BITUMEN RUBBER SEAL BEHAVIOUR ASSESSMENT

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ABSTRACT

As part of the review of the seal design procedures a mechanistic approach was foreseen. A fuller understanding of the behaviour of seals was required for the modelling process, and this led to the investigation of seals behaviour under accelerated and laboratory environments. As part of the process, the behaviour of unmodified bitumen and bitumen-rubber under these conditions was assessed, and aspects from this study are provided in this paper highlighting the behaviour of bitumen rubber under the current design methods. The paper first evaluates the critical factors in the design of seals, and the mechanisms and modes of seal failures. The experimental programme is then presented which consisted of testing with the one-third scale Model Mobile Load Simulator (MMLS3), as well as the Hamburg wheel tracking test (HWTT). Results are then presented and discussed. It was found that the key to good seal performance is the greatest possible binder application rate without resulting in flushing or bleeding, with the postulate that seals performance is more dependent on the higher binder application rates, rather than improved qualities of the binder (but consider always highest possible binder application rate is directly dependent on binder quality).

1.   INTRODUCTION

A seal consists of binder and an aggregate application, which provides an all weather surfacing preventing moisture ingress to the underlying pavement layers, and prevents wear from vehicle tyres. A seal is a system consisting of controllable components such as binder type and properties and aggregate characteristics. External or non-controllable factors include traffic (tyre pressure, load, and applications), environmental influences such as moisture and temperature, and the characteristics of the underlying layer such as the type of support and surface hardness. A designer has to match the controllable factors with uncontrollable ones, to ensure a desired seal performance.

In South Africa seals are designed according to TRH3 (CSRA, 1998). This was the current document when this research was performed (Milne, 2004). As part of the review of the seal design procedures a mechanistic approach was foreseen. A fuller understanding of the behaviour of seals was however required for the modelling process, and this led to the investigation of the behaviour under accelerated and laboratory environments. The objective of the paper is to present the behaviour of unmodified bitumen and bitumen-rubber under these conditions, and to evaluate the current design of bitumen-rubber seals.

The paper first evaluates the critical factors in the design of seals, and the mechanisms and modes of seal failures. The experimental programme is then presented which consisted of testing with the one-third scale Model Mobile Load Simulator (MMLS3), as well as the Hamburg wheel tracking test (HWTT). Results obtained are discussed, and conclusions drawn about the requirements for enhanced performance of seals.

## 2.	FACTORS THAT AFFECT THE PERFORMANCE OF A SEAL

From a review of the literature, assessment of road seals and experience, certain seal components and influences have significant impact of seal performance. These include:

- **Binder type and application**: This was identified through the assessment process (Milne, 2004) as having greatest likely influence on seal behaviour.

- **Environment**: Temperature greatly affects the characteristics of the binder. As such the service regime has daily and maximum/minimum experienced temperature as major performance influences. Moisture has an influence, in terms of adhesion, weathering of the binder, and influence on the seal/base support.

- **Road surface**: The assessment of the influence of underlying road surface was identified (Milne, 2004) as a critical parameter, due to road surface providing the support for the seal stone, and in effect the transfer of applied load through the seal stone to the pavement.

- **Age of seal**: Age of seal affects binder characteristics.

The above variables have been highlighted as critical seal design components, and influence seal performance. Note that the most critical element is the binder.

Properties affecting the performance of the binder within the seal are:

- **Binder type and properties**: The different types of binder, such as penetration grade, cut-back, emulsions and modified binders all behave differently under in-service conditions, and all will affect the performance of the seal.

- **Binder grade**: The appropriate grade for expected climatic, pavement and traffic conditions, both under construction and long term, must be selected to ensure optimal seal performance.

- **Viscosity – temperature relationship**: Each binder's temperature – viscosity relationship will determine the optimal design performance decisions.

- **Spray rate**: The optimal amount of bitumen is required to keep the aggregate on the road (through adhesion), but to maintain enough voids to prevent bleeding. The optimum amount of binder is determined by the size and shape of stone, and the volume of voids in the compacted stone layer, traffic, gradients and condition of underlying surface.

- **Viscosity at application**: Viscosity at application determines the uniformity of the spray, where too low temperature causes streaking (due to high viscosity at the spray bar), and too high temperature binder degradation.

Roque et al (c.1989) report that on levelled surfaces (prior to reseal) the application rate had a direct relationship to retained aggregate, e.g. chip retention on the lower emulsion application rates was inadequate (due to absorption of the binder into the levelling course). However, on worn surfaces, even the minimum recommended binder was sufficient to retain the aggregate, with increase in binder only decreasing the macro texture of the seal coat. Binder application was found to be the most sensitive of all seal design variables, which supported Milne's (2004) finding above.

Binder properties are improved by modification, such as by adding rubber crumbs to bitumen. The bitumen characteristics that are improved by modification are:

- **Reduced temperature susceptibility** (improving the range over which the binder is not too brittle or too soft). Hanekom *et al* (1999) describe this as extension of the plasticity interval - the difference in temperature between the softening point and

Fraass breaking point. Note that this also fulfils the desire of practitioners to increase low temperature flexibility, reduce temperature sensitivity, and to increase high temperature viscosity.

▪ **Cohesive strength** (the ability of the binder to perform in a visco-elastic manner without losing integrity).

▪ **Adhesive properties** (the ability of the binder to retain aggregate and adhesion to the pavement).

▪ **Resistance to ageing**.

▪ **Flexibility and resilience** (ability to recover after deformation loading).

3.   MECHANISMS AND MODES OF BITUMINOUS SURFACING FAILURE

The modes of failure of seals described by Robertson et al (c.1990) include the following:

▪ **Deformation** of the seal in terms of rotation of the seal stone, affecting available voids for the binder and texture depth, and flow of binder causing bleeding.

▪ **Thermal and fatigue cracking** occurs when the binder molecular network becomes too rigid and the ability of the binder to deform elastically is reduced.

▪ **Adhesion, cohesion and moisture damage** when molecular and intermolecular bonds between binder and aggregate are destroyed, particularly by moisture.

These modes of failure were considered in developing a performance evaluation model for use in the evaluation of the seal panels after testing. TMH9 (CSRA, 1992) describes the condition and performance of the pavement and is not sufficiently detailed insofar as the seal is concerned. Consequently a different set of criteria were evaluated using the principles of TMH9 (CSRA, 1992).

The seal performance was evaluated in terms of the following assessment parameters:

▪ stone loss

▪ embedment

▪ rotation to average least dimension (ALD)

▪ flushing/bleeding

▪ base distress

▪ crushing

▪ general performance (visual)

The rating system given in Table 1 was used. Note that the best performance was rated as zero defects, and the poorest performance was given a high rating of 3.

Table 1: Seal Performance Parameters Ratings (Milne, 2004)

Performance Criteria	Performance Parameter (Rating)	Performance Rating Highest	Poorest
Adhesion	stone loss (R_{SL})	0: none	3: stripping (5% of trafficked area or more)
Deformation	embedment (R_E)	0: none	3: flush (embedded to zero texture depth)
	rotation (R_R)	0: as laid	3: ALD Note: rotation is desirable but for the purpose of this evaluation, maximum voids are desired (modified binders are used), and as such the viscous property of the binders with maximum void content was rated best for purpose.
	flushing/bleeding ($R_{F/B}$)	0: none	3: bleeding – severe
Aggregate	crushing (R_C)	0: none	3: severe
	polishing	**	**
general performance (visual assessment)	(includes cracking) (R_A)	0: good visual appearance Note: This parameter was used to credit the negative numerical affect of rotation to ALD for seals that perform well and to note cracking (in this project)	3: poor
	base distress*	0: none	3: failure Note: when distressed base occurred the overall rating was reduced to "credit" the seal to counter the negative affect numerically of poor performance of the seal due to embedment, flushing. However this is only REPORTED, as assessment of seals is made EXCLUDING base effects
	* record only ** note taken only, not visible on these tests		

The performance ratings of the seals were determined (calculated as a percentage of worst possible performance rating), and termed Performance Index (lowest value is best performance). Performance Index is defined as:

$$\text{Performance Index} = \left[\frac{(R_{SL} + R_E + R_R + R_{F/B} + R_C + R_A) x100}{18} \right] \quad \text{(Eq. 1)}$$

Where:

R = Performance Rating (0-3)

Subscript:

SL = Stone Loss

E = Embedment

R = Rotation to ALD

F/B = Flushing or bleeding

C = Crushing

A = Appearance

Note that each of the above performance parameters has equal rating in the formula.

4.   SCOPE OF EXPERIMENTAL PROGRAMME

Performance tests were designed to evaluate the un-modified and modified seals under severe conditions, to assess the performance of the binders under extreme conditions. The pneumatic tyred <u>Model Mobile Load Simulator and Hamburg wheel tracking tests were used as APT devices.</u>

4.1   Model Mobile Load Simulator (MMLS3)

An external test bed was used in the accelerated test programme. A 200 mm thick G5 quality base was constructed on a concrete slab floor. The test area was sufficiently long to allow testing of all the binders simultaneously.

The following binder types of relevance to this paper were tested (full programme in Milne (2004)):

- 80/100 penetration grade bitumen

- 20 % modified by mass (80/100 per grade bitumen as base)
  - Bitumen rubber (COLAS manufacturing method)
  - Bitumen rubber (TOSAS manufacturing method)

The seal properties are shown in Table 2. The binder application rates were selected based on TRH3 (CSRA, 1998).

Table 2: Seals evaluated with MMLS3

Binder Type		Net Binder Application	Net Binder Application	Base Bitumen		Aggreg'e Size (Hornfels ACV 10 %)	Penett'n (dmm) (needle at 25ºC)	R&B Soft'ng Point (ºC)
Type	Modifier	Lower Application	Higher Application	Grade	Refinery			
80/100 pen (COLAS)		0,9 l/m²	1,1 l/m²	80/100 pen	SAPREF (Durban)	13,2mm	90	44
20% Bitumen Rubber (COLAS)	Crumbs	2,0 l/m²	2,4 l/m²	80/100 pen	SAPREF (Durban)	13,2mm	-	61
20% Bitumen rubber (TOSAS)	Crumbs	2,0 l/m²	2,4 l/m²	80/100 pen	NATREF (Sasol'g)	13,2mm	44	62

The temperature test ranges were decided upon as follows:

- **Ambient Temperature**

The aim was to achieve 25 – 35 ºC, which represents the visco-elastic range and to enable assessment of typical conditions in practice. The road temperature varied between 20 – 36 ºC throughout the days of testing, although it dropped to 16 ºC minimum during the winter months. Testing was done throughout the day and no undue low temperatures were experienced on the test days.

- **Elevated Temperature**

Blowers were used to heat the road surface temperature to 50ºC for the full test duration, to represent the binder viscous range.

▪ **Cold Temperature**

Cold air was blown onto the seal surface to reduce the seal temperature to 10 ºC for the full test duration. The temperature of 10 ºC is on the border of brittle range of bitumen behaviour.

• **Loading**

TRH3 (CSRA, 1998) indicates that single seals can accommodate 750 to 2000 elv/lane/day, increasing to up to 2000 – 5000 elv/lane/day with the use of modified binders. Converting these lives to MMLS3 applications of 600kPa tyre pressure and 2,1kN per axle, provided a required 200 000 applications without "lateral wander". The application stress equates to an equivalent 5-year traffic load, using an equivalency factor of 40 elv's (equivalent light vehicle) per E80 (80kN axle load) and a conservative factor of 3 increase due to the effect of lateral wander in practice.

4.2   Hamburg wheel tracking tests (HWTT)

To supplement the MMLS3 based seal performance tests, a supplementary performance test was developed to test the seals under extreme conditions, specifically severe moisture and ageing. These tests do not simulate or model results as the MMLS3 does, but have value in comparative performance evaluation of the seals in extremes. The HWTT is typically used to predict moisture damage in asphalt.

The HWTT device is shown in Figure 1. The wheel is steel, with hard rubber coating, of diameter 204 mm, width 47 mm, applying a force of 705 N ± 22 N to the seal to be tested. Testing speed is 0,305 m/s.
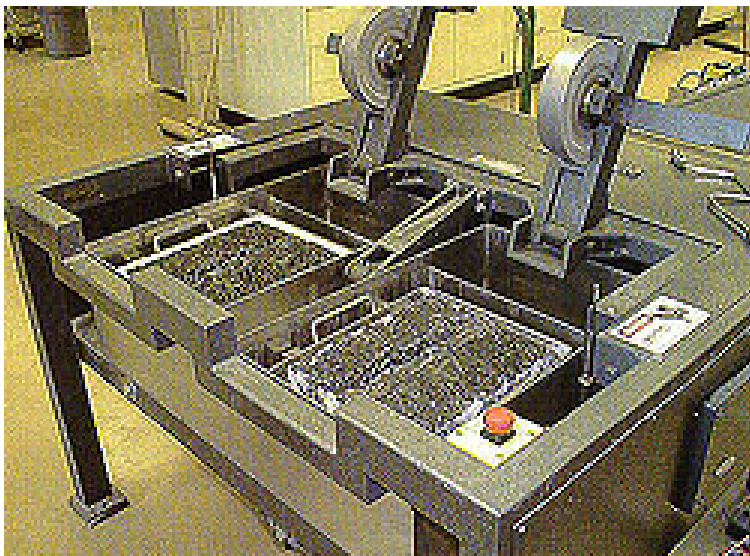

Figure 1: Hamburg wheel tracking test with seal tiles

Concrete prisms were cast to fit the test apparatus, which enabled a set of three samples to be tested at one time. Concrete was chosen to eliminate base effects when testing the seal performance under water (i.e. no punching or rutting would be able to occur). Single seals were constructed in the same way as for the MMLS3 testing. The binder application rates were as for the MMLS3 tests (even though no punching into the base could take place) (1.1 ℓ/m^2 for the pen grade binder and 2.4 ℓ/m^2 for the bitumen rubber, and a test at an application rate of 1.5 ℓ/m^2 for both binders was also applied. The concrete prism with seal was soaked for 12 hours, prior to testing, submerged in the water bath. Tests were conducted at 40 ºC. In this test regime an acidic (quartzite) and basic (dolerite) aggregate was used. Performance of the seals was measured at intervals to 5000 repetitions in terms of mass of stone loss.

5.   RESULTS AND DISCUSSION OF EXPERIMENTAL PROGRAMME

5.1   Model Mobile Load Simulator (MMLS3)

The performance plots are given in Figure 2a for the 80/100 pen bitumen, and in Figure 2b for the COLAS bitumen rubber. The performance index scale is "0" for no visible distress, and "100" for extreme distress, i.e. poor performance. Note that the TOSAS bitumen rubber reflected the same trends as the COLAS plots, and is not included. It may be seen in the source document (Milne, 2004).
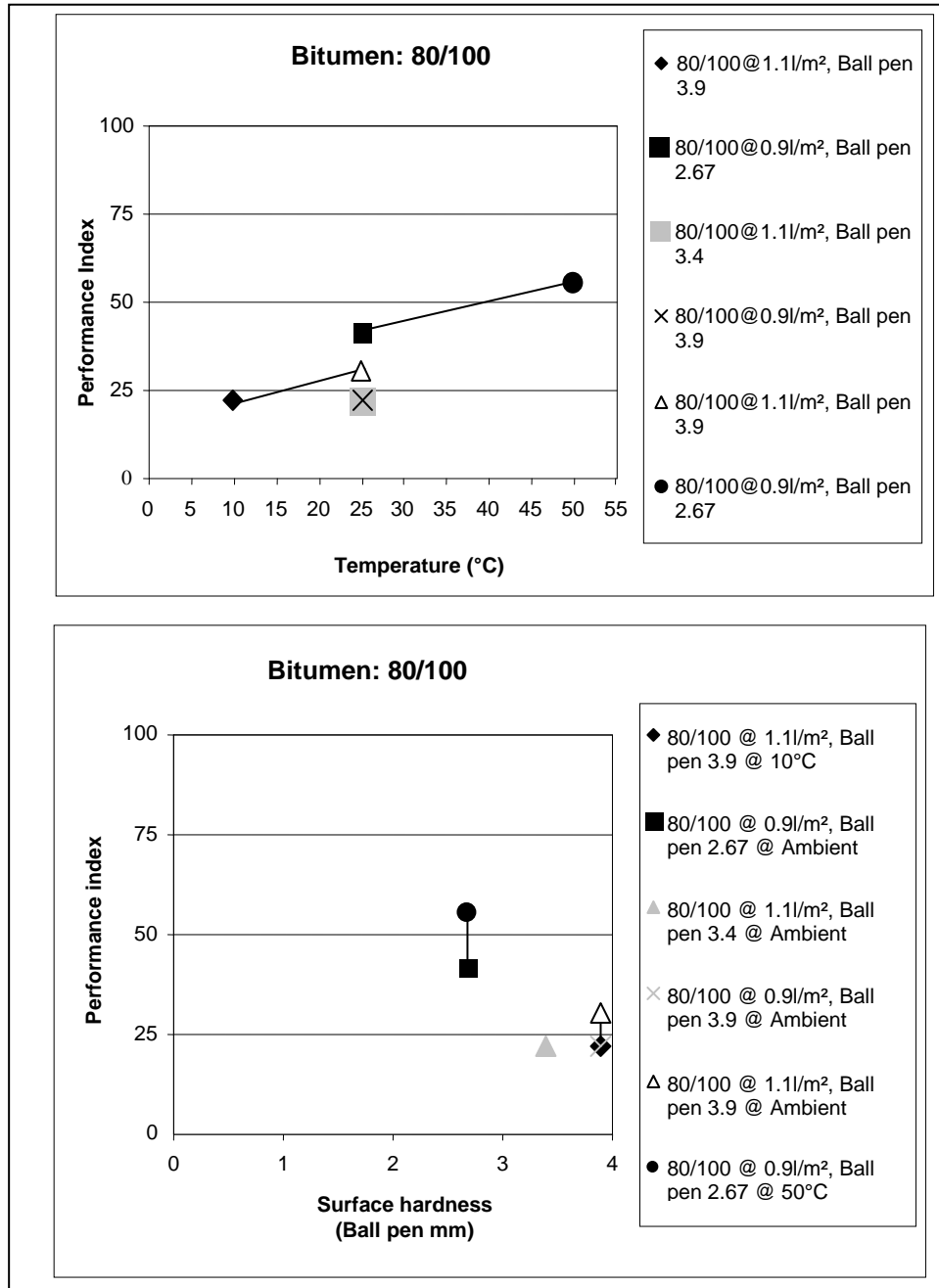

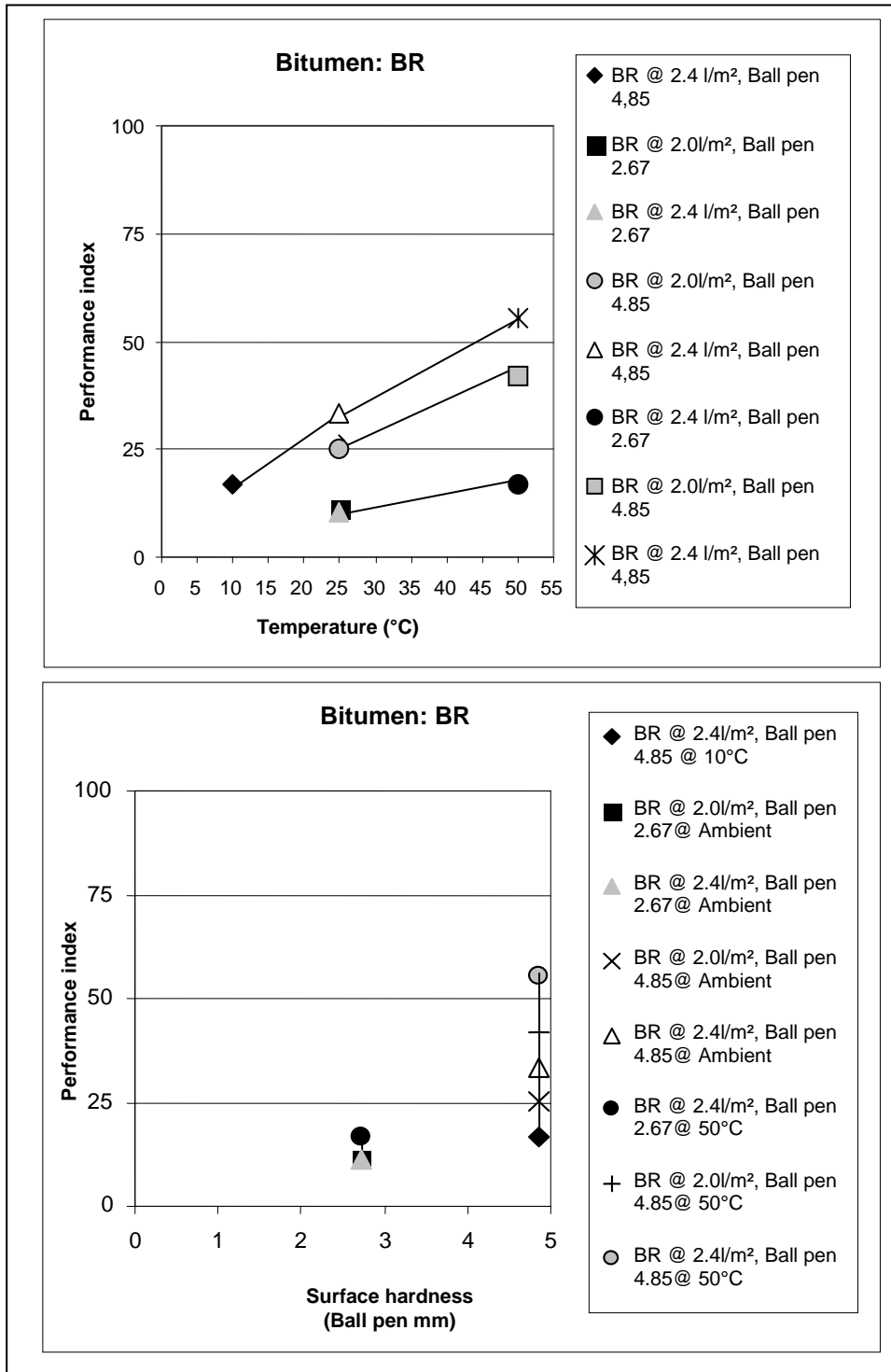**Figure 2a. Performance plots of single seal constructed with 80/100 pen bitumen.**

**Figure 2b:** **Performance plots of single seal constructed with COLAS bitumen rubber**

The two binders show interestingly different performances. Remember that the seals were tested without the binder having an opportunity to age. The seal with the 80/100 pen bitumen showed that the higher binder rate gave better performance for all surface hardness. This means that the binder was able to hold the aggregate in place, but that distress types associated with higher binder contents (flushing, bleeding) were averted. Performance decreased with an increase in temperature. With increased ball penetration value, i.e. reduced surface hardness the better the performance. It is hypothesised that the additional punching provided a reduction in surface voids, which resulted in an integral

surfacing, without bleeding. The binder application rate may have been low for the test conditions.

The bitumen rubber seal showed reduced performance (i.e. increased index) with an increase in temperature and application rates. Improved performance was found for the same application rate on a harder surface. These results suggest, unlike in the case of the penetration grade bitumen, that the application rates were at the limit, even though the performance was the same or better than the bitumen. Since the binder was still fresh (2% of extender oil was used to make the bitumen rubber), it is also apparent that the accelerated test programme was unduly harsh.

## 5.2   Hamburg wheel tracking tests (HWTT)

The HWTT provides interesting comparative results. Before presenting the results the concern expressed by Izzo and Tahmoressi (1999) about repeatability should be considered before drawing absolute conclusions. The mass loss increased approximately linearly with load applications, as illustrated in Figures 3a and 3b below.
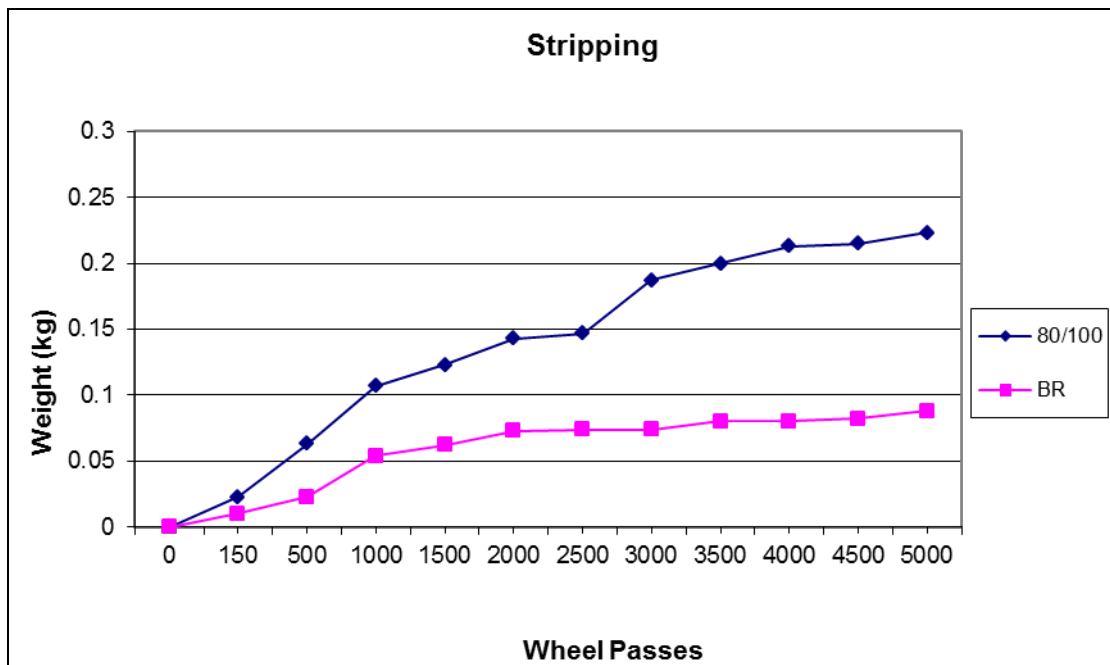
Wheel Tracking Test 1 (soaked)

Bitumen Type:	80/100	Colas BR
Application (l/m^2):	1.1	2.4
Stone Size (mm) & Type:	13mm Quartz	13mm Quartz

Figure 3a: Wheel Tracking Test 1 (Soaked)
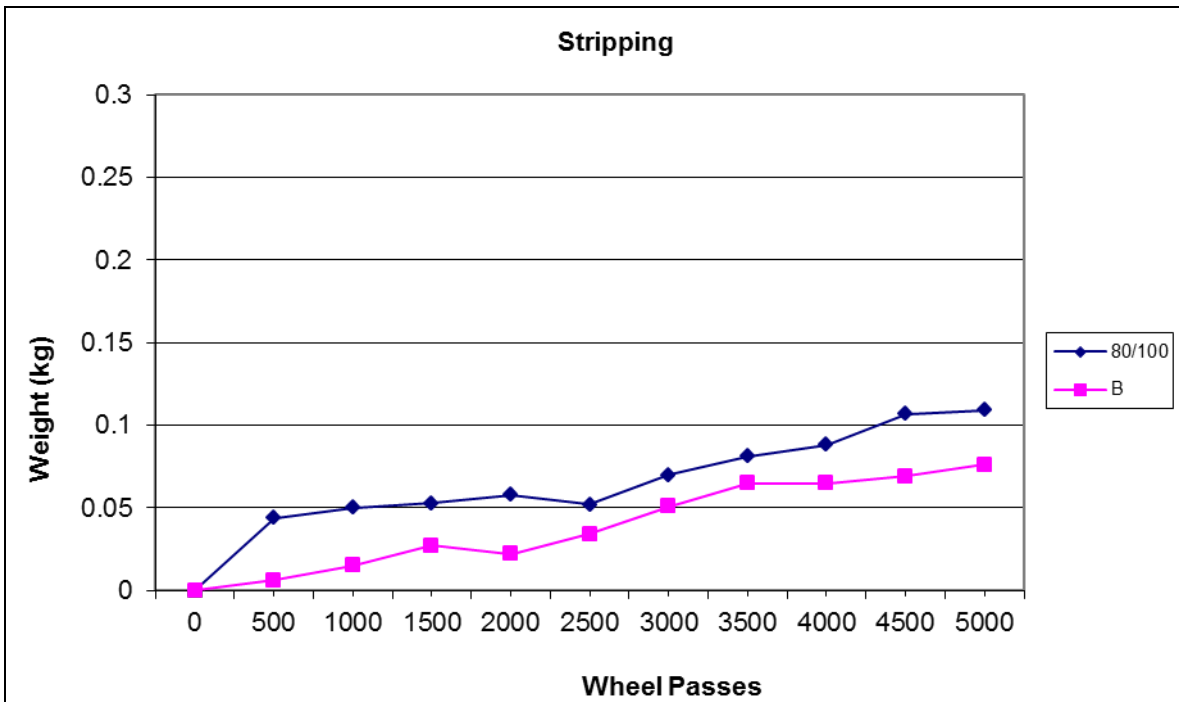
Wheel Tracking Test 2 (reduced soaking)

Bitumen Type:	80/100	Colas BR
Application (l/m^2):	1.1	2.4
Stone Size (mm) & Type:	13mm Quartz	13mm Quartz

Figure 3b: Wheel Tracking Test 2 (reduced soaking)

At the design application rates (2.4 l/m^2) the bitumen rubber outperforms the penetration grade bitumen for both types of aggregate, even considering the variability of replicate tests; this is to be expected because of better adhesive properties. Reducing the bitumen rubber application rate reduces the benefits of the binder, as the larger binder volume limits stripping.

5.3   General Behaviour Assessment

Subjectively combining the MMLS3 results that are performance based, and the HWTT that are comparative tests, a general performance indication was obtained. Bitumen rubber gave the best performance of the binders tested in terms of dry or wet adhesion. No cracking was evident, as the test loads were too light to fatigue the pavement. The relative softness of the bitumen rubber allowed flushing in the accelerated test, which gave it a poorer rating for this parameter even than for the 80/100 pen bitumen. This initial apparent distress is however a long-term benefit, as the binder is able to successfully resist aging, as long as there is sufficient texture in the seal to prevent pick-up of the binder.

The behaviour of the seal developed was used as input into the numerical model, as reported by Milne et al (2004).

6. CONCLUSIONS AND RECOMMENDATIONS

The test protocols presented provide a systematic procedure for the rapid evaluation of seals with different binders. It was found that the two procedures complement each other, as the normal environment, including temperature, is dealt with by the MMLS3, whereas the HWTT deals with the moisture in the environment.

It was found that, as was to be expected, that bitumen rubber outperformed penetration bitumen. One of the reasons is the higher application rate which does not bleed under normal circumstances, whereas penetration bitumen would bleed with such high application rates. Under accelerated testing some flushing was noticed for high binder application rates, but the performance index was similar to penetration bitumen. It is thus paramount that the highest possible application rates should be used within the design environment. Penetration grade bitumen performs satisfactorily in average environments, where extreme conditions are not found.

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