Development of a New Asphalt Mix Design Manual for South Africa

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***Abstract*—A need existed to update the South African design methods for asphalt mixes, particularly in the light of current developments in the country such as the revision of the South African Road Design System (SARDS), and the increasing demand for, and the use of products such as high modulus asphalt mixes with reclaimed asphalt and slags, warm mix, and cold mix as alternative mixes to conventional hot-mix asphalt. Generally, there is a worldwide shift from empirical-based asphalt mix design approach towards performance-related design approaches, due to advances in asphalt technology, increased volumes of heavy vehicles on roads, and there is also a demand for higher performance mixes, and a need to review the current criteria for asphalt layers in contract specifications. This paper presents the development of a new asphalt design manual. The paper presents key highlights such as (a) the performance grade binder selection methodology in which the binder is selected based on loading and environmental conditions, as a replacement of the traditional penetration grade binder selection method, (b) the move from aggregate grading bands (as per the current South African Committee of Transport Officials specifications) towards the use of control points to select the design aggregate grading, and (c) the three levels of asphalt mix designs proposed for the manual. The manual however, requires validation through additional laboratory testing before it can be used with confidence by industry.**

Keywords—aggregate selection; binder selection, asphalt mix design; perofrmance-related test

I. Introduction

The design methods for asphalt mixes in South Africa have traditionally focussed on the design of Hot-Mix Asphalt (HMA). The most recent update of the HMA design method was published in the form of an interim design guide by Taute et al [1] , supplemented by Sabita Manual 24 "*User Guide for the Design of Hot Mix Asphalt*". The interim design guideline came about as a response to changes in traffic loading, design practise, and mix types since the introduction of the Marshall-based design described in TRH8:1987. An important new aspect in the interim guideline document was the shift towards performance related specifications, a trend that has found much support both locally and internationally. The interim guidelines, as the name implies, were intended as a preliminary product, to be updated as the proposed methodology was validated. Significant developments in asphalt technology have taken place since the publication of the interim design guidelines almost a decade ago, but these have not yet been translated into a holistic review of the design methodology in South Africa. A need exists to update the South African design methods for asphalt mixes, particularly in the light of the following developments:

- The revision of the South African Pavement Road Design Method (SARDS) currently underway. The revised SARDS will allow for linkages between asphalt mix design, structural design and field performance in terms of resilient response and damage evolution. In current South African practise the design of asphalt mixes and the mechanistic-empirical design of the pavement structure are generally treated separately.
- The increase in the application of mix types that cannot be classified as conventional hot-mix asphalt and require alternative design methods, such as warm mix, cold mix, reclaimed asphalt mixes, and high modulus asphalt based on the French Enrobé à Module Élevé (EME) technology. This is the reason for the shift in focus in this document from HMA to asphalt in general.
- International and local advances in asphalt technology.
- Increase in volumes of heavy vehicles on South Africa's roads.
- A demand for higher performance mixes, often leading to more sensitive mix designs.

Furthermore, the methodology proposed in the interim design guide has never been properly validated. A need was identified for a consolidated design manual containing well-validated methods to replace the existing guidelines.

The development of the mix design manual was based largely on a research project commissioned by the southern African Bitumen Association (Sabita), and carried out by the CSIR. The project comprised of an extensive state-of-the-art study (Denneman et al. [2]), consultations with industry experts, and followed by a comprehensive laboratory testing programme conducted on 13 South African asphalt mixes from different provinces of the country. The intention was to increase the reliability of mix designs in terms of performance prediction, whilst at the same time simplifying the design process by reducing the number of test methods involved. The manual is currently interim, and requires validation before it is fully adopted for practice.

This paper presents the development of the new asphalt design manual. Key aspects on new aggregate selection methodology, binder selection, and performance-related mix design procedures are presented. The laboratory development programme that was followed to propose criterial for various performance parameters of asphalt mixes is also presented. The direct link of the asphalt mix design to pavement design is under review, and was not part of this paper

II. RECENT TRENDS IN ASPHALT MIX DESIGN

A. Advances in Asphalt Mix Design

Recently, there is a trend towards the implementation of performance specifications for asphalt mixes.

In the USA, performance testing of asphalt was introduced in 1993 as part of the Superpave research effort. Innovations in terms of asphalt design included performance-based grading system for bituminous binders, aggregate grading requirements, and mix design procedures and test methods.

In Europe, performance testing is also becoming dominant. Notable contributions to the paradigm shift to performance testing have come from France where they started implementing performance-related testing in the 1980s. In the interest of free trade, the European Union has recently released the EN 13108 [3] and EN 12697 [4] standards series for bituminous mixtures. The intention is that the second generation of these standards will be fully performance-related. The association of Australian and New Zealand road transport and traffic authorities, Austroads, also implemented a performance-related asphalt design method [5]. The Austroads performance-related method has three levels of complexity. The structure of the different analysis levels share similarities with the European and American design methods.

B. Performance-Related Tests and Specifications

The design philosophy in the new manual follows the international trend, which is to move from a more empirical-based mix design approach towards the implementation of performance-related approach to set specifications for asphalt mixes.

A performance-related asphalt mix design manual requires conducting performance testing to establish guideline values for the mix and specifications. A proper volumetric mix design should result in a well-balanced mix that has adequate resistance to rutting, fatigue, ageing and water infiltration. For most design situations, however, some validation of the mix performance is required. Thus, several performance evaluation tests are available for use in the laboratory and for validating the mix design. It should be mentioned that these performance tests are associated with a significant amount of investment specifically in advanced laboratory testing equipment and training of engineers and technicians in testing and data analysis. The cost benefit is that rehabilitation of a premature failure of an asphalt pavement is far more costly and will exceed the cost of these investments.

Performance specifications are based on the concept that mix properties should be evaluated in terms of the loading and environmental conditions that the asphalt material will be subjected to in service. This is in contrast with the traditional Marshall mix design approach in which specifications are based on empirical test methods. The intention of these specifications is to describe the performance requirements, without necessarily prescribing the composition of the composite materials. An advantage of this approach is that it reduces barriers to innovation and promotes the efficient use of natural resources, without sacrificing performance.The material parameters determined during the mix design phase should have a direct relation to the performance of the material in the pavement structure.

III. ASPHALT MIX DESIGN

Three levels of mix design i.e., Level I, Level II, and Level III are recommended in the new manual for South Africa (Fig.2). The use of levels allows for the selection of a design process that is appropriate for the traffic loads and volume (expressed as E80s) over the service life of the asphalt pavement and mitigate exposure to the risks associated with structural damage.

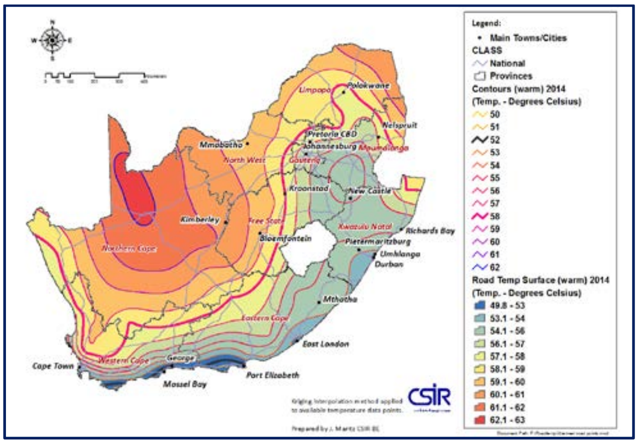

Fig. 1. 7-day average maximum asphalt temperatures

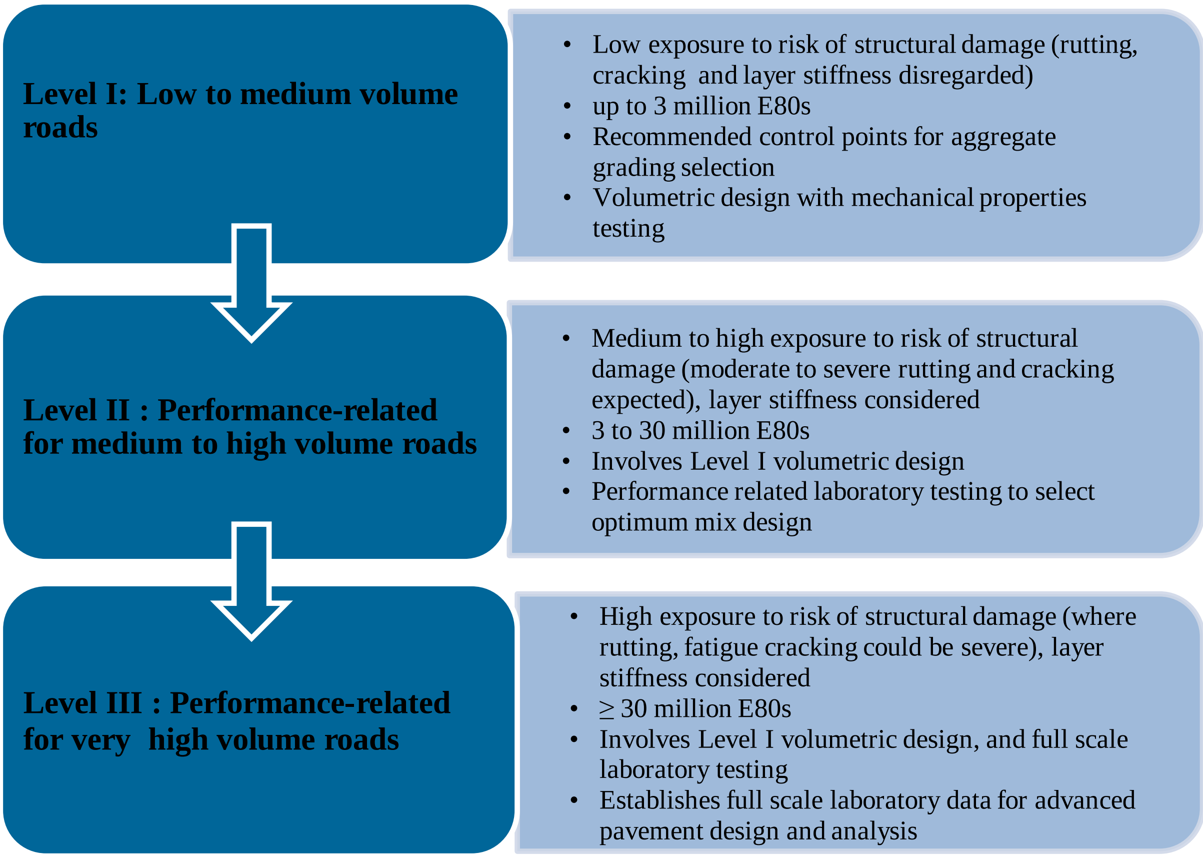

Fig.2. Mix design levels

IV. Level I Design Process

This level of design requires either Marshall or Gyratory specimen preparation. It is mainly volumetric design with mix compliance with performance related requirements of durability based on tensile strength ratio (TSR) from modified Lottman test, stiffness obtained from indirect tensile strength (ITS) test, permanent deformation from dynamic creep test, fatigue from Semi-Circular Bending (SCB) test, and water permeability.

The first major step is to select mix type based on design objective and situation. In this manual, asphalt mixes are primarily classified into two main categories based on aggregate packing i.e. sand-skeleton or stone-skeleton types. Determining the aggregate packing characteristics of the mix is a critical choice to be made for mix type selection.

In sand-skeleton mixes, the loads on the asphalt layer are mainly carried by the finer aggregate fractions, with the larger fractions providing bulk and replacing a proportion of the finer fractions. There is no meaningful contact between the individual larger aggregate particles. Examples include semi-gap graded asphalt, gap-graded asphalt, and medium / fine continuously graded asphalt.

In the stone skeleton mixes, the spaces between the coarser aggregate fractions are filled by the finer aggregate fractions, but do not push the coarser aggregates apart. Contact between the coarser aggregate fractions is thus assured. This situation results in the loads on the layer being carried predominantly by a matrix (or skeleton) of the coarser aggregate fraction. Examples include coarse continuously graded asphalt, stone mastic asphalt, ultra-thin friction courses, and open graded asphalt (porous) asphalt.

The second major step is to select appropriate mix components in terms of binder and aggregate. A suitable grading is developed from the different aggregate fractions. The binder content is set based on a minimum richness factor, similar to the film thickness used in South Africa. Using this trial mix design, Marshall or gyratory compacted specimens are produced, and used to determine the optimum design. The volumetric properties of the specimens are determined and compare with criteria. Following this, the optimum mix is evaluated against durability (TSR), ITS, creep modulus and fracture criteria.

A. *Aggregate Selection*

To achieve suitable aggregates packing to ensure that relevant performance characteristics of a particular mix are met, aggregates of various sizes are mixed in certain proportions. Such proportions are defined by the particle shape, texture and size distribution as represented by a grading. This grading will then be used primarily as a quality assurance measure to ensure that the intended packing features are achieved and maintained for a particular aggregate type.

To guide designers, especially when preparing a first-off design with specific aggregates in a particular application, some guidelines are offered here. It is suggested that the grading of an aggregate blend should lie within certain key control points as follows:

- The nominal maximum particle size (NMPS) – designated as one sieve size larger than the largest sieve to retain a minimum of 15 percent of the aggregate particles
- The 2 mm sieve, and the 0.075 mm sieve.

Table I provides grading control points for four nominal maximum particles sizes of aggregates typically used for production of sand skeleton (often continuously graded) asphalt mixes in South Africa.

TABLE I. AGGREGATE GRADING CONTROL POINTS

Sieve Sizes [mm]	Percent Passing NMPS							
	28 mm		20 mm		14mm		10 mm	
	Min	Max	Min	Max	Min	Max	Min	Max
37.5	100							
28	80	100	100					
20		85	80	100	100			
14				85	80	100	100	
10						85	80	100
7.1								85
5								
2	19	45	23	49	28	58	32	67
1								
0.6								
0.3								
0.15								
0.075	1	7	2	8	2	10	2	10

The general requirements and specifications for aggregates are as follows:

- Coarse and fine aggregates obtained from crushing or natural sources should be clean and free from decomposed materials, vegetable matter and other deleterious substances;
- The aggregate blend may contain natural fines not obtained from the parent rock being crushed, subject to limitations of the proportion of such materials based on mix type and experience with the materials;
- The coarse aggregate is in most cases, crushed rock. Certain types of crushed blast-furnace slag may also be used, provided they satisfy the strength requirements and are not too water absorbent;
- The fine aggregate may be crusher sand, slag sand, clean natural sand, mine sand, selected river gravel or a mixture of these.

The standard test methods and recommended criteria to determine the suitability of aggregates for asphalt mix design are presented in Table II.

B. Binder Selection

The goal is to select a binder that will, in conjunction with the aggregate configuration, contribute to the performance of the asphalt under the prevailing conditions in such a manner as to provide the best "value for money." Binder selection for an asphalt layer should be supported by the general considerations of traffic, climate, the modes of damage expected for the asphalt layer (e.g. rutting, fatigue and ravelling), pavement structure and condition of the existing pavement, where appropriate, and availability of binder and aggregate types.

South Africa is in the process of translating from penetration grade type bitumen specification to a performance grade specification. Since the compliance criteria for the various environmental and traffic situations are in the process of being formulated, an indication of a performance grade specification framework and related testing, likely to be implemented, is given in this document. As matters progress, the information in this manual will be updated. For the time being, the current specifications for binders generally used in asphalt mixes as given in SANS 4001-BT1 for penetration grade bitumen and in TG1 *The use of modified binders in road construction* will hold sway.

Performance grade specifications for binders focus on the evaluation of binder properties based on the traffic loading and environmental conditions (mainly temperature), which the binder will be subjected to in the field. The temperature of the asphalt layer, in conjunction with the grade and age of the binder, plays a pivotal role in determining the stiffness or dynamic modulus of the asphalt layer. South Africa is divided into two performance graded (PG) binder zones based on the 7-day average maximum temperatures (Fig.1):

- **PG 58 Zone** which would include the Western Cape (except for the northern inland regions), Eastern Cape, most of KwaZulu-Natal, eastern half of the Free State, Gauteng, South Eastern part of Limpopo, and Mpumalanga (except for the eastern region bordering Mozambique).
- **PG 64 Zone** which covers the rest of the country, including the Northern Cape (except for the mountainous southern region), North West, the extreme northern coastal region of KwaZulu-Natal and rest of Limpopo.

It has been proposed that a single low temperature grade of --10˚C or -16˚C for binders will suffice to cover the entire country and will simplify the number of binder grades required as well as minimise the logistics requirement in terms of the number associated with production requirement, storage tanks, etc.

TABLE II. AGGREGATE GRADING CONTROL POINTS

Property	Test	Standard	Criteria
Hardness / Toughness	Fines aggregate crushing test: 10% FACT	SANS 3001-AG10 [6]	Asphalt surfacings and base: minimum 160 kN Open-graded surfacings and SMA: 210 kN
	Aggregate crushing value (ACV)	SANS 3001-AG10 [6]	Fine graded: maximum 25% Coarse graded: maximum 21%
Soundness	Magnesium sulphate soundness	SANS 5839 [7] SANS 3001-AG12 [8]	12% to 20% is normally acceptable. Some specifications requires ≤ 12% loss after 5 cycles
Durability	Methylene blue adsorption indicator	SANS 6243 [9]	High quality filler: maximum value 5 More than 5: additional testing needed
Particle shape and texture	Flakiness index	SANS 3001- AG4 [10]	20 mm and 14 mm aggregate: maximum 25[1] 10 mm and 7.1 mm aggregate: maximum 30
	Polished stone value (PSV)	SANS 3001–AG11 [11]	Minimum 50[2]
	Fractured faces	SANS 3001-AG4 [10]	Fine graded: at least 50% of all particles should have three fractured faces Coarse graded and SMA: at least 95% of the plus 5 mm fractions should have at least one fractured face
Water absorption	Coarse aggregate (> 5mm)	SANS 3001-AG20 [12]	Maximum 1% by mass
	Fine aggregate (< 5mm)	SANS 3001- AG21 [13]	Maximum 1.5% by mass
Cleanliness	Sand equivalency test	SANS 3001-AG5 [14]	Minimum 50 total fines fraction
	Clay lumps and friable Particles	ASTM C142–97 [15]	Maximum 1%

[1] For certain types of mixes, e.g. UTFC, a maximum flakiness index of 20 is preferred

[2] Consideration can be given to adopting a limiting value of 45, with due regard to material availability, traffic, road geometry and climate.

C. Minimum Binder Content Requirements

The minimum binder content for each trial blend is determined using richness modulus, specific surface area and density of the aggregates. Richness modulus (*K*) is a measure of the binder film thickness surrounding the aggregate. The richness modulus is a proportional value related to the thickness of the binder film coating the aggregate. It is akin to the film thickness calculation in the South African TRH 8. *K* is obtained from:

$$B_{ppc} = K \times \alpha \times \sqrt[5]{SA} \quad (1)$$

B_{ppc} = mass of binder *expressed as a percentage of the total dry mass of aggregate, including filler*. B_{PPC} can be converted to the binder content by mass of total mix (P_B) generally used in South Africa using Eq. 2

$$B_{ppc} = \frac{100 \times P_B}{(100 + P_B)} \quad (2)$$

K = richness modulus - minimum K values for mix types evaluated for this manual are provided in Table III.

α = correction coefficient for the relative density of the aggregate (*RDA*), computed as follows:

$$\alpha = \frac{2.65}{RDA}$$

SA = specific surface area (m²/kg).

TABLE III. TYPICAL MINIMUM RICHNESS MODULUS VALUES

Mix Type	Minimum *K*
Sand Skeleton	≥ 2.9
Stone Skeleton	≥ 3.4

V. LEVEL II AND LEVEL III DESIGN PROCESS

These are performance-related mix designs. The volumetric design of Level I is the starting point for Level II and Level III mix design levels. The main difference between the two levels is that a full scale laboratory testing is conducted at Level III to predict permanent deformation and fatigue characteristics of the mix with the purpose being to establish a direct link between mix design and pavement design.

For Level II and Level III mix designs, the first of the performance-related criteria is aimed at creating a workable mix. The workability test is conducted on short-term aged gyratory compacted specimens. If the workability criteria are met, then specimens are tested subjected to permanent deformation and fatigue tests. The optimum mix is selected based on permanent deformation and the fatigue performance, and evaluated against compliance with durability (TSR) and stiffness (dynamic modulus). Both permanent deformation and dynamic modulus characteristics of the mix are determined from the Asphalt Mixture Performance Tester (AMPT) system (repeated load axial test), and fatigue characteristics are determined from four-point beam fatigue testing system.

For Level II design, permanent deformation is determined for three binder contents. The optimum mix is determined based on a flow number parameter obtained from the repeated load axial test conducted at one test temperature using one deviatoric stress level and one confining pressure. Fatigue characteristics are then, evaluated for the optimum mix at one test temperature and three strain levels. The dynamic modulus of the mix is also evaluated at one test temperature, and one loading frequency.

For Level III design, the permanent deformation test is conducted at three test temperatures on the optimum mix using three deviatoric stresses, and one confining pressure to record plastic strain at 20 000 cycles. The fatigue characteristics at this level are determined at three test temperatures and three strain levels to generate fatigue curves for the mix. In addition, a full factorial test of dynamic modulus is conducted at the six load frequencies (sweep test) and at five temperatures. Thus, a full test is required at this level of design for the asphalt material.

VI. LABORATIORY TESTING PROGRAMME TO DEVELOP THE MIX DESIGN CRITERIA

An extensive laboratory study was conducted to establish interim (typical) values for the performance-related properties. A total of 13 mixes were used for the laboratory programme. The materials for the mixes were supplied by two prominent asphalt manufacturers. Mix design sheets for individual mixes were made available to the CSIR. Subsequently, the mixes were replicated at the CSIR laboratory and evaluated for the various performance parameters. The results are presented in the manual as interim, requiring laboratory verification/validation tests.

Manufacturer A:

- Medium continuously graded mix with 50/70 penetration grade binder
- Porous bitumen-rubber open graded (BROG) mix
- Bitumen-treated base mix with 35/50 penetration grade binder.
- Coarse continuously graded mix with AE2 modified binder
- Medium continuously graded mix with AE2 modified binder
- Medium continuously graded mix with a 60/70 penetration grade binder
- Bitumen-rubber asphalt semi-open graded mix (BRASO).

Manufacturer B:

- Bitumen-treated base mix AP-1 binder
- Medium continuously graded mix with 50/70 penetration grade binder
- Medium continuously graded mix with 50/70 penetration grade binder and 20 % RA
- Continuously graded mix with 50/70, warm mix additive and 20 % RA
- Medium continuously graded mix with AP-1 binder
- Gap-graded SMA with AP-1 binder

A. *Materials and Sample Preparation*

Raw materials (aggregate and binder) were sampled at the asphalt plants in accordance with TMH5 (*Sampling Methods for Road Construction Materials*). At the laboratory, to further ensure homogeneity of the materials sampled, bags of similar aggregate sizes were mixed together by riffling and quartering. Aggregates were oven dried for a minimum of 16 hours at approximately 105°C. Following drying, the materials were split down by riffling to the approximate quantities required for the various compactions. Dry sieve analyses were carried out on randomly selected bags to ensure that the material has been adequately riffled. The required grading (target grading) was made up in triplicate and tested for conformance with the specifications. This was done by wet grading analysis. Obtaining the correct grading from the mix proportions given is an indication of accurate sample preparation.

B. *Production of Test Specimens*

The mixes were reproduced as designed by the manufacturers. Mixing and compaction of specimens was done in accordance with the CSIR test protocols [16]. After mixing, the material was placed in an oven set at compaction temperature for four hours to induce short-term ageing, after which the mix was compacted. Slabs were compacted to design density, whereas gyratory specimens were compacted to the expected initial field densities of approximately 93 percent of maximum void-less density. Gyratory compacted specimens were used for the workability, permanent deformation and dynamic modulus testing, and the compacted slabs were cut into beams for fatigue testing.

C. *Development of Workability Criteria*

Workability is assessed by monitoring the effort required to compact the asphalt mix in the gyratory compactor (AASHTO PP 60 [17]). Three replicate specimens were tested for each mix. The Superpave gyratory compactor available at the CSIR pavement materials laboratory was used for the test. Compaction was done at a rate of 30 gyrations per minute and a compaction pressure of 600 kPa. The angle of gyration was 1.25° (external). Interim criteria were set for the minimum air void content after 25 gyrations, to ensure that the desired density can be readily achieved under the rollers in the field (see Table IV).

TABLE IV. WORKABILITY CRITERIA[1]

Mix Type	Number of Gyrations	Voids
Sand Skeleton	25	$0 < V_{25} - V_{des} < 2$
Stone Skeleton	25	$0 < V_{25} - V_{des} < 2$

[1]: Interim, requiring lab validation tests. V_N = voids at number of gyrations; V_{des} = design voids.

D. *Development of Permanent Deformation Criteria*

Permanent deformation properties determined from repeated load uniaxial or triaxial tests are key parameters to model rutting potential in the current pavement design methods. For each asphalt mix, three duplicate sets of gyratory compacted specimens were tested. Test specimens were compacted to the dimensions of 150 mm diameter by 170 mm high following the AASHTO PP 60 [17] procedures. The specimens were cored and cut from the 150 mm diameter by 170 mm high samples to a final nominal dimension of 100 mm diameter by 150 mm high to achieve the recommended voids of 7% ± 0.5% (typical field voids for continuously graded mixes at the time of construction).

The AMPT permanent deformation (flow number) test method is proposed (AASHTO TP 79 [18]) to determine rutting characteristic of the mix. Flow number is an indication of rutting. Typically, asphalt mixes with high flow number can be expected to exhibit better rutting performance than a mix with low flow number under the same conditions. For Level III design, a deviator stress of 483 kPa and confining pressure of 69 kPa are applied on the specimen subjected to a haversine loading of 0.1 s and 0.9 s rest period at one test temperature of 55°C. The test is conducted until the flow point or 10 000 load cycles is reached. The flow point represents failure of the specimen, and gives a flow number parameter, which is defined as the number of load pulses when the minimum rate of change in permanent (plastic) strain in the mix occurs. For Level III design, it is proposed that three deviator stress levels of 138, 276, and 483 kPa and one confining pressure of 69 kPa be applied on the sample at three different test temperatures of 25, 40 and 55°C to record plastic strain at the maximum load cycles of 20 000.

At the time of the preparation of the manual, the applied deviator stress for AMPT permanent deformation testing had not been standardized. It was therefore not appropriate to set criteria for the sand and stone skeleton mixes tested for the manual. Therefore, typical flow numbers (Table V) are provided for asphalt mixes based on AMPT permanent deformation tests conducted at the deviator stress of 600 kPa with no confinement.

TABLE V. TYPICAL FLOW NUMBER (FN) (CYCLES)

Mix Type	Binder Type[1]	Temperature (°C)	
		40	55
Sand Skeleton	50/70	850	120
	AP-1	8 100	1 000
	AE-2	900	80
Stone Skeleton	35/50	1 900	250
	AE-2	1 300	150
	AP-1	4 000 – 6 500	NA
	AR-1	700	50

[1] Binder type refers to the empirical grades, as binders could not be tested according to the incomplete performance graded specification as yet.
NA: Test results not available

As seen from Table V, the high deviatoric stress (i.e. 600 kPa) with no confinement does not clearly discriminate between rutting performance of some of the sand and stone skeleton mixes. In addition, asphalt mixes failed at low number of load cycles. This is unrealistic, as the asphalt material has little time (low number of cycles to failure) to deform when compared with the expected rutting behaviour in the field.

Investigations by the CSIR are currently underway to determine whether or not modifications such as sample confinement, reduced deviatoric stress levels can be made to overcome any identified deficiency in the AMPT permanent deformation test. The current investigation is focused on determining the effect of three deviatoric stresses (138, 276 kPa, and 483 kPa) and confining pressure of 69 kPa on flow number, permanent strain at flow, and rate of permanent deformation. The aim is to standardise the test for future use in South Africa, if needed.

In the meantime, it is recommended that the Hamburg wheel tracking test should replace the AMPT permanent deformation test for design levels II and III. The Hamburg wheel tracking test can be used to assess both rutting resistance and moisture sensitivity based on the standard test method AASHTO T 324 [19]. Agencies that specify this test have established criteria for rutting resistance based on the deformation or rut depth after a specified number of passes. The commonly used criteria for the Hamburg wheel tracking tests in the USA are presented in Table VI. These are recommended values for tests conducted on a dense-graded mix at the temperature of 50°C using a wheel load of 705 N [20]. The values are based on the types of PG binders used in the mix. In comparison with the AMPT permanent deformation test, the criteria for Hamburg wheel tracking test is not based on traffic.

TABLE VI. REQUIREMENTS FOR HAMBURG WHEEL TRACKING TEST (TEXAS DEPT. OF TRANSPORTATION, [21])

High Temperature Binder Grade	Minimum Passes to 12.5mm Rut Depth
PG 64-22 (unmodified binder)	10 000
PG 70-22 (modified unless it contains RA binder)	15 000
PG76-22 (modified)	20 000

In South Africa, the available criteria are based on Transportek wheel tracking test (see Table VII). The standard test protocol for the Transportek wheel tracking device is to perform the test at 60°C and at a load of 600 kg. The criteria can be used as a tentative guideline to the evaluation of rutting performance.

It should be noted that wheel tracking tests (e.g. Hamburg test) is empirical, and do not provide engineering properties for the asphalt mixes, and can at best be used to rank the mixes for rutting performance. However, the test affords more ready access for designers. The results obtained from a wheel tracking test can be compared against those of a mix known to provide acceptable rutting performance. There is a need though, to set some criteria, preferably for all mix types, i.e. sand and stone skeleton mixes.

TABLE VII. INTERIM CRITERIA FOR TRANSPORTEK WHEEL TRACKING TEST [1]

Repetitions to 10 mm Rut Depth	Mix Classification
< 2500	Poor
2500 - 5000	Medium
> 5000	Good

E. *Development of Fatigue Criteria*

The four point bending (4PB) fatigue test is proposed for evaluation of the asphalt mixes in the manual. Fatigue tests were conducted on the mixes in accordance with the protocols developed for the SARDS project as discussed in Anochie-Boateng et al [22], which is based on the AASHTO test protocol T321[23]. The tests were conducted on beams (400 mm long by 65 mm wide by 50 mm high) cut from slabs. Three duplicate specimens were prepared and tested at the design voids and design binder content for all 13 mixes.

For Level II design, the fatigue test is conducted at one test temperature of 10°C, a loading frequency of 10 Hz, and at three strain levels to generate fatigue curve for the mix. For Level III design, the test is conducted at three test temperatures of 5, 10 and 20°C, a loading frequency at 10 Hz, and at three strain levels. The fatigue life of the mix (number of repetitions to failure) is defined as the load cycle at which the specimen reaches 50% reduction in flexural stiffness relative to the initial stiffness i.e. the stiffness at the first 50 repetitions. The fatigue results for the mixes tested are presented in Table VIII as typical values in the manual.

TABLE VIII. TYPICAL FATIGUE LIFE VALUES

Mix Type	Binder Type	Fatigue Life $\times 10^6$ @10°C		
		200με	400με	600με
Sand Skeleton	50/70	1.2	0.03	0.004
	AP-1	4.9	0.04	0.002
	AE-2	14.0	0.35	0.040
Stone Skeleton	35/50	0.9	0.02	0.002
	AE-2	10.2	0.15	0.013
	AP-1	1.0	0.03	0.004
	AP-1 (SMA)	6.8	0.19	0.023
	AR-1	NA	NA	0.313
	AR-1	9.5	0.40	0.063

F. *Development of Durability Criteria*

In South Africa, the modified Lottman test in accordance with ASTM D4867M [24] is generally used to assess the durability (resistance to moisture damage) of asphalt mixes. Local performance criteria in terms of the ratio between original and indirect tensile strength (ITS) are available for HMA [1], and presented in Table IX. Although the modified Lottman tests were conducted on the asphalt mixes, the test results were not available for inclusion in the manual.

TABLE IX. MOISTURE RESISTANCE CRITERIA (MIN TSR)

Climate	Permeability		
	Low	Medium	High
Dry	0.60	0.65	0.70
Medium	0.65	0.70	0.75
Wet	0.70	0.75	0.80

G. *Development of Stiffness Criteria*

The SARDS requires characterisation of South Africa asphalt mixes by dynamic modulus property. Dynamic modulus values obtained from laboratory frequency sweep test data are usually used to construct master curves to characterize the HMA over ranges of temperature and frequency. During the development of the manual, dynamic modulus tests were conducted on the gyratory compacted specimens (100 mm in diameter x 150 mm high) of all the 13 mixes at five test temperatures (-5, 5, 20, 40, 55°C) and six loading frequencies (25, 10, 5, 1, 0.5, 0.1 Hz). The test was conducted in the AMPT testing system (same as permanent deformation) and in accordance with AASHTO TP 79 [18]. During testing, the specimens were subjected to a haversine compressive load pulse. The axial stresses and the corresponding axial strains recorded for the last 10 load cycles for each test are normally used to compute the dynamic modulus of the sample. Typical dynamic modulus values for the asphalt mixes tested are provided in Table X.

For Level II design, dynamic modulus test is conducted at the six loading frequencies, and at one test temperature of 20°C. For Level III design, a full factorial test of dynamic modulus is conducted at the six frequencies and at five test temperatures.

TABLE X. DYNAMIC MODULUS CRITERIA

Mix Type	Binder Type	Temperature (°C)				
		-5	5	20	40	55
Sand Skeleton	50/70	24 200	19 800	10 000	1 700	450
	AP-1	26 200	21 700	11 200	1 900	700
	AE-2	19 850	15 500	6 800	1 100	500
Stone Skeleton	35/50	24 750	19 800	10 150	2 300	600
	AE-2	22 150	18 000	7 950	1 200	500
	AP-1	25 000	21 250	12 500	3 000	950
	AR-1	13 000	9 000	3 600	850	350
	AR-1	9 200	5 750	2 250	500	NA

VII. CONCLUSIONS

This paper provided the structure and background of the newly proposed performance-related asphalt mix design method for South Africa. The paper also highlighted some of the more prominent features of the new mix design method, as well as laboratory development programme that served as the basis for setting interim performance-related criteria for asphalt mixes. Based on the information presented in this paper, it can be concluded that:

- there was full commitment by both the asphalt and pavement industries as well as the CSIR to advance asphalt mix design in South Africa. This was demonstrated through the project as there were regular interactions between the representatives of the industry and the CSIR.

- the test procedures presented in the manual as well as the interim performance-related values/criteria require validations or revisions. Recall that the development of the manual commenced in 2012, and with time, some improvements in some of the protocols (e.g. the AMPT permanent deformation test protocol) might have taken place, which may warrant revisions or adjustments in the typical values presented in the manual.

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