BALANCING ASPHALT RUT RESISTANCE WITH DURABILITY AND SAFETY REQUIREMENTS ON RUNWAY REHABILITATIONS

E Horak
Kubu Consultancy (Pty) Ltd, South Africa
ehorak@global.co.za
S Emery
University of Witwatersrand, South Africa
emery@iafrica.com
I Mihaljevic
Kamen Engineering, Australia
kamen@kameneng.com

ABSTRACT

Runways carry less traffic than a typical highway, but typically much higher loads. The hot-mix asphalt requirements for runways are therefore different from those of roads, being more demanding on rut resistance and durability. Runways surfaced with typical road type asphalt mix designs tend to suffer more from durability related deterioration than normally found on roads partly due to the lower traffic loading frequency. Large parts of the "unused" runway surface therefore tend to be prone to environmentally induced ageing, cracking and stripping. The requirement for airfield asphalt surface layers to be rut resistant leads to hot-mix asphalt which tend to be lean in bitumen content and therefore sensitive to durability related deterioration. A number of runways do not have purpose designed surface friction courses resulting in marginal macro and micro-textures. The important safety aspect of cross-fall geometry and longitudinal geometry is often also not to standard. This can cause ponding, sheet flow and skid problems in wet weather and also further contribute to durability related deterioration. When rehabilitating such runways it is therefore important to improve all these seemingly conflicting structural, safety and functional demands. In this paper lessons learnt and innovative techniques are illustrated by referring to a number of recent rehabilitations and upgrade projects in southern Africa and Australia.

1 INTRODUCTION

There are obvious differences between roads and airfield pavements and therefore should have differing design requirements. It is often found though that the more dominant market leader in flexible pavements is the roads field and designs tend to be transferred blindly from this field to that of airfields with little consideration for the actual operating and performance differences. Some of the primary differences between highways and airfields are the types of loads and number of loads that are experienced during the design life. Airfield pavements tend to experience far fewer load repetitions over their design lives than do highway pavements. Cooley [1] showed that the busiest parts of the busiest airfields in the USA can experience up to 20 times less traffic loading than a busy highway. In addition wheel track wander of aircraft is much wider than that on highways, which is also a function of the much wider pavements on airfields. There are literally many pavement areas on an airfield that may not have a single load applied during the pavement's entire life. These areas would typically be those of the overrun area, shoulder areas and even high strength pavement immediately adjacent to the shoulder interface and the keel area.

The differences in traffic loading between roads and airfields imply that there will be some areas on an airfield which may not experience distress in the form of fatigue or deformation. Such areas would definitely experience more environmentally related types of distress such as age related cracking, ravelling and stripping. This dictates different design and rehabilitation goals for the different areas on a runway and clearly also different from the design goals for a road situation

The quantum of loadings differs between the road and airport situation. In most countries, road traffic loading is converted to the legal axle load or standard axle load such as the equivalent 80kN axle load (E80) and is used as design input for roads. This can be converted to 40kN per dual wheel loading and typically a 0.7 MPa contact pressure per wheel. A runway design using a typical design aircraft such as the Boeing 747 has a wheel load of approximately 225kN per wheel on their main gear and a tyre pressure of 1.39MPa per wheel. The tyre pressure of such a typical design aircraft is roughly double that of a truck tyre pressure. This has implications particularly for rut development as the resultant vertical stress distribution in the top 50mm to 100mm in the asphalt base and surface layers is very different if super-imposed with typical temperature variation and related asphalt stiffness variation as illustrated conceptually in Figure 1.
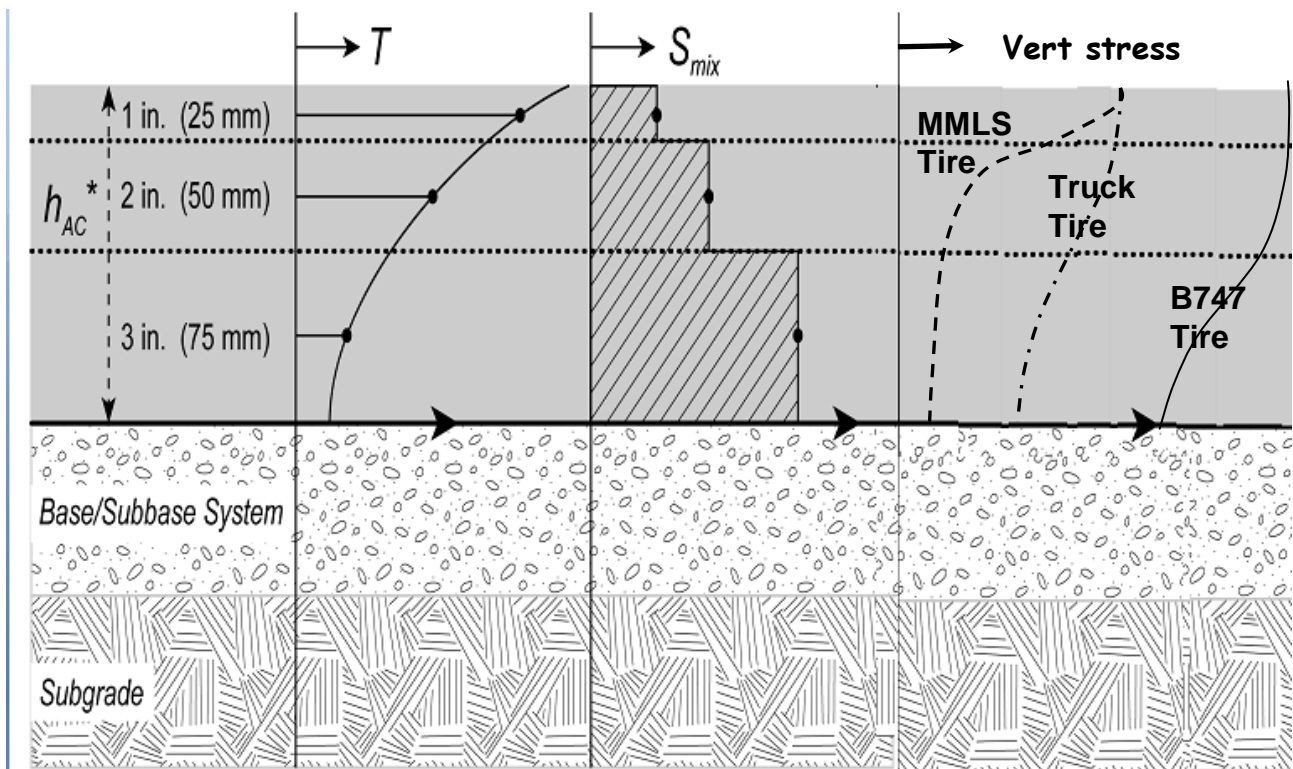

Figure 1 - Temperature stiffness and vertical stress distribution in an HMA surface layer. (Adapted from Monismith [2])

Finite element modelling of the effect of high aircraft tyre pressure on flexible pavements shows that the high aircraft tyre pressures and non-uniform contact stresses at the tyre-pavement interface cause high shear strains/stresses in the asphaltic mix layer which are responsible for rutting and near-surface cracking. This requires high stability and shear strength asphalt mixtures [21].

It is often found in practice that airfield HMA is designed the same as for a road HMA and that often leads to deformation problems due to the subtle differences in aspects such as air voids in the mix. Part of the reason is the fact that the larger HMA market is the roads

sector and these design standards and norms tend to be used more and more frequently for airfield works with scant recognition of the actual differences mentioned before.

In recent runway rehabilitation investigations, the issue of deformation and environmental related distress have led to exploring possible ways and means of managing these aspects better than the current design methodologies and specifications allow for. The application is illustrated with recent case studies to demonstrate concept and design philosophies.

2. PERMANENT DEFORMATION

2.1. Creep or rut fundamentals

Prior to developing ways and means to measure, model or calculate rutting in hot-mix asphalt (HMA) on airfields, the fundamental aspects are revisited to provide guidance and direction in the arguments and comparisons. The fundamental behaviour of creep and therefore rutting is illustrated in Figure 2, which is applicable to hot-mix asphalt. [3]. A clear distinction is made between the phase I of initial densification type primary creep or permanent deformation (rut) behaviour and the phase II of steady state secondary creep behaviour. The latter creep phase is linked primarily with shear related deformation which is the most common type of rut development over the life of a HMA layer exposed to repeated loading. The last phase is tertiary creep when total failure occurs and is not the focus of the discussion as failure in that state is obvious and is beyond design preventative measures.

Rutting in HMA layers exposed to repeated traffic loading occurs predominantly at elevated temperatures. Shape distortion (shear) in the steady state phase (II) is the main contributor to permanent deformation in the asphalt-bound layer, compared to volume change (densification) [2] which occur primarily during phase I. It was observed for highway loadings and subsequently also for airfield pavements, that rutting is mostly limited to the top 75mm to 100mm because of the high shear stress under the edge of a loaded tyre and just below the surface coupled with the higher pavement temperatures occurring at or near the surface of the HMA layer. Aspects of this concept are illustrated in the temperature distribution and associated stiffness variance in Figure 1.

2.2. Hot mix asphalt design procedures used on airfields

2.2.1. Overview of design procedures

The Marshall asphalt design method has its origin in airfield asphalt material design. It is still the dominant design method for airfield hot-mix asphalt. This design methodology is clearly in need of an upgrade as the latest generation widebody aircraft, such as the Airbus A340 and Boeing 777, are showing up the limitations of using Marshall design and therefore requires additional consideration of permanent deformation resistance [23]. HMA for highway pavements in the USA is most commonly designed in accordance with the Superpave mix design method as outlined in AASHTO M323, "Standard Specification for Superpave Volumetric Mix Design." Cooley et al [22] found that the Superpave design methodology has had limited application on airfield asphalt design [1], and research is still on-going to do this [for example: 22]. Whilst with road asphalt design there is invariably one optimum design, the same asphalt mix is not necessarily good for the varying demands on an airfield even if Superpave is being used.
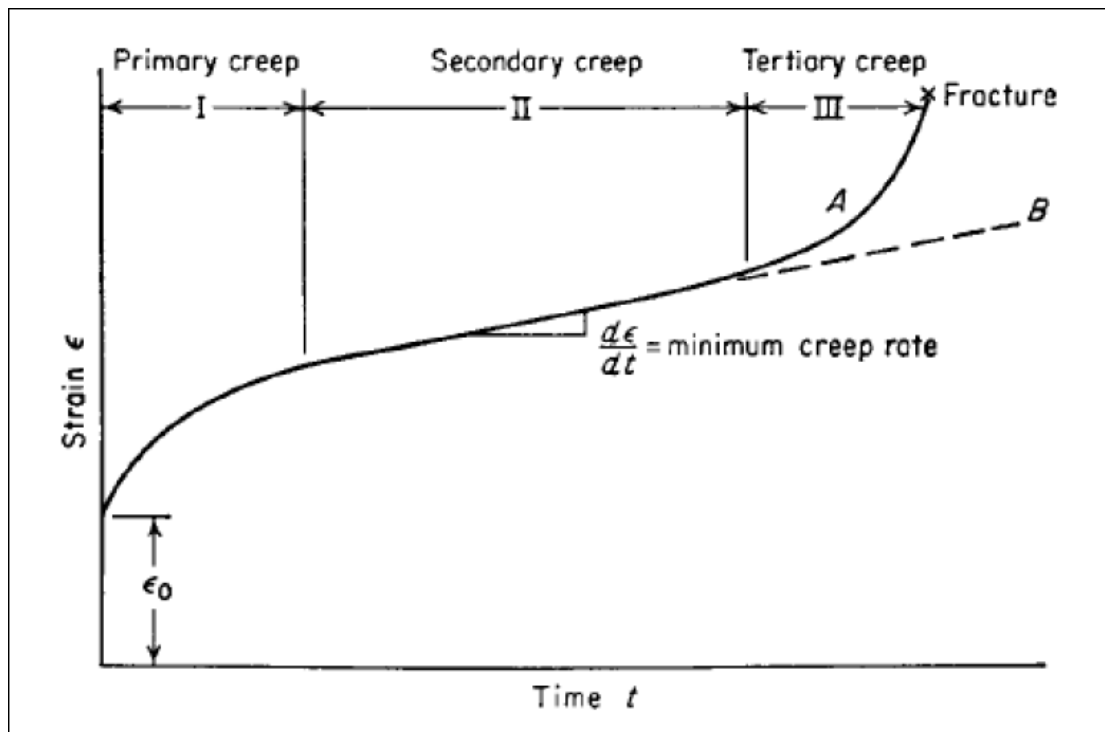
Figure 2 - Generic creep behaviour of materials [3]

Marshall specifications utilize Marshall stability and flow as a proof test during mix design. However, the criteria used are not a true reflection of rut resistance performance over the life of the asphalt mix for reasons given above. The Superpave design procedure has moved forward in terms of trying to include proof tests [1], but currently there is still uncertainty in HMA design methodologies regarding which universal test should be used or how it is actually calibrated with real life rut occurrence [3].

When selecting optimum asphalt mixes, all these design methods mentioned are similar in that volumetrics are used as the basic criteria. Air voids, voids in mineral aggregate (VMA) and voids filled with asphalt (VFA) are all directly or indirectly specified. There are slight differences in the specified volumetric requirements, the most important is the use of a range in design air voids in the Marshall method [1&22].

2.3. Measuring rut

2.3.1. Dynamic creep

The shortcoming of basically all HMA design methods is the absence of reliable rut performance specification and measurements. The current South African HMA design methodology makes use of the Dynamic Creep and calculated Creep Modulus criteria to ensure HMA mixtures are not rut prone. Literature reviewed [3][4][5] shows that the Dynamic Creep test has major repeatability and reliability problems. It seems that part of the reason is that the current protocol and calculations do not make a distinction between the primary and secondary and tertiary creep phases and tend to mix particularly the first two phases in the calculation.

2.3.2. Rut testing devices

Full scale accelerated pavement testers (APT), such as the Heavy Vehicle Simulator (HVS), have been used on airfield pavements in South Africa, but this is a very costly test and not used for normal design purposes. Laboratory rut test devices are more common.

4

Currently there is no universally accepted rut testing device which can accurately predict rut progression [3]. In most cases these devices (e.g. the Hamburg device) are used as benchmark tester to discern between rut propensities on a relative or comparative basis. Most of these testing devices are still attempting to establish criteria for road pavements and there is not such a large data base for airfield pavements yet.

The Model Mobile Load Simulator (MMLS or MMLS3) is one such scale tester for evaluating the rut propensity performance of asphalt mixes in the laboratory or field, and this has been used with some success on airfield pavements [6] [7] [8]. The test bed for trafficking by the MMLS in the laboratory allows nine 150 mm cores to be placed adjacent to each other, each fitted snugly into a restraining mould that provides circumferential support to the test specimens. Standardisation of test protocol is important and therefore it is suggested to use the MMLS3 Baton Rouge Protocol [12], or its updated version [9] be used. MMLS testing can be adjusted to simulate field conditions in the laboratory, accommodating wander, in-situ operating temperatures, applied tyre pressure and also traffic speed.

Figure 3 shows actual MMLS3 test results by way of illustration of the output. In Figure 3, Graph 1 shows testing of a range of different bitumens in a standard airfield hot-mix continuously graded asphalt, using trafficking conditions simulating fast moving traffic on a runway. The bitumen sensitivity is minor in relative terms, with a rut depth at 100,000 cycles of between 1mm for a premium PG76 type bitumen (A10E, 6% SBS modified) and 2.1mm for a 40/50 penetration (C320) unmodified bitumen. The multi-grade (Class 1000/320) and 30/40 penetration (C450) unmodified bitumen fall in between. The magnitude of differences in rutting shown here would generally reflect that shown in service in high speed runway environments, so that a more viscous bitumen would show moderately less resistance to deformation as function of operating conditions. This is stark contrast to graph 2 which shows MMLS testing results simulated for slow moving taxiway environment, where a factor of four was established as the difference between poor and adequate performing mixes. The main difference between graph 1 and 2 is that in the case of Graph 2 the operating speed of the MMLS was slowed down to correspond with slow moving taxiway type operations and it clearly is possible to discern more rut prone binders for such operating conditions.

As can be seen the MMLS has value in comparing relative rut propensity by adjustment of testing protocol, e.g. speed and temperature, to discern between bitumen binders and possibly gradings.
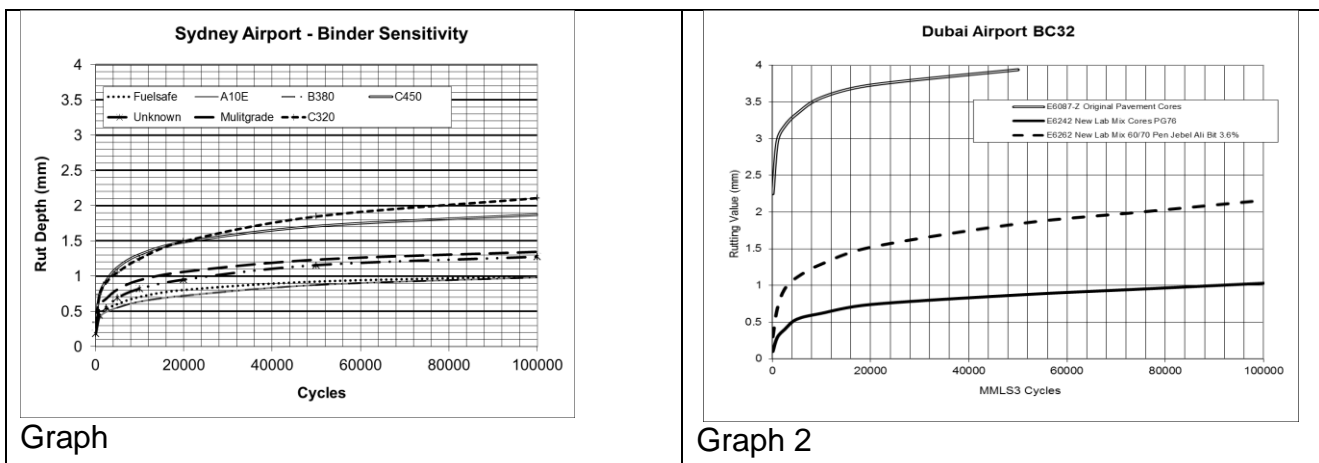

Figure 3 – MMLS3 test results

A more fundamental testing device which determines permanent strain accumulation in the steady state rut phase is the Repeated Load Test in Shear Test – the Superpave shear tester (SST) which was developed as part of the Strategic Highway Research Program to simulate the shear situation of HMA layers under repeated loading conditions [2][10][11]. The Repeated Simple Shear Test at Constant Height (RSST-CH), thus developed can perform a repeated load test in shear. A repeated haver-sine shear stress is applied to the 150mm test specimen and strain measured throughout the test.

2.3.3. Demonstration of rut determination via MMLS testing

Walvis Bay International Airport (WBIA) is on the west coast of Namibia, Africa. WBIA was recently upgraded by lengthening and widening the existing runway to meet ICAO 4F criteria. The runway geometry was allowed to have a very flat cross fall of 0.6% due to the arid environment. A minimum 50mm thick continuously graded HMA surfacing was specified, which ended up in some cases being 150mm thick (incorporating an underlying HMA "scratch-coat" in order to accommodate undulations and irregularities of the Dry-Bound Macadam (DBM) basecourse beneath [24]. The high ambient temperatures raised a concern that the thick asphalt would be rut prone and exacerbate the drainage and ponding problems caused by the flat cross fall allowed.

Various cores were sampled from WBIA and tested in the laboratory with the MMLS to determine the likely rut propensity linked to the anticipated traffic volume. The test temperature of $50^{o}C$ was chosen to be representative of the 0-50mm asphalt thickness in the Walvis Bay area. Cores were prepared for the MMLS testing in South Africa. Tests were also done at $45^{o}C$ on cores taken below the 50mm overlay. The bitumen content was 4.8% on average with a voids content of 4.5%.

The actual MMLS rutting in the testing ranged from 2.18mm to 2.31 mm for the 50mm surface asphalt. These MMLS tests were all done at the area representative surfacing temperature of $50^{o}C$, and at 100,000 load applications. These values are above the adjusted Baton Rouge 1.44 mm limit for airfield asphalt [12]. The 1.44mm rut depth was reached at just over 5 000 load applications in the worst case. These MMLS results need to be correctly interpreted in terms of the context of actual aircraft traffic on this specific airfield and other factors as will be shown.

The MMLS test done on 90mm thick cores at $50^{o}C$ had the same rut propensity trend and final values as for the 50mm and 60mm core depth tested. This tends to confirm that due to the temperature and mix stiffness variance in depth of the asphalt layers, the main contribution to rut development is confined to the top 50mm.

The MMLS test data was used to calculate asphalt rut depths for the runway and taxiway at WBIA. This airfield is trafficked by low volumes of aircraft. The design aircraft was the Boeing 747-400 with 20,000 load repetitions and the design period is 10 years before asphalt overlay. The realities of the design traffic actually attracted and expected within the trends in the world airline market led to an adjustment of a lower traffic scenario of 6,500 load repetitions. The expected runway field rut depths are summarised in Table 1 for thin and thick layers of asphalt for the realistic scenario of 6,500 load repetitions as well as the initial optimistic 20,000 load repetitions.

ICAO compliant cross fall of 1.5% on runways would allow for 20mm to 25mm rut (and undulations) development as measured under a 3m straight edge which will still allow water drainage and water ponding prevention. However, the rut depth to indicate functional failure due to water ponding at WBIA with its cross-fall of only 0.6% is estimated as limiting

rut development to less than 9mm. The calculated field rut depths are shown in Table 1 using the method discussed by Emery [23]. It clearly shows that the rut estimate is less than 9mm.

Table 1 - Summary of calculated field asphalt rut depths for WBIA runway (2009)

Airside Section	Calculated rut depth at design traffic (mm)			
	6,500 departures		20,000 departures	
	Thin asphalt (58mm thick)	Asphalt + thick scratch coat (116mm thick)	Thin asphalt (58mm thick)	Asphalt + thick scratch coat (116mm thick)
Runway	2.9	(2.9+1.7*)=4.6 mm	3.8	(3.8+2.2*)=6.0 mm
Taxiway	3.9	(3.9+2.2*)=6.1 mm	5.0	(5+3*)=8.0 mm
Functional limit	9.0 mm			

*The calculated Relative Stress Potential was calculated to adjust rutting measured in the MMLS to that which would be caused by the design aircraft at the appropriate depth of pavement [12]

The asphalt mix tested with the MMLS can thus be considered as meeting the low design traffic exposure applicable to the WBIA situation for the design period of 10 years even though it is marginally over the adjusted Baton Rouge criteria developed for high aircraft traffic volumes.

The draft Baton Rouge test protocol [12] suggests that age hardening due to known high ultraviolet exposure could be taken into consideration which further reduces potential rutting of the exposed asphalt mix. In general aging is accounted for by reducing the expected rutting as finally estimated from the MMLS rutting performance by as much as 30%.

2.3.4. Demonstration of rut determination via RSST-CH testing

Four asphalt cores from WBIA were tested by the RSST-CH at the CSIR asphalt laboratory in South Africa. Table 2 below shows a summary of the results obtained and associated calculations. The deformation response of the material in the RSST-CH is characterized using the mathematical representation of a creep curve shown in Figure 4. The slope of the creep curve in the secondary, or steady state creep phase, is a primary indicator of permanent deformation potential [2].

Values are provided for the total strain in the primary creep phase (a) and the slope (m), or strain rate, in the steady state creep phase. The permanent strain (expressed as percentage) was obtained from the RSST-CH test result graphs at the 5 000 repetitions.

Table 2 - Summary of results and associated calculations

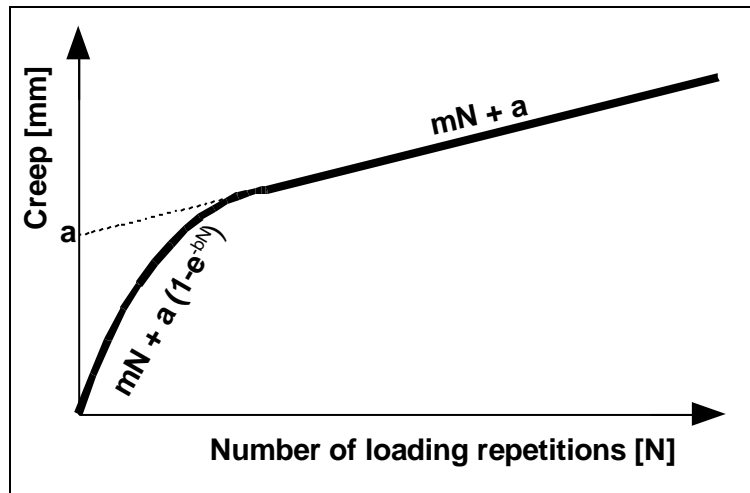| Sample	G (Complex Modulus) [MPa]	m [ε/cycle]	a [mm]	Percent strain at 5 000 load repetitions	Percent strain at 25 000 load repetitions	Deacon [10] approximation rut calculation
4642-A	7.25E+01	2.75E-06	3.38E-03	1.7	7.2	4.25mm
4642-B	5.17E+01	6.73E-06	9.23E-03	4.3	17.8	10.75mm
4642-C	5.02E+01	9.09E-06	7.32E-03	5.4	23.5	13.5mm
4642-D	5.83E+01	3.22E-06	1.05E-02	2.5	9.1	6.25 mm
			Average	3.5	14.4	8.75 mm

Figure 4 - Mathematical representation of creep curve

RSST-CH results of two HMA mixes on international airfields in Doha, New Doha International Airport (NDIA) [13] and in California, San Francisco International Airport (SFIA) [14] have been used as a direct benchmark or comparison. The WBIA cumulative traffic is only approximately 5% of the NDIA and SFIA traffic totals. On a proportional basis this means WBIA should be compared with the derived strain and deformation calculations for 1250 RSST-CH repetitions only. However, the test acceptance criteria previously developed of 5% permanent strain at 25,000 repetitions for NDIA and SFIA were determined at 1250, 3000 as well as 5000 repetitions for the WBIA RSST-CH permanent strain measurements. It was found that the asphalt mix at WBIA will be below 5% strain for 1250 and 3000 repetitions, but just marginally meet this adjusted test acceptance criteria for the 20 year design period at the 5000 RSST-CH repetitions. Deacon's approximation [10] was also used to calculate rut estimates using the 1250, 3000 and 5000 repetitions strain values. This approximation shows that the rutting in the WBIA asphalt mix would marginally be below 10mm at the end of the asphalt service period for the 5000 repetitions criteria, while for the 1250 and 3000 repetitions related strain values it will be well below 10mm.

Age hardening was not included in any of the calculations, but literature available clearly indicates that it will have beneficial resistance to the rut propensity of the WBIA asphalt mix. Walvis Bay is an area with known high ultra-violet exposure and therefore age hardening. The fact that this analysis of the CH-RSST results was done over a comparative 20 year period will definitely count for a further reduction of the rut estimations.

3. ENVIRONMENTAL ASPECTS

3.1. Background

Environmental related distress observed on airfields are mostly related to ageing and premature ageing aspects such as block cracking, map cracking, stripping and ravelling. Stripping is the one aspect which can go largely undetected in runway rehabilitation design [15] and can lead to other distress forms such as delamination of thin asphalt layers [16]. Cooley [1] notes that the current Marshal based HMA design methods used on airfield design as well as Superpave utilize tensile strength ratio (e.g. Modified Lottman tests) to provide a measure of moisture damage potential. The methods specified have slight differences in the criteria, but the underlying test method is the same. Specification values

only differ slightly (0.75 or 0.8). However stripping on airfield pavements still occurs despite application of these criteria.

There are various stripping theories and several laboratory tests which can be used to quantify the degree of propensity of asphalt to moisture damage. These theories generally indicate that moisture damage occurs in the presence of water and pore pressure, and is influenced by the properties of aggregates and bitumen. Pavement engineers are aware of the fact that moisture damage is influenced by the aggregate and bitumen properties in the presence of water. They look for practical techniques to identify the onset of moisture damage problems in a pavement and the methods by which the interference of water with the bitumen-aggregate bond can be prevented. None of the theories can singly explain the phenomenon of stripping in asphalt due to the variability in materials, environment, construction practices, and evaluation methods, since there are complex interactions among these different main factors [17][18].

Stripping can often remain undetected by normal visual and instrument surveys. This can lead to unsuitable rehabilitation designs, which leave weak stripped asphalt layers in place close to the surface. A helpful practical guide was suggested by Chen [19] which classifies air voids and their connectivity as observed in asphalt mixtures via core surface observance into three categories of permeability which are illustrated in Figure 5 as being:
- effective,
- semi-effective and
- impermeable

This can be used during runway rehabilitation design as a surrogate measure of stripping when visually assessing cores of existing hot-mix asphalt.

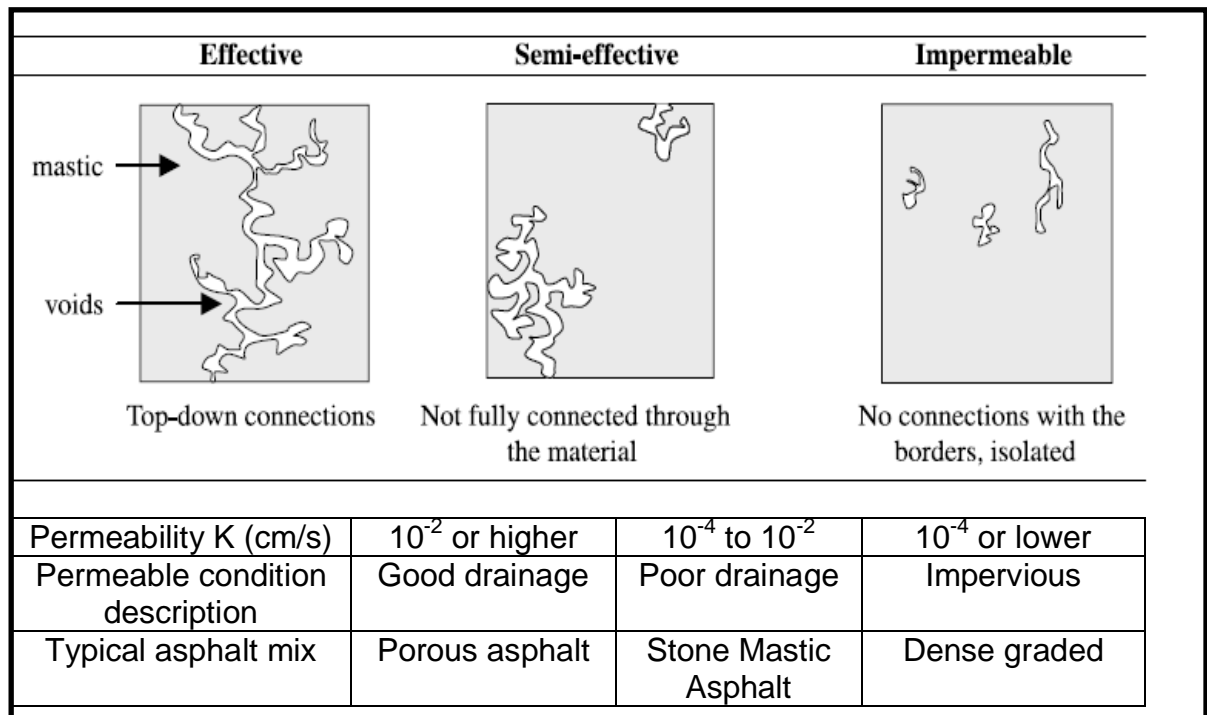|	Effective	Semi-effective	Impermeable
Permeability K (cm/s)	10^{-2} or higher	10^{-4} to 10^{-2}	10^{-4} or lower
Permeable condition description	Good drainage	Poor drainage	Impervious
Typical asphalt mix	Porous asphalt	Stone Mastic Asphalt	Dense graded

Figure 5 - Classification of air void connectivity in mixtures [19]

3.2. Stripping quantification on a South African airfield

The use of Chen's classification [19] during runway rehabilitation was demonstrated by means of visual assessment of cores from OR Tambo International Airport, Johannesburg.

This is in a moderate climate (Koppen climate classification Cwb: temperate dry winter. Annual rainfall 863mm). The main runway was rehabilitated and upgraded with an asphalt overlay in 2006. The visual assessment done at that time, as part of the rehabilitation design investigation process, showed that the surface distress could be described as 'moderate to severe' for the two outer or off-keel strips. The visual condition survey of the central keel area of the runway showed less pronounced signs of distress. Deformation was encountered within the central 8m wide strips left and right of the centreline. The most prevalent distress forms recorded were ravelling, longitudinal and block cracking on the off-keel areas. In some areas up to 95% of the surface was found to be ravelled, with a rated moderate to severe condition.

Coring indicated that the existing asphalt surfacing comprised a typical combined thickness of 100mm, mainly comprising an open graded friction course (OGF) as final wearing course and two lower layers comprising of various asphalt wearing course sections including stone mastic asphalt and open graded asphalt. In the keel section, the ageing and brittle OGF was replaced in 1997 by a continuously graded dense asphalt wearing course.

Available core information was re-analysed again in 2011 in detail to identify and further quantify the extent of the moisture damage that occurred in the OGA layer prior to the 2006 rehabilitation and overlay. Records of the position of the cores were accessed, layer thickness and a detailed description of the visual observations of the cores recorded were re-examined. The wording used to describe the core visual condition contained terms such as identification of ravelling, and description of stripping potential as linked to descriptions of air void observance (small, linked, intermittent, etc.) which could be used as a basis to convert it using the Chen [19] classification of Effective, Semi-effective and Impermeable shown in Figure 5. The core positions on the runway were also identified in the keel area (inner 22m) and those in the off-keel area (beyond 11m from centre line) and shoulder area. The resultant classification of the approximately 110 cores is shown in Table 3.

The results clearly show that 56% of the cores on all areas were impermeable. It showed that 44% of the cores of the total area showed either effective (31%) or semi-effective (13%) inter-connected voids and stripping potential. The off–keel area had classifications of effective and semi-effective voids and stripping, yet the off-keel area is normally not associated with traffic induced moisture movement. The conclusion could be made that the evidence of stripping on this runway was not strongly associated with traffic induced moisture movement.

Table 3 - Coring classification results on main runway of OR Tambo prior to overlay

Classification	Areas cored		
	Keel area %	Off-keel area %	Total area %
Effective stripping	11	20	31
Semi-effective stripping	6	7	13
Impermeable	37	19	56
Total	54	46	100

3.3. Durability quantification on Australian airfields

Emery [20] reported on the performance of hot-mix asphalt surfaces on Australian airfields. Part of the investigation was the analysis of the observations and test results of a national airfield asphalt coring programme. The Australian airfield hot-mix asphalts are dense graded to a common specification (given in that paper), with the addition of 1% lime to

reduce stripping. The climates ranged from dry to wet (Koppen BWh, BSh, Csa, Cfa, and Csb).

The coring programme found that stripping of airfield pavements was more widespread than previously perceived, with the obvious concern over durability. The bulk of the stripping assessment of the cores was done using a wet/dry tensile modulus assessment similar to the modified Lottman test; here the tensile elastic modulus ratio was used. Figure 6 shows one aspect of the stripping assessment in Australia showing that in-situ air voids does not have a great influence on the stripping potential.
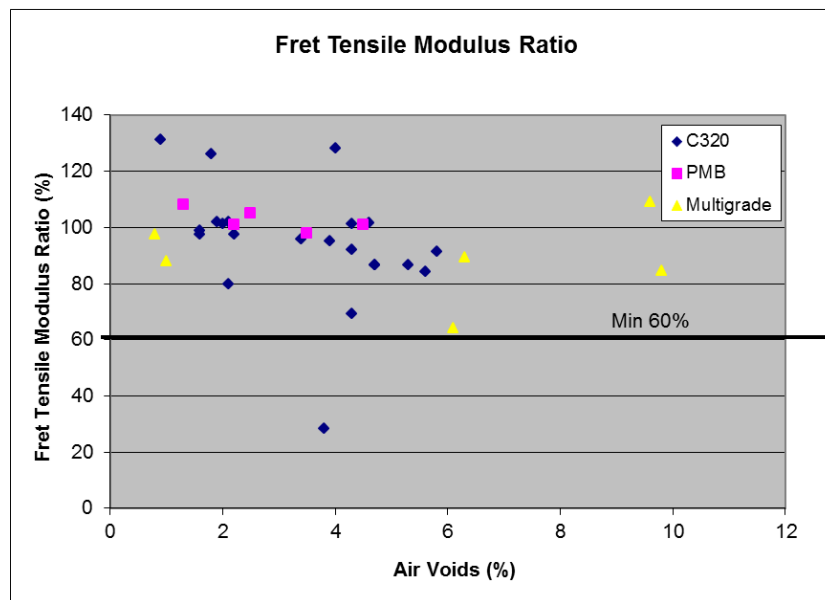

Figure 6 – Tensile Modulus Ratio

In addition, a small group of experienced practitioners assessed some cores visually. There were 102 cores with results, of which 101 were usable. These were assessed in terms of stripping as 44 in good condition, 42 in marginal condition, and 15 in failed condition.

A more detailed statistical analysis of the originally reported results has been done and found that:
- There was more stripping in taxiways than runways,
- Stripping could not be related to wheel tracks. This surprising result might be explained by the very low traffic on airfields. In road terms, the "within wheeltrack" trafficking on many airfields might be considered to be virtually the same as the "outside wheeltrack" trafficking. There will be exceptions for particularly busy sections of taxiways on busy airfields, but not for many airfields. This argument was also made regarding the traffic situation described by Cooley [1] when compared to a busy highway trafficked situation.
- Stripping is more prevalent in areas with higher annual rainfall.
- Stripped layers were thinner than either the 'not stripped' or marginally stripped layers.
- The degree of stripping did not vary by asphalt age. It was thought that because stripping often occurs quickly, it could already have occurred in any asphalt prone to it. Another interpretation is that factors other than age cause stripping.
- The effect of bitumen on stripping was confounded by both the effect of rainfall on stripping and the fact that different bitumens were being used in different

11

climates. The individual bitumens clearly perform differently in their resistance to stripping in wetter climates (mean annual rainfall > 1000 mm).

- o hot-mix asphalt made with unmodified bitumen (Class 320, similar to 40/50 pen) was more likely to be stripped,
- o hot-mix asphalt made with multi-grade bitumen (Class 1000/320) was less likely to be stripped,
- o hot-mix asphalt made with polymer-modified bitumen (A10E, in the 6% SBS class) was slightly more likely to be stripped. This was somewhat surprising, since polymer-modified bitumens are considered more resistant to stripping. Most of these cores were from Sydney Airport, and there are known difficulties there with stripping that may have influenced the results. However if polymer-modified bitumen was as good in resisting stripping as is supposed, a different result should have been seen.
- o In the drier areas (mean annual rainfall < 1000mm), hot-mix asphalt made with unmodified bitumen appears less likely to strip.

Stripping can be related to both physical and material features. Poor manufacture and construction can result in stripping, while the use of sub-standard materials in particular bitumen, may also promote stripping. In general terms good quality aggregates are used in Australia for airfield construction and therefore aggregates do not appear to contribute to stripping potential.

4. APPLICATION OF LESSONS LEARNT

4.1.Hot-mix asphalt (HMA) design philosophy

Airports provide an array of operational conditions and the magnitude of aircraft loading and speed, and traffic wander, varies significantly from slow moving taxiways to high speed runways. Until recently, the same HMA would be specified for all these areas. The bitumen volume would generally be high, filling to capacity the allowable volume of free voids within the asphalt. These hot-mix asphalts would provide for durable mixes reducing the risk of loose material and foreign object damage. This has worked well for areas of nil and low traffic.

Functionally, HMA for high speed runway segments which are rich in bitumen can, in some instances, compromise rut resistance. However the lower traffic volumes and appreciable aircraft wander generally minimise early life rutting deformation for on high speed runway segments, and the shear capacity of the asphalt is not as critical there as it is for areas of slow moving traffic such as on runway ends, taxiways and aprons where the aircraft is moving slowly. For slow speed applications, it has been observed that aircraft wander would iron out ruts formed by earlier trafficking. The asphalt would discreetly move about beneath the aircraft until such time that high strain together with fatigue distress would take hold.

This design philosophy is proving unacceptable in light of recent trends for increasing aircraft traffic volumes, wheel loads and tyre pressures, particularly for pavements located in climates with high field temperatures. In response, practitioners have introduced additional design philosophies including minimum refusal voids, stiffer or more resilient bitumens, changes to particle size distributions and the general optimisation of hot-mix asphalt materials in the design phase using tests such as the MMLS wheel tracking.

Structural improvements to HMA subjected to channelized slow moving traffic will generally maintain an adequate air void structure, but they lead to decreased bitumen film thickness from that normally expected for airfield hot-mix asphalts. There is now a compromise between rut resistance and HMA durability, which may be a concern particularly for runway applications if not properly engineered. It is therefore important to map the operational environment of a pavement segment in order to adequately design an optimal asphalt treatment, even if this area is small. The possibility now exists that different mixes are used on different areas of the runway, Although this philosophy has not been used on airfields in more recent times, it has been used for the design of asphalt materials in other applications for many years, including for car-parks, residential/urban environments and heavily trafficked highway's which all attract different compaction requirements, bitumen contents, and bitumen types.

4.2. Application opportunity for design philosophy

A recent upgrade of the Waterkloof Air Force Base (WAFB) near Pretoria offered the opportunity to balance the demands of trafficking, drainage and environmental exposure in the hot-mix asphalt designs produced. The SA Interim HMA Design Guide was used in the specifications, but a deliberate shift away from its implicit "roads mentality" was followed. In short it meant denser and bitumen richer mixes were provided on the non and low-trafficked areas to cater for the lack of further compaction and to provide for improved resistance to ageing and related environmental distress.

The WAFB design was a 22mm thin friction course, over 40mm HMA over 150mm bitumen-treated basecourse (BTB) on top of a 400mm cement treated subbase. Normal Marshall design was used, and specific attention given to ensure film thickness was at least 10 to 12 micron without negatively affecting indirect tensile test (ITS) values or Marshall stability flow criteria normally used. The BTB was designed with a 60/70 penetration bitumen and was placed in two layers to maximize compaction efficiency. Minimum densities of 95% or 97% of the theoretical maximum density minus the numerical value of the percentage design voids (Marshall or modified Marshall) was achieved with careful attention to compaction effort and technique. The bitumen content of 4.7% was deliberately allowed to be at least 0.5% higher than laboratory design optimum to ensure a thick film thickness even at this level and air voids were encouraged to be on the lower side of the specified 3% to 6%. The rationale followed was to enhance the impermeability of this BTB as part of the holistic risk management system for this site which is in a high risk dolomite area.

The 40 mm continuously graded hot-mix asphalt layer was constructed with 3% Sasobit compaction aid (a warm mix modifier) with 5.2% bitumen content. This was applied to ensure that higher and more uniform compaction could be achieved than the specified 93% minimum Marshall density. The air voids range was narrowed to 3% to 5% to encourage a lower than normal air void content. This was again to encourage an impervious asphalt surfacing layer in line with the holistic risk management described above. The compaction of the off-keel runway and shoulder areas were also monitored to ensure that even higher densities were reached with specifically air voids encouraged to approach the 3% limit rather than the 5% specified upper limit. It is known that continuously graded mixes tend to become less permeable if it goes higher than the standard 7% air void limit set for roads.

A proprietary ultra-thin friction course (UTFC) of 22 mm thickness with a maximum aggregate size of 7mm was applied over the runway width of 45m. This application improved wet weather skid resistance and macro texture. Detailed analysis of the layer

thickness via 25mm diameter cores indicated that the layer thickness achieved was in fact 25mm average. The grading and bitumen content were monitored, but were part of the product guarantee system provided with this UTFC product. Based on the experience gained on the BTB and HMA layers special attention was given to longitudinal joints. It was insisted that the cold edge be cut back with the roller blade to ensure straight edges and to ensure optimum compaction was achieved next to the cold joint.

4.3. Macro-texture measurements

ICAO gives guidance on macro texture and measured skid resistance. "The proof of the pudding is in the eating" and macro texture was measured on the new completed runway on the UTFC. In Figure 7 the sand patch measurements of the mean texture depth (MTD) is shown. As can be seen measurements at various offsets from the centreline gave MTD values above 1.1 mm. This is above the criteria set by ICAO and will be monitored over time to ensure maintenance triggers will be picked up to ensure the macro texture is well maintained as per ICAO requirements. Spot check measurements on the surfacing of the existing secondary runway with an aged continuously graded surfacing gave values around 0.8mm which is below the set criteria and clearly justifies the upgrade in future to also include a UTFC.
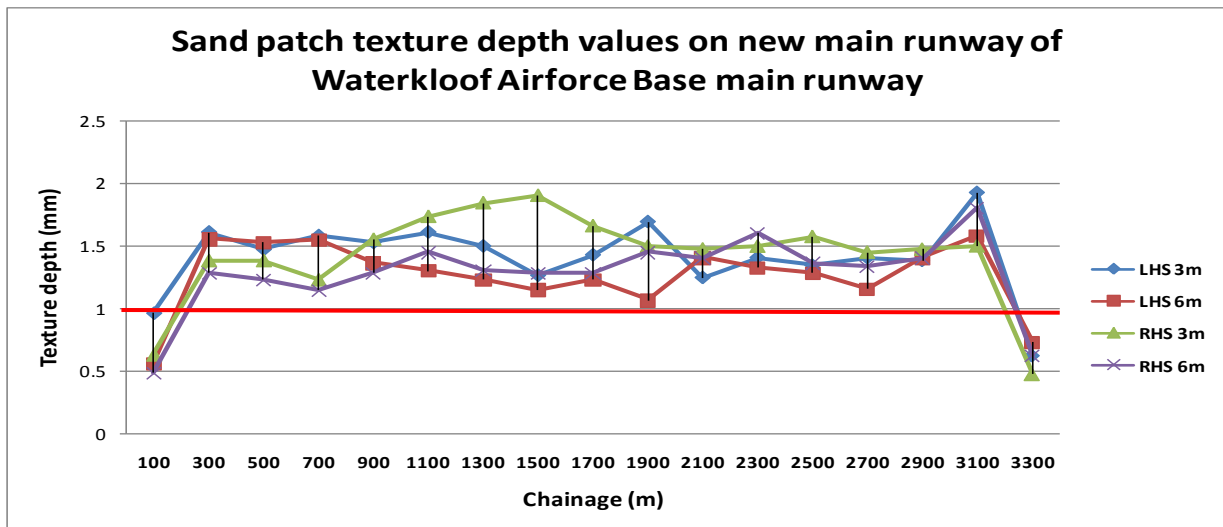

Figure 7 - Sand patch texture depth measurements on WAFB new main runway

4.4. Friction measurements

Friction measurements were taken at both 65kph as well as 95kph with the Griptester. Only the 95kph values are shown here as it better shows the impact of micro-texture and macro-texture at higher speeds on measured skid resistance [25]. The eastern portion of the secondary runway could also still be measured. In Figure 8 the Griptest numbers (GNs) are shown for both the new UTFC surfaced main runway and the old continuously graded secondary runway. It clearly shows that the UTFC surfacing on the main runway provides values above the ICAO design value criteria while the secondary runway surfacing is below that value. The secondary runway GN value is however still above the maintenance intervention and minimum values, though.
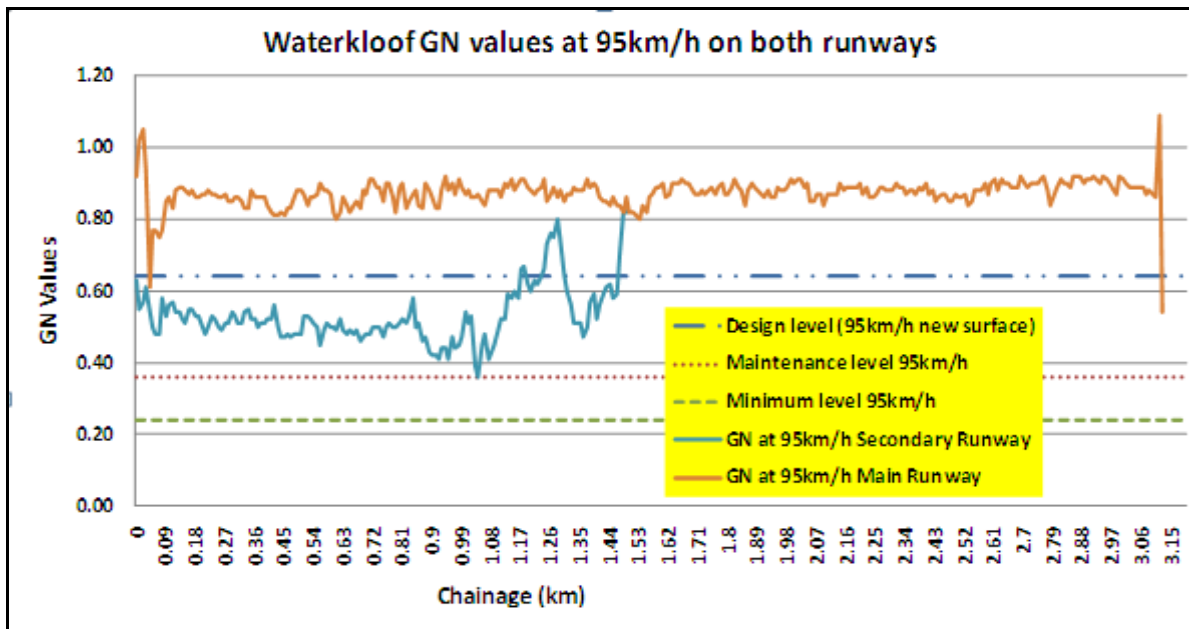
Figure 8 - Grip test numbers for main and secondary runways on WAFB

5. CONCLUSION

Runways carry less traffic than a typical highway, but typically much higher loads. The hot-mix asphalt requirements for runways are therefore different from those of roads, and include more focus on rut resistance and durability.

The Marshall method is still the dominant design method for airfield hot-mix asphalt although the latest generation widebody aircraft such as the Airbus A340 and Boeing 777 are showing up the limitations of using Marshall design, and require additional consideration of permanent deformation resistance. Laboratory hot-mix asphalt rut test devices are increasingly used, and scale device like the MMLS have given good results. The Superpave Repeated Simple Shear Test at Constant Height has also been used with success.

Durability is important because of the low traffic levels on some areas of an airfield. Most ageing distress, such as cracking and ravelling is easily seen at rehabilitation design stage, but stripping is the one aspect which can go largely undetected and can lead to other distress forms such as delamination of thin asphalt layers. On roads, stripping can often be associated with high traffic volumes and wet climates, but on airports stripping has been found in very low traffic areas and in dry climates. Analysis of cores with stripping damage from various airport pavements has found that air voids content, pavement structure, rainfall and pavement age have the highest influence, while repeated loading has a marginal effect.

Examples are given of the design of hot-mix asphalt for runways which balance the compromise between rut resistance and durability. The operational conditions and the magnitude of aircraft loading, speed and wander varies significantly from slow moving taxiways to high speed runways. Until recently, the same hot-mix asphalt would be specified for all these areas, but now the possibility exists that different mixes can be used on different areas of the airport and indeed within individual pavement segments to accommodate the various operational conditions and related durability requirements..

REFERENCES

1. Cooley LA, Ahlrich RC and James RS (2007) Implementation of Superpave mix design for airfield pavements. 2007 FAA Worldwide Airport technology Transfer Conference, Atlantic City, New Jersey, USA, April 2007.

2. Monismith, CL; Popescu, L; Harvey, J (2006) Rut Depth Estimation for Mechanistic-Empirical Design Using Simple Shear Test Results, Journal of the Association of Asphalt Paving Technologists, Volume 75, 2006.

3. Denneman E. (2008) Assessment of the permanent deformation characteristics of a standard Hot-Mix Asphalt; Level one analysis of laboratory study results. Technical memorandum CSIR/BE/IE/ER/2007/0014/B, March 2008

4. Long FM, Verhaeghe BMJA, Taute A and Visser AT (2001). Validation and refinement of the methods for prediction of permanent deformation – Interim guidelines for the design of HMA. Contract report CR – 2001/56, Prepared for SANRAL, HMA project management group, Pretoria.

5. Oliver JWH, Alderson AJ, Tredrea PF and Karim M (1995). Results of the laboratory program associated with the ALF Deformation Trial. Report APRG 12 - ARR 272, Australian Road Research Board, Victoria, Australia.

6. Smit, A. F., Hugo, F., Rand, D., and Powell, B. (2003) Model Mobile Load Simulator Testing at the National Center for Asphalt Technology Test Track, Transportation Research Record 1832, Transportation Research Board, National Research Council, Washington, D. C.

7. Molenaar, P, Hugo, F, Beukes, J and Catin, G (2004) Rehabilitation of Rwy 03L-21R at Johannesburg International Airport: Selection of Asphalt Mixes using MMLS3 Testing. 8th Conf. Asphalt Pavements Southern Africa, Sun City, South Africa

8. Kruger, J, Hartman, A and Loots, H (2004) Towards developing a test protocol for field permanent deformation performance evaluations using the MMLS3. Proc 8th Conf Asphalt Pavements Southern Africa, Sun City, South Africa

9. RPF (2008) Draft Protocol Guideline 1: Application of the MMLS3 for evaluating permanent deformation and moisture damage of asphalt. December 19, 2008 (First Draft Version 3 Rev1). Road Pavements Forum, South Africa.

10. Deacon JA, Leahy RB and Monismith CL (1995) Mix testing and analysis systems resulting from SHRP contract A003A. Proc. ASCE Transportation Congress, Vol 1, pp 691-711.

11. Harvey JT, Hoover TP, Coetzee NF and Monismith CL (2002) Rutting evaluation of asphalt pavements using full scale accelerated load and laboratory performance tests. Federal Aviation Administration Technology Transfer Conference, May 2002.

12. Hugo, F (2004) Overview of Applications of the Model Mobile Load Simulator Mk3 (MMLS3) by the International Users Group. Baton Rouge. March 2004

13. Leahy RB, Popescu L, Dedmon C, and Monismith CL (2008) Materials and Pavement Evaluation for the New Doha International Airport Using Mechanistic-Empirical Technology. Proc. 2008 Airfield and Highway Pavement Conference, American Society of Engineers, September 2008, pp. 301-321.

14. Monismith, CL., B.A. Vallerga, J.T. Harvey, , F. Long, and A. Jew, (2000) Asphalt Mix Studies – San Francisco International Airport," Proc. 26th International Air Transportation Conference, San Francisco, CA, June 2000, American Society of Civil Engineers, 2000

15. Olivier PA, Emery SJ, Horak E and Pretorius P., (2010) Holistic pavement management – Experiences with performance based pavement management in Australia and South Africa. Proceedings of the 2010 SARF/IRF conference, Somerset West, South Africa.

16. Horak E, Emery SJ, Maina JW and Walker B. (2009) Mechanistic Modelling of Potential Interlayer Slip at Base Sub-base level. Proc. 2nd Bearing Capacity Conference for Roads Railways and Airports, Champagne Illinois, USA.

17. Caro S, Masad E, Bhasin A and Little DN., (2008a) Moisture susceptibility of asphalt mixtures, Part 1: Mechanisms. International Journal of Pavement Engineering. Vol. 9, No 2, April 2008, pp 81-98. Taylor & Francis.

18. Caro S, Masad E, Bhasin A and Little DN., (2008b) Moisture susceptibility of asphalt mixtures, Part 2: Characterisation and Modelling. International Journal of Pavement Engineering. Vol. 9, No 2, April 2008, pp 99-114. Taylor & Francis.

19. Chen, JS, Lin, KY and Young, SY (2004) Effects of Crack Width and Permeability on Moisture-Induced Damage of Pavements. Journal Materials in Civil Engineering, ASCE, May/June, pp276-282.

20. Emery S., (2005) Asphalt on Australian Airports. Australian Asphalt Paving Association. Pavement Industry Conference, Surfers Paradise, Queensland, Australia.

21. Wang, H. and Al-Qadi, IL. (2010) Effect of High Aircraft Tire Pressure on Flexible Pavements: Near-Surface Damage. FAA Worldwide Airport Technology Transfer Conference. April 2010. Atlantic City, New Jersey, USA.

22. Cooley, LA., Ahlrich, RC, and James, RS (2010) Design of hot mix asphalt for airfield pavements using the Superpave gyratory compactor. FAA Worldwide Airport Technology Transfer Conference. April 2010. Atlantic City, New Jersey, USA.

23. Emery, S and Mihaljevic, I (2008) Accelerated Load Testing of Asphalt Mix Designs for Heavy Duty Pavements in Hot Climates. 23rd ARRB Conference, Adelaide 29 July-1 Aug, 2008.

24. Horak E, Emery S and Walker B (2011). Novel measures to attenuate aggressive salt migration and crystallization on a Namibian airport runway project. Paper accepted for presentation at 2011 Conference of Asphalt Pavements in Southern Africa (CAPSA), Champagne Castle, South Africa.

25. Benedetto, A. (2002) A decision support system for the safety of airport runways: the case of heavy rainstorms, Transportation Research Part A: Policy and Practice, 36, 665-682.