THE EVALUATION OF ASPHALT MIX SURFACE REJUVENATORS IN SOUTH AFRICA

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ABSTRACT

Ageing of a seal or asphalt surfacing increases the stiffness of the layer, resulting in a decreased ability to resist cracking. Asphalt surface rejuvenators have been used traditionally as an economical maintenance technique to extend the binder lifetime, thereby postponing eventual costly rehabilitation.

Rejuvenators vary in nature, whether they are emulsion-based or solvent-based, making it very difficult to have national specifications for rejuvenators. This class of materials are, therefore, ideal candidates for certification by Agrément South Africa. A guideline for the evaluation of rejuvenators has been proposed for the roads industry by Agrément South Africa (O'Connell, 2017). The guideline defines asphalt rejuvenators as a proprietary product with suitable properties to extend the lifetime of an asphalt mix layer (or seal); by delaying the appearance of fatigue-related distresses such as cracking and potholing, without increasing the risk of skid-related accidents.

The paper discusses the guideline evaluation techniques and the results obtained for one commercial rejuvenator evaluated to date. The paper serves to fulfil the need for knowledge dissemination on rejuvenators in the South African transportation industry.

1 INTRODUCTION

Asphalt mix surface rejuvenators are road products that restore binder flexibility, combat the effects of oxidation and replace the maltenes lost due to oxidation in order to restore that balance of maltenes to asphaltenes (Rogers *et. al*., 2014). Rejuvenators are meant to be a cost-effective solution to prolong the life of an asphalt layer or bituminous surfacing past key maintenance and rehabilitation points.

This paper does not address the evaluation of rejuvenators (rejuvenation additives) which are used in for recycled asphalt, in order to combat the effects of the aged binder in the recycled asphalt.

To date there have been no standards nor design procedures available to industry on asphalt rejuvenation in South Africa. Despite the inadequacy of available information, the industry has supplied clients with rejuvenators displaying varied and inconsistent results. It is for this reason that Agrément has drafted a technical evaluation of asphalt rejuvenators for certification titled “Proposed Guidelines Document for the Assessment and Certification of Asphalt Rejuvenators” (O’Connell, 2017).

This paper will discuss the above-mentioned guideline document, its testing and evaluation procedure, followed by a South African case study regarding the performance of a product that was submitted for certification.

2 REVIEW OF INTERNATIONAL GUIDELINES AND CRITERIA

The timing and selection of pavements requiring rejuvenation has varied, internationally. Boyer (2012) has pointed out that it is less expensive to work with good pavements and that fog seal rejuvenators are to be used regularly, every four to six years. Brownridge and Grady (2006) has also suggested that pavements should be rejuvenated when still in a good condition. The criterion recommended is between three and seven years with no base failures or any other early signs of distress.

The rejuvenator performance requirement suggested by Boyer (2012) is depicted in Table 1.

Table 1: Desired material performance for rejuvenators (Boyer, 2012)

Property of recovered binder	Requirement		Test Method
	Pavement < 3 Years old	Pavement > 3 Years old	
Absolute viscosity 60°C (Pa.s)	≥ 25% Decrease	≥ 40% Decrease	ASTM D 2171
Complex modulus 60°C (G*)			AASHTO 315
Viscosity 60°C ($\eta = G^*/\acute{\omega}$) (Pa.s)			
Phase angle @ 60°C	Report		

The absolute viscosity is not a test carried out routinely in South Africa, and the authors do not believe that the equipment is available in South Africa. The complex modulus of the binder correlates with the cracking resistance, only to a limited extent, and can lead to erroneous conclusions when polymer modifiers are present in the binder.

The pavement condition index (PCI) was used by Vitale and Siddiqi (2016) to quantify treated and untreated roads. No statistical methods or standards were however used in the analysis to evaluate the changes, although the values were compared to a PCI classification system for roads. It is the authors’ opinion then any visual evaluation system should only be used in conjunction with other parameters, considering the subjective nature of any visual evaluation.

Brownridge and Grady (2006) specified the property values of emulsion-based rejuvenators and not the resulting effect on the rejuvenated pavement. Table 2 depicts the asphalt mix rejuvenation emulsion specifications (Brownridge and Grady, 2006).

Table 2: Asphalt mix rejuvenating emulsions specification (Brownridge and Grady, 2006)

	Test	Test Method		Specifications	
		ASTM	AASHTO	Minimum	Maximum
Tests on Emulsions	Viscosity @ 25°C (SFS)	D-244	T-59	15	40
	Residue (% w)	D-244 (mod)	T-59 (mod)	60	65
	Sieve Test (% w)	D-244 (mod)	T-59 (mod)	-	0.1
	Miscibility Test	D-244 (mod)	T-59 (mod)	No coagulation	-
	Particle Charge Test	D-244	T-59	Positive	
	% Light Transmittance	GB	GB	-	30
	Cement Mixing	D-244	-	-	2.0
Tests on Residue from Distillation	Flash Point (°C)	D-92	T-48	196	-
	Viscosity @ 60°C (cSt)	D-445	-	100	200
	Asphaltenes (%w)	D-2006-70	-	0.40	0.75
	Maltene distribution ratio	D-2006-70	-	0.30	0.60
	$\frac{PC + A_1}{S+A_2}$ (1)	D-2006-70	-	0.50	-
	Saturate hydrocarbons (S)	D-2006-70	-	21	28

(1) Where $\frac{PC + A_1}{S+A_2} = \frac{\text{Polar compounds+First Acidaffins}}{\text{Saturated hydrocarbons+Second acidaffins}}$

It is the authors' opinion that such non-performance based specifications should be avoided, and that the performance of the proprietary product should take preference. Non-performance based specifications which refer to the product characteristics are good for being used as quality control measures during manufacturing of the product.

3 INTERIM GUIDELINES FOR THE ASSESSMENT AND CERTIFICATION OF ASPHALT REJUVENATORS

3.1 Background

Agrément South Africa follows a consistent process in their guidelines for the certification of innovative construction products. The seven stage procedure as defined by Agrément (2017), systematically determines whether a product is "fit for purpose". The process includes an assessment of the applicants' data and production control, quality control of laboratory testing, installation of the product and performance trial, issuing of certification and monitoring the product over a predetermined period of time.

The criteria, sampling, processes and requirements as stated in the Proposed Guidelines Document for the Assessment and Certification of Asphalt Rejuvenators (O'Connell, 2017) will be discussed.

3.2 Selected Criteria

The criteria that were selected for the evaluation of rejuvenators are listed in Table 3 along with the philosophy behind each selection. The criteria were selected based on an international literature review, as well as local engineering experience.

The drying time required for any applied surface rejuvenator, has not been selected as one of the criteria. Drying time of the product is stated in the method statement of the applicant, and the product must comply accordingly.

Table 3: Criteria philosophy for rejuvenated surfaces (O'Connell, 2017)

Criteria	Test	Philosophy
Visual condition of pavement	TMH 9 Comparative visual appraisal: Treated vs untreated (1992)	Improvement in the treated area may be followed or alternatively, the rate of deterioration of both the treated or untreated areas may be compared.
Skid resistance	SCRIM or Griptester	By definition in the guideline, a surface rejuvenator may not impair the skid resistance of a surfacing.
Presence of volatile materials	Gas chromatography analysis	This is an attempt to see if the performance of the rejuvenator is linked to the presence of volatile components such as petrol, spirits, etc. A rapid dissipation of volatile material may indicate a temporary improvement in binder performance.
Resistance against abrasion (binder adhesion)	Comparative Cantabro test: Treated vs Untreated	Abrasion loss is affected by means of the Los Angeles Abrasion machine. The percent of weight loss (Cantabro loss) is an indication of durability and relates to an improvement in the quality of the asphalt binder, which is indicated by improved cohesion. This test method determines the abrasion loss of 150 mm cores which have been trimmed to a height of 10 mm.
Resistance to cracking (binder stiffness)	Comparative G*.Sinδ @ 28°C: Treated vs Untreated	G*.Sin δ, as determined by a dynamic shear rheometer (DSR), is used to control fatigue cracking in the SUPERPAVE specifications, and is based in part on the results of controlled-strain fatigue tests that were developed as a part of the SHRP research effort (Deacon et al, 1997). The lower the value of G*.Sin δ, the higher the resistance of the binder to fatigue cracking. G*.Sinδ is currently, and overwhelmingly, the most widely used fatigue parameter in the USA, even though the parameter has some drawbacks as discussed in 3.3 below.
Binder viscous component	Comparative δ @ 28°C: Treated vs Untreated	The phase angle gives an indication of the ratio of the viscous component to the elastic component. As the phase angle increases, so

		the viscous component increases, resulting in improved resistance to cracking for the same value of G*.

3.3 Fatigue Criteria to be Investigated in Future

The use of the parameter G*sinδ to control fatigue cracking was based in part on the limited results of controlled-strain fatigue tests on mixes containing two different aggregates and eight unmodified binders. In the development of this fatigue parameter, researchers used the concept of dissipated energy, where energy is dissipated during loading and unloading periods (see Figure 1). In an elastic material, the stored energy during loading (equal to the area under the deflection curve) is fully recovered during the unloading period. In a viscoelastic material, the dissipation of energy occurs in a hysteresis loop during the loading and unloading periods and the area within the loop represents the dissipated energy (Liu, 2011 and Rowe, 1996).

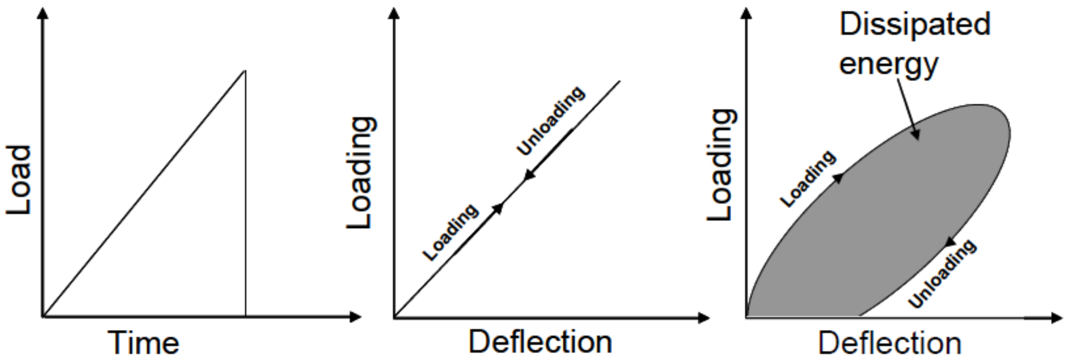


Figure 1: (a) Load versus time applied on specimen (b) Ideal elastic behaviour and (c) a viscoelastic behaviour (Liu, 2011 and Rowe, 1996)

The dissipated energy per loading cycle when a viscoelastic material is sinusoidally loaded, with the load/deflection relationship expressed as stress/strain, is given as follows (Martono, 2007):

$$w_i = \pi \tau \gamma \sin \delta$$ Equation 1

where w_i is the dissipated energy at cycle i, τ is the shear stress, γ is the shear strain, and δ is the phase angle.

The SUPERPAVE® property for predicting binder fatigue performance, G*.sinδ is derived from Equation 5.1 at a constant strain that can be expressed as:

$$w_i = \pi \gamma^2 (|G^*| \sin \delta)$$ Equation 2

where G* is the complex shear modulus

According to Equation 2, fatigue resistance favours a lower G* and a lower δ representing a softer more elastic binder. Hence the binder material would be able to develop a lower stress per deflection and it would be capable of recovering back to its original condition.

The limited study resulted in a recommendation of a maximum value of 5 000 kPa for G*.sinδ at the intermediate pavement temperature.

Studies have shown that G*Sinδ is not sufficiently accurate and correlation with actual performance reduces when modified binders are included in the evaluations. Furthermore, the correlations are limited as a result of its reliance on measurements within the linear viscoelastic (LVE) range of non-damaged specimens (Anderson *et al*., 1994; Marasteanu *et al*., 1999). The small strain levels adopted in linear visco-elastic rheological characterisation by DSR cannot be considered to realistically predict binder damage accumulation. This was especially so, given the actual stress and strain rates frequently encountered in road pavements. Consequently, poor correlation between the linear viscoelastic G*sinδ and HMA fatigue performance has been reported (Tsai *et al*., 2005; Stuart *et al*., 2002).

Currently, a number of improved fatigue indicators are being investigated in the USA as well as South Africa. These include:

- The master curve R-value
- ∆Tc from the bending beam rheometer can be used to evaluate the intermediate temperature cracking and it is likely that this will be specified by agencies in the USA.
- The Glover-Rowe (G-R) parameter from the binder master curve after PAV ageing. Maxwell parameters are used to derive the G-R parameter and is equivalent to G'/(η'/G'), serving as a surrogate for tensile strain at failure (Anderson *et al*, 2014)

The above-mentioned parameters are all currently being investigated as part of a new performance graded binder specification for South Africa and the data being collected and analysed will allow one or more of these parameters to be specified as a rejuvenation parameter, whether in terms of minimum values to be attained or whether a minimum improvement must be achieved.

3.4 Application trial section

The onus is on the applicant to organise a trial section conforming to the applicable requirements as shown in Table 4.

Table 4: Application trial site requirements (O'Connell, 2017)

Property	Requirement
Surface condition	Good condition, with no major fatigue distress.
Substrate	Asphalt mix paving, preferably medium continuous mix using unmodified binder
Texture depth	Sufficient to accommodate the applicant's recommended spray rate, in order to prevent run-off and tackiness
Average daily truck	≥ 80

traffic	
Age	≥ 3 years

3.5 Testing and performance of trial section

The evaluation procedure of the trial section is indicated in Tables 5 and the property requirements are listed in Table 6.

Table 5: Performance sampling and testing (O' Connell, 2017)

Time period	Sampling	Process / Testing
Prior to application		Visual condition
		Skid resistance
	1 x 100 mm core	GC analysis
Application – Leave 10 m^2 untreated		
After drying		Visual condition
	1 x 100 mm core	GC analysis
20 – 24 hours	-	Skid resistance
30 days	-	Visual condition
	1 x 100 mm core	GC analysis
3 months	-	Visual condition
	11 x 150 mm cores in treated area, 11 x 150 mm cores in untreated area	GC analysis
		Cantabro
		G*.Sinδ @ 28°C
		δ
6 months	-	Visual condition
	1 x 100 mm core	GC analysis
12 months	2 x 100 mm cores: Treated and untreated areas	Visual condition
		GC analysis

Table 6: Requirements for rejuvenation treated materials at the trial site (O'Connell, 2017)

Criteria	Test	Proposed interim limits	Relevant period
Visual condition of pavement	TMH 9 Comparative visual appraisal: Treated vs untreated (1992)	Monitor only	Installation, 30 days, 3 months, 6 months, 12 months
Skid resistance	SCRIM or Griptester	Maximum 20% loss. May not cause instability when car turns 90° at 10km/hr	24 hours after installation
Presence of volatile materials	Gas chromatography analysis	Monitor only	Installation, 30 days, 3 months, 6 months, 12 months
Resistance against abrasion (binder	Comparative Cantabro test: Treated vs	≥ 15% difference	3 months

adhesion)	Untreated		
Resistance to cracking (binder stiffness)	Comparative G*.Sinδ @ 28°C: Treated vs Untreated	≤ 20% difference	3 months
Binder viscous component	Comparative δ @ 28°C: Treated vs Untreated	Monitor only	3 months

3.6 Certification

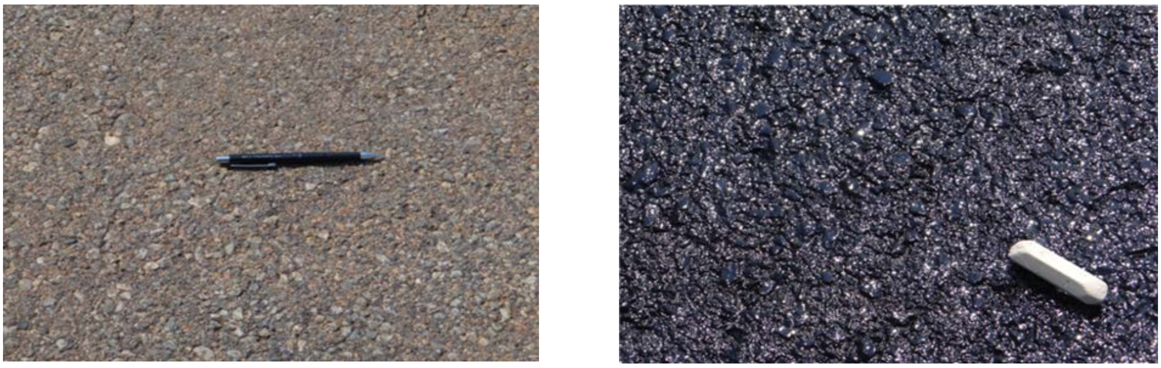
Temporary certification may be issued by Agrément SA after a 3 month period after the following requirements have been met:

- Successful evaluation of the installation site to date as well as at least one additional site, older than one year, where the product has been successfully applied, and
- Successful evaluation of production and quality control systems

Permanent certification may be issued upon completion of the One-year long trial section.

4 Agrément Case Study

The product was applied to an existing surface at a rate of 0.4 l/m^2 manually by rollers. The drying time, was 2 hours which is within the 4 hours limit, stated in the method statement (Figure 2). The results for the rejuvenated surface are listed in Table 6.



a) Prior to treatment **b) After treatment**

Figure 2: Product application

Table 6: Testing for Agrément certification

Property	Treated Area	Untreated Area	Improvement	Proposed Agrement limits
After 3 Months				
Resistance against abrasion (%)	28.5	31.4	9.4 %	≥ 15 %
G*.Sin δ @ 28 °C (MPa)	6 480	8 810	26.4 %	≥ 20 %
δ @ 28 °C (°)	37.9	36.5	1.4	Monitor Only
After 5 years				
Resistance against abrasion (%)	18.5	21.8	17.8 %	≥ 20 %
G*.Sin δ @ 31 °C (MPa)	4 820	5 820	17.2 %	≥ 20 %
δ @ 31 °C	41.1	38.7	2.4	Monitor Only

Skid resistance results were made available for the five-year old section, before and after treatment. The British Pendulum Number (BPN, ASTM E303-93) and Gripnumber (GN) were both employed to evaluate the skid resistance.

For the dry test for the British Pendulum Test, the average untreated resistance was 84.75 BPN with a coefficient of friction of 1.18. The average treated resistance was 88.63 BPN with a coefficient of friction of 1.26. This results in an increase in Coefficient of friction of 6.8%. For the wet test, the average untreated resistance was 58.50 BPN with a coefficient of friction of 0.73. The average treated resistance was 75.00 BPN with a coefficient of friction of 1.01. This results in an increase in Coefficient of friction of 38.4%.

The Griptest results are illustrated in Figures 3 and 4.

Note that when comparing the results after 3 months and 5 years, there were differences in testing procedures between 3 months and 5 years. The evaluation was still in an experimental phase and testing parameter were being refined.

- The resistance to cracking and binder viscous component was completed at 31°C after 5 years when compared to 28°C after 3 months.

- The Cantabro test (resistance to abrasion) was completed on 15 mm cores for 3 months and 10 mm cores after 5 years (Figure 5).

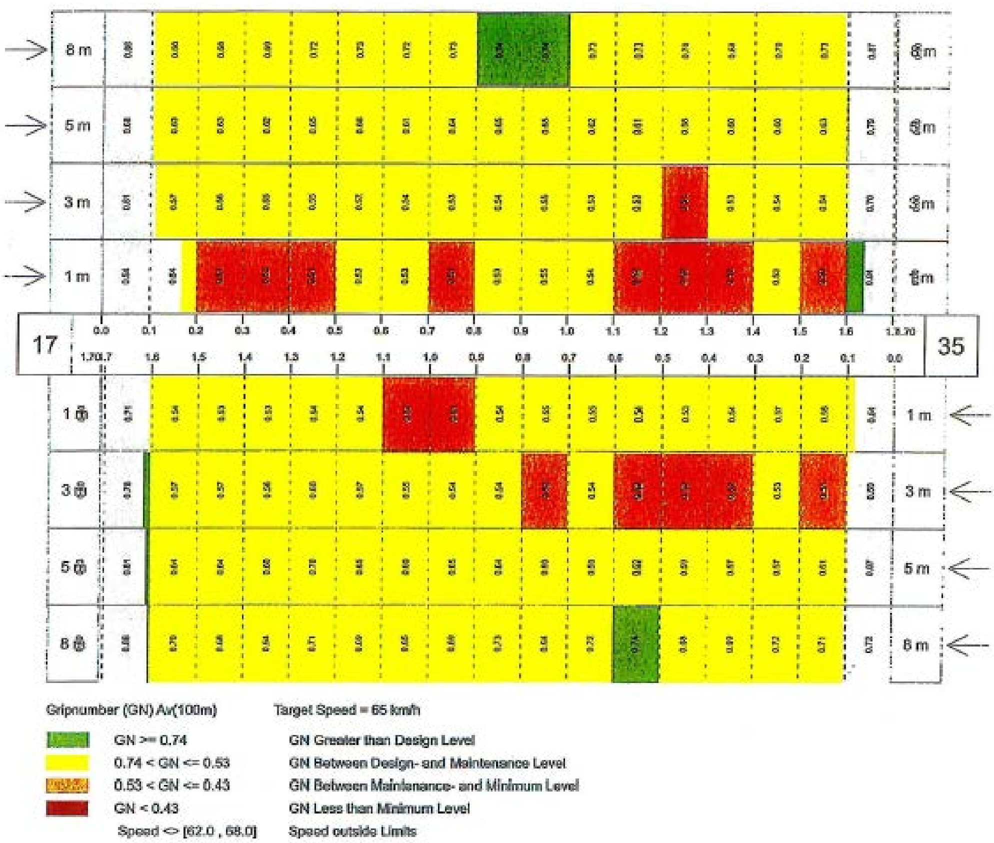


Figure 3: Griptester results prior to application

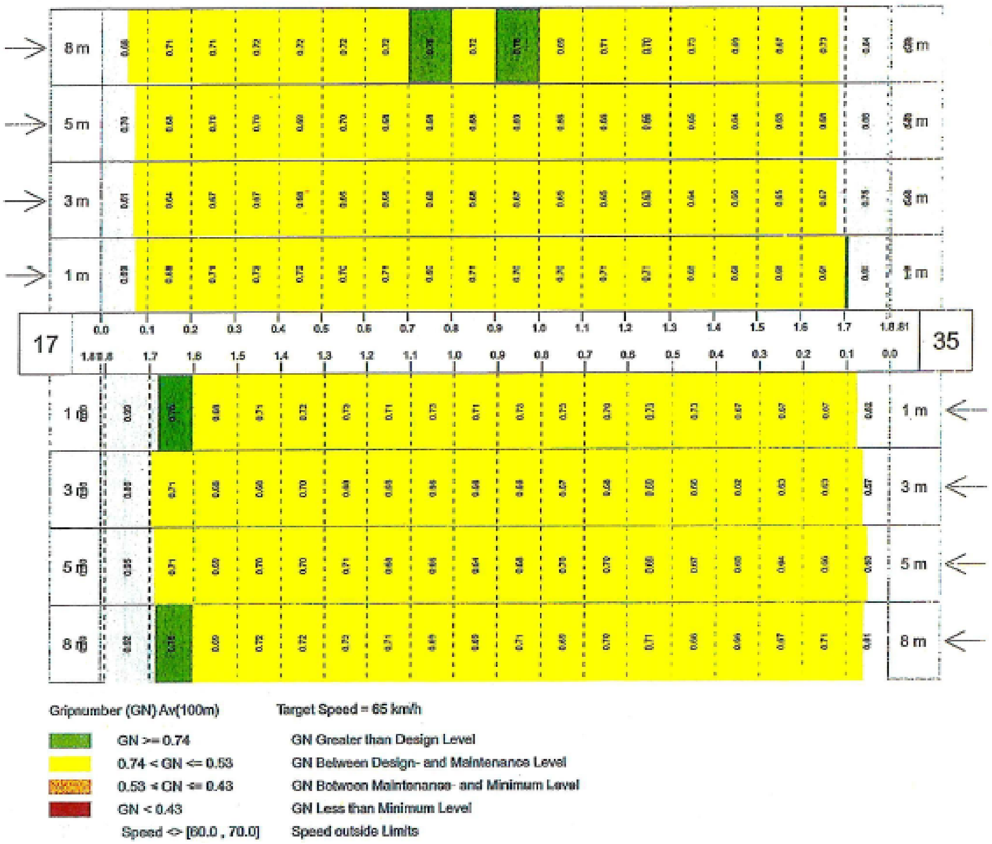


Figure 4: Griptester results one week after application

Figure 5: The top 10 mm of the cores of the untreated area

5 Conclusion and Recommendations

To date there have been no guidelines or product evaluation procedures available to industry in South Africa. As a result the performances of surface rejuvenators have been variable, resulting in poor skid resistance on occasion.

Due to the nature of the product, estimates were made regarding the proposed performance level limits, which were based on work done in the literature as well as local engineering experience. However, only limited information is available, so it is the intention that these limits

be refined towards specifications in time as further product testing provides additional information.

It is the hope that this paper will provide a platform for knowledge dissemination, which will stimulate further research and standardization in the surface rejuvenation industry.

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