (SAMI's)[6].

The finite element procedure was used to examine the distribution of stress in an overlay in the vicinity of a crack for situations with and without a SAMI. Figures 1 and 2 illustrate the effective stress distribution for a specific situation with and without the interlayer. Comparing these stress contours on the figures, it is clear that there is a large reduction in stress levels at the top of the crack when a SAMI is used. Hence it is more the reduction in stress contours that prevents crack propagation, although it must be added that the superior tensile strength of B-R binder also helps to resist the ripping open of the membrane in the vicinity of the crack. Some South African designers consider that crack activities, or relative crack movements under wheel loads, as high as 800 micron can be effectively dampened this way.

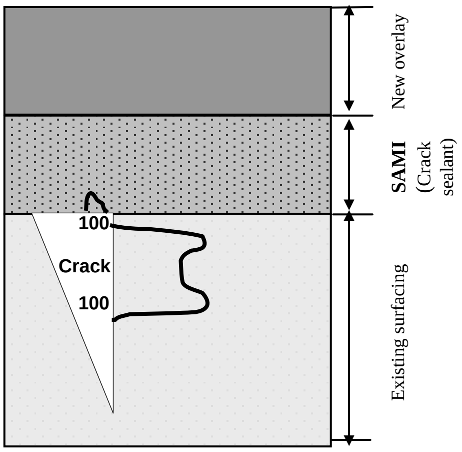

Figure 1[6]: *Effective stress distribution in asphalt overlay (in psi)* ***with*** *stress absorbing (SAMI)*

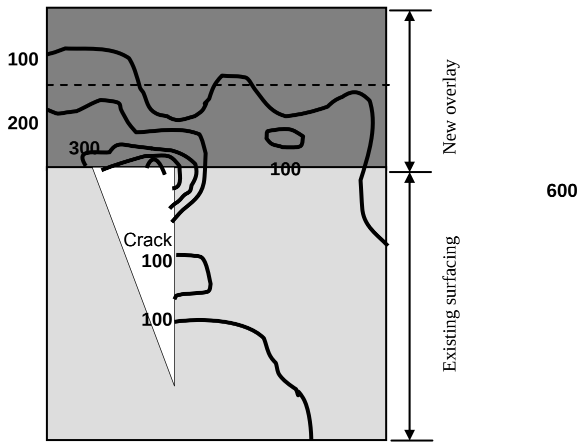

Figure 2[6]: *Effective stress distribution in asphalt overlay (in psi) (SAMI)*

One of the oldest SAMI's in South Africa was placed in 1986 and 19 years later it is still performing well[7]. The original cement treated base had measured crack activities measured up to 700 micron and deflections as high as 600 micron under a 80 kN dual wheel axle. The SAMI consisted of a 13,2mm quartzite aggregate (with an ALD of 8,8mm, 10% FACT value of 335 kN and pre-coated). The B-R binder spray rate was 2,4 to 2,7 ℓ/m^2. It is standard practice in South Africa to fill the SAMI voids in between the aggregate to as much as 80% full, all to prevent pockets forming between the bottom of asphalt and top of seal binder. Pockets here will lead to stripping should rainwater ever enter. Also, the SAMI as seal is opened to traffic for only six weeks before overlaid with an asphalt, this cover reduce embedment, wear, tear etc. Filling SAMI voids up to 80% and not the normal chip and spray level of 45% requires about 1,6 more binder hence the very high application rates. This SAMI together with a 40mm B-R asphalt has successfully carried 11 x 10^6 E80 to date.

2.6 Greater equivalent layer thickness

Modified binders, and especially B-R binder are used in South Africa to reduce the punching in of chips, which is possible because of the binder's higher stiffness. The mechanism is that during construction when the chips are spread they tend to fall upright and stay upright within this very stiff binder. Chips standing upright create voids much larger than when they are lying with their least dimension vertical. The upright position may be altered by quick rolling immediately behind the bitumen distributor or by heavy traffic during hot days early in its service life. However, by deliberately delaying rolling and under light traffic the chips will remain more proud and the B-R seal can be purposely constructed to accommodate more punching. The latter technique is useful when rehabilitating lightly trafficked roads which are cracked and in a poor condition requiring a thick waterproofing seal.

2.7 Lesser stone embedment

The modified binders, especially the non-homogenous B-R binders, are stiffer than conventional binders. With the individual chips being bound together with a more stiff binder the chip seal will have better load distributing characteristics since it will now act as a rigid and uniformly distributed load on top of the base, thus preventing individual chips from punching in. Alternatively a binder in its liquid state cannot bind the chips together so solidly that individual movement is prevented, hence punching-in is possible while the binder is in it's liquid state. The higher the softening point (such as for B-R binder) the less time the seal will be exposed to the punching in forces resulting in a reduced embedment over the seals life span. The South African designers take advantage of this condition and they reduce the design embedment of conventional binders by as much as 50% when using B-R binders.

On National Road N4, near Witbank, an open graded asphalt failed in the slow lanes. Rehabilitation comprised the 25mm deep milling out of the asphalt and inlaying it immediately with a continuously graded asphalt. Thereafter the total road width was chip and spray sealed with a 13,2mm aggregate at approximately 0,01 m^3/m^2 and a B-R binder at approximately 1,8 ℓ/m^2. The problem that could arise out of this method is that the asphalt is still fresh and soft and that the chips could punch in. However, after eight years the B-R binder is still successfully resisting punching-in and embedment.

2.8 Resistance to binder absorption[9]

Porous and dry surfacings tend to absorb binder often resulting in loss of aggregate from a new seal. In South Africa some aggregates (especially quartzitic sandstones from the Eastern Cape) are known to have long-term absorptive characteristics i.e. with time the lighter fractions of binder migrate into the chips. The migration or loss of binder on the stone / binder interface results in a prematurely dried out seal. This phenomenon is encouraged by binders with a low softening point (softer binder), which is in the liquid phase for a longer period. B-R binder is often prescribed because of its high softening point (less hours in liquid phase) and also because of its higher viscosity (reluctance to migrate) as a second line of defense in the unlikely event of the softening point of B-R be exceeded. The application of pre-coating fluids will also retard this migration action but not in the case of long-term absorption, when the thicker B-R is preferred.

2.9 Lesser pre-treatment

It is standard practice in South Africa to pre-treat existing surfacings before re-sealing, if the texture is too coarse. Normally, if the texture depth is above 0,6mm, and a conventional binder is to be used, then a pre-treatment such as fog spray or slurry seal will be called for. If a modified binder is used, the maximum texture depth may be increased to 1mm and if a B-R is used up to 1,2mm texture depth was used successfully. The real saving in this case is that construction activities need pass over the road one less time because pre-treatment is excluded.

A recent example of this type of saving is on the N1/4 from Touwsriver to Laingsburg. An S-E2 polymer modified double seal was initially specified. After construction started the road was found to be a more cracked state than it was at tender stage due to an extremely (and rare) wet rainy season. Also the portion of the seal close to Laingsburg will undergo severe temperature changes as it falls within the arid and dry “Moordenaars Karoo”. After calculations it was found that if the slurry pre-treatment was left out a bitumen-rubber double seal could be constructed and at a lower cost.

2.10 Superior structural capacity

The SAMI also enhances the asphalt’s structural capacity that provides a thinner but equivalent asphalt thickness, with resultant cost savings as shown in Table 1. Note that a gap grading is typically a grading with an absence of the 2.00 to 6.5mm fractions. Please note the difference in equivalent thickness between the 2nd and 3rd column, all because of the SAMI’s contribution to strength.

Table 1. Structural equivalent with SAMI

Conventional dense graded asphalt (mm)	Equivalent bitumen rubber gap-graded asphalt (mm)	Equivalent bitumen rubber gap-graded asphalt with SAMI (mm)
37	30	-
60	30	-
75	45	30
90	45	30
105	60	45
120	65	45
135	45 BR + 45 (AC)	60
150	45 BR + 60 (AC)	60

3. CONSTRUCTION OF B-R CHIP SEALS

3.1 Bitumen Rubber binder[2]

In South Africa the rubber crumbs, penetration grade bitumen, extender oil, and other approved materials are normally blended in a patented high-speed blender (3 000 r.p.m). This blended bitumen is then pumped to a holding tank with continuous circulation and heating facilities. Here the blend is elevated to temperatures of between 170 – 210°C and allowed to react for a minimum of 1,0 – 4,0 hours whilst the chemical digestion process is completed. Some manufacturers use the bitumen distributors as holding tanks i.e. the blended bitumen are delivered directly to the bitumen distributor. In the bitumen tanker or distributor it is heated, chemically digested and re-circulated until the B-R conforms to the specification, and then it is sprayed using the same vehicle.

The base binder is usually an 80/100 penetration grade bitumen. The rubber crumbs are produced by processing and recycling pneumatic tyres using a mechanical comminuting process (cryogenic techniques are not used in South Africa). The crumbs are pulverized, free of fabric, steel cords and other contaminants. The South African specification allows for 20 – 24% rubber and is given in Table 3. However, varying the rubber crumb content adds another variable and further complicates the manufacturing process. The more reliable manufacturers pre-select the type of tyre and have now standardized on 20% of rubber crumbs to simplify the process. Talc powder (max 4%) may be added during comminuting to ensure that the crumbs are free flowing and dry. The South African specification for rubber crumbs appears in Table 2. Extender oil may be used to enhance the chemical digestion process and is a petroleum-derived resinous, high flash point aromatic hydrocarbon conforming to the SA specification as furnished in Table 2. A diluent is allowed and is a distillate of hydro-carbon.

Table 2. Rubber crumb specification*[2, 11]*

Sieve analysis		**Test method**
Sieve size (mm)	**Percentage passing by mass**	
1.18	100 (minimum)	MB-4
0.60	40 - 70	
0.075	5 (maximum)	
Other requirements		**Test method**
Natural rubber hydro-carbon content	30 % (minimum)	BS 903 Parts B11 and B12
Fibre length	6mm (maximum)	
Bulk Density (gm/cm^3)	1.10 – 1.25	MB-16

Table 3. Properties of extender oils*[2, 11]*

Property	**Requirements**
Flash point	180 °C (minimum)
Percentage by mass of saturated hydrocarbons	25 % (maximum)
Percentage by mass of aromatic-unsaturated hydrocarbons	55 % (minimum)

The bitumen-rubber blend, including extender oil and/or diluent, if necessary, must comply with the requirements of Table 4.

Prior to commencement of the work, the supplier must state in writing the percentage of rubber and the blending / reaction temperature he intends to use for his specific product.

The actual percentage of rubber may not deviate by more than 1% from the stated value and the actual reaction temperature may not deviate by more than 10% from the stated value.

A continuous record of both percentage rubber added and reaction temperatures must be kept on site by the contractor. The bitumen-rubber must comply with the requirements of Table 5. No batch of bitumen rubber binder may be used unless tested and conforming to the requirements of Table 5.

Table 4. Bitumen Rubber blend[2,11]

Property	Requirements
Percentage of rubber by mass of total blend	20 % - 24 %
Percentage of extender oil by mass of total blend	4 % (maximum)
Percentage of diluent by mass of total blend	5 % (maximum)
Blending / Reaction temperature	170°C - 210°C
Reaction time (reaction time commences when all the rubber crumbs have been added to the blend)	0.5 - 4.0 hours

Table 5. Blended Bitumen Rubber binder[2, 11]

Property	Requirements	Test method
Compression recovery:		MB-11
after 5 minutes	70% (minimum)	
after 1 hour	70% (minimum)	
after 4 hours	48% - 55% (minimum)	
Ring-and-ball softening point	55 to 62°C	MB-17
Resilience (%)	13% - 35%	MB-10
Dynamic viscosity (Haake at 190°C)	20 - 40 DPa.s	MB-13
Flow	15 mm - 70 mm	MB-12

The contractor must provide the engineer with time-temperature ratios in regard to the above properties of his specific product before work may start in order to determine the final process and the acceptance limits.

The methods of testing bitumen-rubber material have been published in TG 1: The use of Modified Binders in Road Construction(11).

If a supplier uses a diluent, an ageing test may be required in which the binder is placed in an oven for 5 hours at 150°C, after which time it must comply with the above specifications.

The contractor must provide the performance record for three recent projects of the materials he intends to use in order to assess the successful use of the materials. The information must include mean values obtained for the prescribed tests as well as any relevant comments. This information must be submitted at tender stage.

A complication in testing B-R binder is that the chemical reaction changes whilst the product is still above 120°C. Hence, if parameters such as softening point, viscosity, resilience, compression recovery, etc. is specified, then the time at which it must be tested must also be specified. It is South African practice to specify the time of sampling just before spraying. Figure 1 is a graph of B-R density vs. time to demonstrate the time dependence.

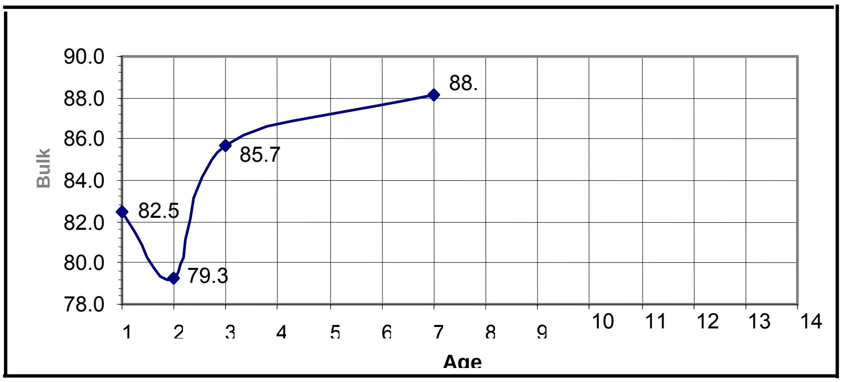

Figure 1. Bitumen Rubber time study

If used, extender oil must be a resinous, high flash point aromatic hydrocarbon conforming with the requirements in table 3.

The chemical composition of the base bitumen and the nature of the rubber dictate the need to introduce an extender oil. The bitumen and extender oil, when combined must form a material that is chemically compatible with the rubber.

<u>3.2 Aggregates for seals</u>
The aggregate must consist of approved crushed stone of the specified grade and size and must comply with the following requirements in regard to grading, hardness and shape:

- *Grading:* The grading must comply with the requirements set out in Table 6.

Table 6. Single-sized crushed aggregate grade[2,11]

Sieve size (mm)	Percentage by mass passing				
	26.5mm nominal size*	**19.0mm nominal size**	**13.2mm nominal size**	**9.5mm nominal size**	**6.7mm nominal size**
37.50	100	-	-	-	
26.50	85 - 100	100	-	-	
19.00	0 - 30	85 - 100	100	-	
13.20	0 - 5	0 - 30	85 - 100	100	
9.50	-	0 - 5	0 - 30	85 - 100	100
6.70	-	-	0 - 5	0 - 30	85 – 100
4.75	-	-	-	0 - 5	0 – 30
3.35	-	-	-	-	-
2.36	-	-	-	-	-
Fines content: Material passing a 0.425mm sieve (max)	0.5	0.5	0.5	0.5	0.5

*Note that the 26,5mm stone is hardly used in seal applications and is not discussed further

- - *Hardness:* The aggregate crushing value must not exceed 21 and when tested in accordance with South African TMH1 method B2 the 10% FACT value (dry) must be at least 210 kN and the wet to dry ratio must be at least 75%.

The polishing stone value must be at least 50 unless otherwise specified or approved by the engineer.

- *Shape:* The maximum flakiness index, when tested in accordance with South African TMH1 method B3, must comply with the requirements in Table 7.

Table 7. Flakiness Index[2, 11]

Nominal size of aggregate	Maximum flakiness index % Grade 1
19.0 mm	25
13.2 mm	25
9.5 mm	30

For the Average Least Dimension (ALD) for the 19.0mm, 13.2mm and 9.5mm aggregate must be 12.0mm, 8.0mm and 6.0mm respectively.

- *Winter limitations:* No B-R binder must be used for the purpose of constructing surface seals between the winter periods of 01 May to 31 August of any year.
- *Overlay restrictions:* When constructed to serve as a SAMI the seal must be left open to the atmosphere and be trafficked for a period of at least six weeks. This allows locked in volatiles to evaporate or else these may dissolve the asphalt along the bottom contact plane of the overlay causing delamination.
- *Weather limitations*: The minimum road surface rising temperatures at which the spraying of the different types and grades of binder may be done are 25°C. No B-R work must be done during foggy or rainy weather or when cold wind is blowing and the road surface temperature is below 30°C.

3.3 Construction of single and double aggregate seal[2]

B-R binders are applied by means of a binder distributor. The B-R tack coat must be uniformly sprayed on the properly cleaned and prepared existing surface over the full specified width of the seal (Photo 1).

Photo 1: Spraying of Penetration Coat

Where the tank of the binder distributor could become empty during spraying on gradients, the spraying must be done while the binder distributor is moving uphill. The spraying of adjacent strips must overlap by 100mm subject to adjustment for the particular nozzle fan angle. Chips must not be placed on the 100mm overlap before the adjacent strip has been sprayed. The adjacent strip should not be sprayed before the preceding strip; excluding the 100mm overlap has been covered satisfactorily with chips.

Immediately after the B-R binder has been sprayed, it must be covered with clean, dry aggregate. The actual rates of application of binder and aggregate to be used in the construction are determined by the engineer, after testing the aggregates and designing the seal as outlined in the next section.

The aggregate must be applied uniformly by means of self-propelled chip spreaders. The immediate application of the chips is of prime importance. The spreading of the chips must be done as closely as possible behind the distributor. The chip spreader must be so operated that the tack coat is covered with aggregate before the wheels of the chip spreader or truck pass over the uncovered tack coat.

Immediately after the aggregate has been applied, rolling must commence. A self propelled pneumatic tyred roller with a load of at least 2,0 t per wheel must be used in the case of single seals, and a steel-wheeled roller may also be used in the case of double seals on condition that excessive crushing of the aggregate must not take place. Rollers must operate parallel to the centerline of the road, from the shoulders inwards towards the crown of the road, until the entire surface has been covered at least three times with the wheels of the roller.

After the bituminous binder has set sufficiently to prevent any aggregate from being dislodged, the surface is slowly dragged with a broom drag to ensure even distribution of the aggregate. If there are areas which are deficient in stone chips, additional material must be added by hand so as to leave a single layer of chips lying shoulder to shoulder.

A recent project on the N3/11 involved the construction of a 19mm and 9,5mm double seal. The application rates differed significantly between the slow and fast lanes as the traffic varies accordingly. On the slow lane the ELV's (Equivalent light vehicles) amounts to 55000 a day. The application rates were kept to the minimum rates of 1,8l/m2 for the tack coat and 1,8l/m2 for the penetration coat (Photo 2).

In Photo 2 the stone application rates can be seen. It is of utmost importance to chip the stones shoulder to shoulder in order construct a proper double seal. This prevents unnecessary punching of the 19mm stone into the underlying asphalt. This specific seal is also significantly more quite than most double seals as the wheels travel on the 9,5mm stone.

The next step for the bitumen-rubber double seal is to compete with the thinner asphalt overlays albeit with a lower cost. This investigation is being done at the moment and will be reported on in good time.

Photo 2: 19mm and 9,5mm double seal (note the stone application rates)

4. DESIGN OF CHIP SEALS

The design of chip seals is contained in TRH3: 1998 (COLTO, 1998)[10], which captures the best practice. The design methods evolved from Hanson's concept of partially filling the voids in the covering aggregate and the Average Least Dimension controls the volume of voids. The principles which are applied for seals constructed with conventional binders are as follows:

(a) The minimum amount of voids to be filled with binder to prevent stone loss when there is no embedment into the underlying layer is 42% for single seals and 55% for double seals.

(b) The amount of void loss due to traffic wear of the aggregate is dependent on the hardness of the stone and the traffic. Mixed traffic is converted into equivalent light vehicles.

(c) The required texture depth to provide adequate skid resistance is 0.7mm, and this is the terminal value at the end of the seal's life.

(d) The amount of embedment during construction may vary, but it is accepted that it is 50% of the total embedment with time, which is calculated from the corrected ball penetration test.

(e) The design method makes adjustment for factors such as

- Texture or porosity of existing surface
- Climate – in humid areas the binder content is decreased, while in dry areas it is increased.
- Steep gradients – the binder content is reduced on steep uphills.

(f) The stone spread rate is a function of the Flakiness Index.

Experience has shown that, because of the enhanced properties of bitumen-rubber considerably higher binder application rates can be tolerated than used in seals with conventional binders. Deviations from the design method for conventional binders are the following:

(1) The binder property that has the most important influence on the binder application rate is its stiffness at the operating temperature. The Ring and Ball softening point test sufficiently categorises the binder for this purpose. A binder adjustment factor, based on the softening point and traffic, provides a greater application rate than for conventional binders.

(2) Because of the higher binder stiffness of bitumen-rubber the stone orientation is different from conventional seals. This is particularly true for stiffer binders and lower traffic volumes, leaving greater voids that can be filled. The correction in (1) above takes this into account.

(3) The matrix formed acts more like a mat and the penetration of individual aggregate particles is less than when conventional binders are used. This is taken into account by reducing the total embedment to only 50% embedment to calculate the cold binder application rate.

5. CONCLUSIONS AND RECOMMENDATIONS

Chip and spray seals are micro thin considering the very heavy wheel loads it must carry. For this reason it is of utmost importance that only high quality materials be used. Great attention to detail is required since this seal is repeated for many kilometers. For this reason the South African procedures and specifications (as furnished in this paper) sets very high standards.

Conventional binders were found insufficient to accommodate the present traffic loadings and durability expectations. The coming of modified binders addressed this problem but not as successful as bitumen rubber modified binders. The superior behaviour of B-R binder is believed to come from the natural rubber digested into the bitumen's as well as the anti-oxidants (carbon-black, etc.) imported from the tyres.

The properties largely enhanced by the digestion of rubber into bitumen is the widening of the temperature range, temperature sensitivity, longevity, adhesion, SAMI, reduce embedment, reduced absorption, elasticity, structural capacity, etc.

Careful attention to the construction and the design of the B-R seals has been the underpinning philosophy for their successful use during more than 20 years. The somewhat higher initial construction costs of B-R asphalt are negligible in view of the extended service life in difficult rehabilitation situations rendered by the chip and spray seals and SAMI's when assessed over a full life cycle.

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