A CASE STUDY OF PERMEABILITY DETERMINATION AT LONGITUDINAL JOINTS ON AN AIRPORT ASPHALT PAVEMENT

E HORAK[1], WJvdM STEYN[2] and ABM HORAK[3]

[1] Kubu Consultancy (Pty) Ltd, 68 Molopo Ave, Doringkloof, Centurion, Pretoria, 0157
Phone: +27 83 2281694; Fax: +27 12 667 4682; E-mail: emileh@global.co.za
[2] University of Pretoria, Lynnwood Road, Hatfield, South Africa, 0002
Phone: +27 82 219 9704; E-mail: wynand.steyn@up.ac.za
[3] Final year Civil Engineering Student, Department of Civil Engineering, University of Pretoria, Lynnwood Road, Hatfield, South Africa, 0002
Phone: +27 82 5757392; Fax: +27 12 667 4682; E-mail: aneh@global.co.za

ABSTRACT

A major airport in Namibia was recently rehabilitated by first milling off a delaminated asphalt layer and inlay with a continuously graded asphalt layer and placing an ultra-thin proprietary surface friction course on top. The asphalt inlay work included a cross fall correction with asphalt wedge build up on the centre line tapering off to the off keel area of the runway. Construction was interrupted for 6 months due to unnaturally high rainfall. This interruption came after the asphalt inlay work was completed and a short section of the surface friction course on the main runway was placed. At resumption of work and prior to completion of the proprietary surface friction course white deposits were observed on the surface. The white deposit tended to concentrate along the longitudinal joints of the previously constructed asphalt. The origin of the white deposit was investigated and could be linked to salt leaching from aggregates in the underlying layers. The delaminated asphalt repair has led to a heightened awareness of durability problems. Previous problems on this airport were linked to stripping, crescent cracking and delamination of the previous asphalt overlay. The subsequent field and laboratory work enabled a clear linkage with the construction quality control of longitudinal joints in general. Densities, air voids and binder content could be checked against specification tolerances via normal quality control testing. Air and water permeability testing were done as well as wet and dry modified Lottmann tests. Cores were also inspected visually to give indicative values of permeability. This investigation served to emphasise the lack of focus of current specifications used on quality control of longitudinal joint construction and their longer term durability impact. The investigation provided the basis for improved quality control and specifications for longitudinal joints of asphalt paving in future.

1 INTRODUCTION

Hosea Kutako International Airport (HKIA) is the main gateway airport in Namibia situated 40 km outside the capital, Windhoek. HKIA was rehabilitated in 2010 to 2011 to solve a stripping and delamination problem of the asphalt surfaces occurring on the main runway,

Abstracts of the 31st Southern African Transport Conference (SATC 2012) 9-12 July 2012
Proceedings ISBN Number: 978-1-920017-53-8 Pretoria, South Africa
Produced by: Document Transformation Technologies cc Conference organised by: Conference Planners

taxiways and apron areas. In Figure 1 the general layout of HKIA is shown. The failures manifested as de-lamination of the 50mm asphalt overlay that was done in 1999/2000. The delaminated asphalt showed classical crescent shaped cracks developing associated with braking and turning manoeuvres of aircrafts. Removal of the loose, stripped and cracked asphalt surface layer after crack opening and then patching with cold mix proved to be fruitless, even with a dedicated rapid response team on site. After a carpet of de-bonded asphalt was blown off during a take-off of an Airbus 340, the danger regarding Foreign Object Digestion (FOD) became very real (10). This accelerated the rehabilitation project of N$ 110 million (Namibian Dollar, approximately US$15 million) awarded to an asphalt specialist contractor late 2009.

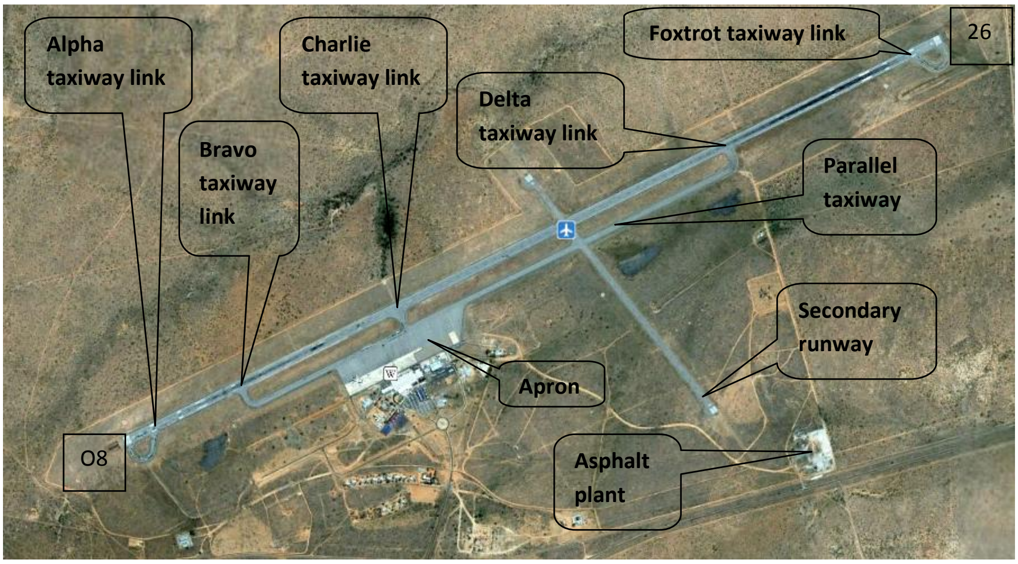


Figure 1. Hosea Kutako International Airport (Google earth image)

The main work activity of the contractor was restricted to night work, approximately 10 pm to 4 am, to accommodate continued operations on this gateway airport during the rehabilitation contract period. The 50mm stripped asphalt surfacing (continuously graded asphalt) was milled off to an average depth of 60mm, where after inlays of 60mm were done with a continuously graded hot mix asphalt (AC) with 2% SBS modifier.

The cross fall of the main runway was also corrected by building a wedge on the centre-line higher than before which tapered down to the sides of the keel area improving the cross fall from approximately 1% to approximately 1.2%. The build up in the centre keel area had to be done in lifts of 50mm to 70mm. Each section worked on per night was milled out over the full width of the runway and filled in to ensure a straight transverse joint with a tapered transverse edge according to ICAO safety requirements (7, 11, 12 &13).

The surface friction course, a proprietary Ultra-Thin Friction Course (UTFC), called ULM, was applied over 30m width of the main runway to cover the milled and inlaid new asphalt layers. The ULM has got a proprietary tack coat consisting of an emulsion with a modifier, sprayed right in front of the hot mix ULM by the paving machine (Horak et al, 2010). The ULM construction started from the low side of the main runway and as much as approximately 1600m was completed when work re-started in May 2011. Work on HKIA had to stop end of October 2010 due to unnaturally high rainfall for this region. The rainfall figures over this period were recorded was determined to be more than four times the long term average annual rainfall for this area. The contractor re-started work mid-May 2011 on the ULM and other asphalt layer work on the main runway after this prolonged period of no construction.

The observations of a white deposit on the completed asphalt work prior to re-commencement helped to drive number of valuable truths home. The focussed testing and investigation in the field and laboratories helped to emphasise the short comings in the current specification and associated construction practice. These aspects are briefly described in the sections to follow.

2 THE LINK BETWEEN LONGITUDINAL JOINTS AND DURABILITY

The rehabilitation on this airport was to repair the durability related delamination and to prevent this from re-occurring (Horak et al, 2009b). The aggregate used on this project is known to be stripping prone and for that reason a proprietary anti-stripping agent as well as 1% lime was added to the continuously graded hot mix asphalt (HMA). Observations and testing done on other airports and roads have created awareness that durability related distress is a major form of environmentally associated distress, even in a semi-arid region like Windhoek, in Namibia. Previous investigations on airports and roads found that stripping can inadvertently be hidden from sight even during normal detailed investigations. It was also found that stripping is often not on areas of high traffic on airport airside surfaces, but rather the non-trafficked areas (1, 2, 6, 8, 14, 21)

Current specifications used in Southern Africa tend to show limited focus on durability detection during construction and tend to focus more on rut and fatigue resistance control (18, 19, 20). This is a typical roads design and construction focus and the associated specifications therefore tend to be applied without any conversion to airport asphalt work as well (5 & 23). There is also a tendency for standard quality control testing and their application to focus on density and voids in the mix during construction. These important factors can only be defined as indirect indicators of durability and should ideally be supplemented with more specific tests.

Past experience and observations showed that by applying the Pareto principle to contributing factors to stripping and durability related distress, the longitudinal joint construction deficiencies in asphalt layer construction can be identified as a major contributor. Stripping, ravelling and de-lamination distress tend to be associated with longitudinal joints even as probable origin of such distress (3). Such longitudinal joints show cracking and opening up earlier than the rest of the paved mat, leading to water intrusion and therefore enhance or accelerate stripping and ravelling (8).

The current specifications allow for testing asphalt on the longitudinal joint with admission that up to 2% lower density is allowed for on cores taken close to the joint, but such results are added to the rest of the larger test sample from the mat. Therefore such lower results can easily be treated as an outlier and via re-coring and re-testing may allow for a mat paved to be approved while the joints may still be suspect.

In Figure 2 the density results from cores in the mat area were separated from the core densities obtained at the joint areas as sampled over the contract period at various portions of the airside asphalt laving work. Only the data sets which were taken at the same place and time were selected from the larger data set. The trend line is added to aid the direct comparison only as the seasonal aspect

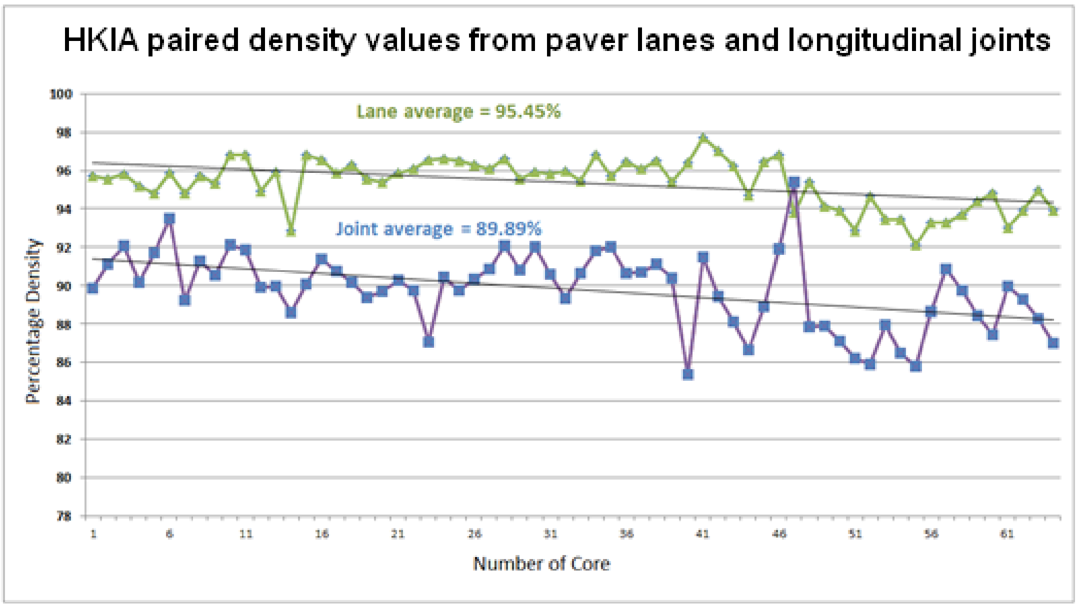


Figure 2. Paired densities from paver lane and joints on HKIA

Figure 2 confirms that the density achieved in the paver lane is on average 95.45% and meeting specifications of 93% minimum. However, the densities obtained at the joints shows that the average is 89.89%. In this case therefore the difference between the lane densities and the joint densities on average is 5.47%. In effect the difference should be measured against the specified 92% minimum. It still means that it is more than the 2% difference which the COLTO specification allows for. This clear differentiation is only possible here in retrospect because the joint densities were treated as a separate data set sample and not included in the analysis of the paved lane mat, as per the quality control plan used. It is clear that the generally high density values would help to pull up the lower values from the joints and still make the specification set with ease.

Investigations showed that the actual joint construction methodology is often left in the hands of the contractor. In practice it often happens that in spite of specifications requiring the cold side of the joint to be cut back at least double the thickness of the asphalt layer thickness, that this often does not happen. Except if awareness is shown by the project management team and strict application of the specification is applied. Coring at the joint area under the quality control plan used is often also not specific enough and not close enough to the joint to identify the immediate area (less than 150mm from the joint) to clearly pick up the observed potential problems at the joint.

In spite of correct procedure and treatment of the joint, the 3m straight edge test across the joint also has a tolerance built in. This tolerance often allows an inevitable slight depression to form on the joint which on runway construction, in particular, allows for “valleys” to form longitudinally. Such slight depressions can potentially lead to water ponding with associated durability distress facilitation, as well as, obvious safety problems due to the lower longitudinal gradients found on airports (12).

The asphalt work on HKIA initially suffered from the same mat quality focus and lesser attention or focus on the longitudinal joints for the contextual reasons mentioned above. Pressure applied from the independent engineer and a change in management team midway through the construction helped to place the correct emphasis on the joint construction and to use the “un-focussed” specifications to their best effect to improve the joint construction quality. On top of this, the fact that construction of the inlays had to be restricted to rather thin lifts of 50mm to 70mm, further contributed to some of the perceived joint construction problems.

Work was done over the winter period when night temperatures often ranging below 4 ºC. The temperature trend was closely monitored overnight and predicted temperatures from weather services were used with 4 ºC being used as cut-off for work. The fact that the asphalt plant was on site helped to manage the temperature drop considerably with short distances to transport and thereby limiting overheating or rapid drops in mixed HMA temperatures due to long standing times. In spite of such precautions low ambient temperatures contributed to mat edges cooling down more rapidly than the rest of the mat and contributed to compaction difficulty with the edges. In retrospect temperature control was not specific enough to distinguish mat edge temperatures from the rest of the body of the mat. The remoteness of the site prevented the use of modern technology like infra-red cameras.

Retrospective coring and testing on work already approved under initial project management identified joints that were not cut back and had to be redone. In other areas suspect joints had to be contractually accepted conditionally. The dilemma of joint repair when the rest of the mat is acceptable by milling out, say 1m across the joint, and then repairing the joint area clearly posed a problem. The fear was that this would create two joints with potentially the same problem and in effect doubling the potential problem. Construction in narrow widths is also known to be fraught with problems. Therefore, it was decided on some form of joint enrichment via a modified fine slurry rejuvenator applied over the 300mm joint area.

The fact that most of the asphalt would be covered with a rich tack coat associated with the UTFC paving technology provided some risk management being applied on top of the other mitigating measures. The UTFC or ULM is known to also help to level out slight undulations as would be expected at the longitudinal joints. Joints in successive layers were also deliberately staggered for that reason. In spite of these measures and corrective action the phenomenon of the white deposits served to emphasise the potential mismatch of the standard specifications if applied to joint construction quality control.

3 INVERSTIGATION INTO THE WHITE DEPOSITS

3.1 Observations

Prior to re-commencement mid-May 2011, after the uncharacteristic heavy rain season, white deposits were observed on various areas of the constructed surfaces of the runway, taxiway and apron on HKIA. The extent and degree of the white deposits peaked approximately one to two weeks after the continuous rainfall stopped in early May 2011. A panel inspection with representatives from all parties was carried out over the whole airside paved area affected with the observed white deposits.

The observations were made are illustrated in the photos in Figure 3 and described as follows:

- The white deposit appears to be associated mostly with the previously laid continuously graded asphalt (AC) joints.

- White deposits showed up randomly in the freshly inlaid AC mat areas but lesser in degree and extent. The longitudinal joints tended to have a higher concentration in degree and extent, but random variation along the length of the joint.

- The white spots also appeared on the shoulder areas treated with a fine slurry type rejuvenator as well as on the ULM areas already laid.

- In the ULM case the white deposits appeared where the AC joints underneath are located and not at the joints of the ULM. Limited, if any, white spots were observed along the ULM joints.

- The white deposit tended to accumulate in the joint longitudinally on the “hot side” of the joints, thus previously constructed. The hot side of the longitudinal joints tended to be visually more open textured than the “cold side” of the joint. The cold side of the joint also tended to be slightly higher than the hot side of the joint due to the construction process. The white deposit therefore tended to accumulate on the lower side of the joint (hot side of the joints).

- The white spots appeared intermittently along the longitudinal joints. It was quickly surmised that the white deposit probably shows up permeability variation and indirectly the known density and air void variance of the joint.

- The white spots in the longitudinal joints of the AC on the main runway were appearing more on the off keel areas and shoulders. Limited or even no white deposits were observed on the centre line and crown of the cross fall.

- It is known that the longitudinal gradient of the main runway slopes down from the 08 end to the lowest end at the 26 end in an undulating fashion. It was clear that the white spots were more visible and higher in observations density at the known low longitudinal points leading up to Bravo, Charlie, secondary runway and Foxtrot intersections. High points such as after the secondary runway intersection, where additional structural strengthening also took place by means of deeper mill and replace, showed limited if any white deposit.

- On some of these downhill sections white deposits appeared in the paved lane mat and appeared to be parallel to the new AC joints at an offset of approximately 1m. The latter deposit line appeared to be the older or original underlying asphalt joint below.

- The white deposits also appeared on the secondary runway treated with the proprietary fine slurry rejuvenator. The white deposit also seemed to accumulate around the hot modified binder used in crack filling applied previously.

- The white spots appeared on the apron joints as well as the taxiway longitudinal joints. In such cases the joints were treated with a 200mm to 300mm wide fine slurry rejuvenator application due to prior concerns about lower density and higher voids at the joints. In spite of this attempt to reduce the surface permeability the white deposits still tended to appear on these treated joint areas.

- The white deposit was virtually tasteless. Initially it was presumed the white deposit may be the leaching out of the dolomitic filler or lime addition used in the AC, ULM as well as the proprietary fine slurry rejuvenator mixes.

- The asphalt plant was also visited and the stone dust and lime storage and addition to the mixes observed. Some of the rock dust paper bags were not covered and were exposed to the weather. It was speculated that this could have led to “balling of the stone dust” being fed into the mix with the blower on site. Such a scenario would have led to uncovered lime or dolomite in the various mixes. This would have been explored in more detail if the origin of the white deposit could not be traced via other means.

- The aggregate stock piles were inspected visually and found to be relatively dust free. A small area of salt deposit was observed next to the heaps clearly linked with some leaching taking place. The white deposits had a clear salty taste.

	Secondary runway at intersection with main runway. White deposits appear around crack seals		White deposit at joint at 08 end (higher end). This area’s joints were previously regarded as below specification on density and voids.
	Longitudinal joints on apron showing variable white deposits in the joint vicinity and random evidence in the paving lanes. Joints were enriched with a fine slurry.		White deposits coming through previously completed ULM not at ULM longitudinal joint, but the AC joint underneath on the 26 end

Figure 3. Photo collage of white deposits on HKIA

3.2 White deposit testing

The white deposit sampled on the asphalt surfacing and samples from the lime and dolomite dust on site were sent to the Council for Geoscience in South Africa who did X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) with Energy Dispersive Micro-analysis System (EDS) to determine composition of the white deposits. The results of the XRD analysis are as shown in Table 1, to follow. It clearly shows that the dolomite and the lime are distinctly different from the white deposit sampled. There is no portlandite or dolomite in the white deposit composition indicating that the white deposit is therefore not due to leaching out of the lime or dolomite in the new AC, ULM or proprietary fine slurry rejuvenator.

The SEM study was aimed to verify the mineral composition determined by XRD and search and characterize any other material that might be present in concentrations below the detection limits of the XRD technique. Backscattered Electron (BSE) images from sample *White spots* were done and analysed. Element distribution maps from a grain that represent a rock aggregate particle with partial asphalt coating were recorded. All minerals identified by XRD were observed as well as some trace minerals i.e. some mullite and Fe-oxides-hydroxides. The analysis of asphalt surfaces showed elevated counts on the sulphur peak compared to the spectra of the other phases. However individual grains with alunite or ettringite composition could not be detected, possibly due to the small sample size.

Table 1. XRD composition analysis

Composition	**Dolomite dust**	**Lime**	**White spots**
Quartz	2.8	trace	3.49
Dolomite	96.7		
Calcite	trace	0.97	
Portlandite		98.68	
Plagioclase (albite)	trace		11.64
K-feldspar (microcline +sanidine)			35.79
Nepheline			11.75
Sodalite			3.17
Analcime			4.04
Natrolite			28.91
Alunite			1.2

The composition of the white deposit is clearly a salt (16). This correlates with the salt crystallization observed at the aggregate stockpile. It is also known that several of the rock types in Namibia have a high salt content. The aggregate used in the overlays were tested for salt previously and found to be salt free. This implies that the salt from the older asphalt layers or even subbase and lower selected layers may in fact be the source of the leached out or crystalized salt deposit observed. It only appeared after the excessive and persistently high (abnormal) rainfall over the period October 2010 to the beginning of May 2011. The most plausible explanation is that rainwater infiltrated the lower strata and asphalt layers through the permeable AC layers, probably at the suspect longitudinal joints. It is also plausible that water infiltrated the lowers strata via the surrounding gravel shoulders and flowed down the longitudinal gradient (10).

The older AC below the newly inlaid asphalt is clearly permeable and the new AC is definitely variable permeable at the longitudinal joints. The dissolved salt has its origin in the aggregate particularly of the older asphalt and aggregate base and subbase layers. It is plausible that the dissolved salts were transported by the water flow in the paved strata and could be driven by a significant water head. The longitudinal gradient linked water head was observed during the delamination investigation. Free water was also observed flowing from the subsurface drainage system directly after the rainy period described above. The white deposits do clearly not constitute a structural problem, but rather a potential durability problem linked to possible stripping and de-bonding. No evidence of such deterioration can currently be seen, but the high moisture on the surface and apparently in the asphalt layers have accentuated the weak points where such durability problems normally tend to start, namely at the longitudinal construction joints and other areas of higher permeability.

3.3 Coring investigation

Permeability is clearly an important aspect of water flow in the asphalt mixture which can be measured directly or indirectly. There are problems in reading permeability directly on a pavement. The Marvil falling head apparatus is often used in South Africa to determine in situ indications of permeability, but this apparatus is prone to instrument handling and installation problems (19). The unevenness described at the joints would have created testing errors and the instrument was not available in Namibia during the investigation. An upper limit of <1.0 l/hour is usually applied to surfacings (18). Unpublished work by the Provincial Administration of the Western Cape (PAWC) found that for permeability higher than 1.2-2.0 litres per hour, the number of interconnected voids in the asphalt reaches a level which may be detrimental to the material due to ingress of water and oxidation of the binder.

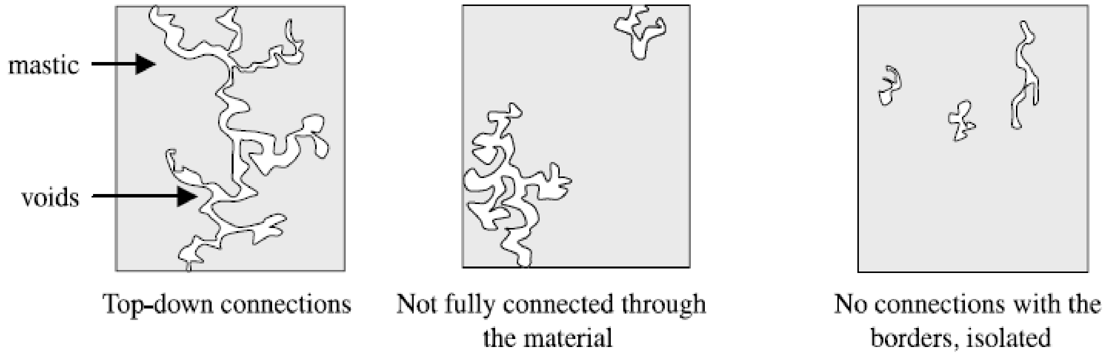
It was therefore decided to do coring at longitudinal joints with white deposits and at apparent sound areas where no white deposits were observed. Two cores in close proximity were taken on such identified spots. Cores away from joints on areas without white deposits were also taken as a control testing.

The cores were prepared for density and void determination by the site laboratory. The cores were properly identified in terms of joint number and position before it was visually rated in terms of permeability as per the description of Chen et al (3). A description of the visual rating system as per Chen et all (3) is modified and shown in Table 2. This visual rating was done by the project management team, the laboratory and the contractor separately and the results were combined.

The cores were sent to a specialist asphalt laboratory in South Africa to also do water and air permeability measurements. The sets of cores were used to do modified Lottman tests (AASHTO T 283) determining wet and dry Indirect Tensile Strength (ITS) for the hot and cold joint sides for areas with and without white deposits. Most of the cores were obtained from all areas on the airside, as indicated in Table 2.

Table 2: Classification of air void connectivity in mixtures (adapted from Chen et al (3))

	PERMEABLE	SEMI-PERMEABLE	IMPERMEABLE



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

In Table 3, to follow, the cores as sampled listed as described in terms of position, whether there are white spots visible of whether it was black or sound. The consensus visual rating using the Chen et al (2004) approach as described above in Table 2 was highlighted using the relative rating system of Red, Amber or Green (RAG) to help with the analysis. The RAG benchmark key for the other values are as indicated below and the ranges are linked with the specified values or logical intervals to help visualize the results (18). These tolerances or ranges of values were also based on the normal specifications used.

3.4 Benchmarking Analysis

Density and voids are normally associated with normal quality control and it was interesting to check how well they correlate or benchmark with actual permeability and the visual classification. The RAG benchmarking was used in a relative manner to do the check. Density values evaluated with the RAG system seem to correlate reasonably with the visual evaluation benchmark methodology. It clearly shows up the definite low density values as effectively permeable or the higher than specified density values with impermeable classification. It is however when densities are barely meeting specification tolerances that the predictor or benchmarking correlation with actual air and water permeability tend to be low. This is a concern as normal statistical evaluation, linked to partial payment, can therefore allow densities to be accepted which are in the amber or warning classification or marginal and yet their permeability values may in fact be in the red or permeable class.

Table 3. *Results from tests and evaluation of cores on HKIA liked with white deposits*

CORE #	LOCATION	White(W) or Black (B)	Chen et al visual rating	Voids (%)	Density (%)	Air permeab. ($x10^{-8}/cm^2$)	water permeability (l/h/m2)	Lottman (TSR)
D1A	APRON	W	Permeable		90.1		458	
D1B	APRON	W	Permeable		89.6	6.08	450	
D1C	APRON	B	Impermeable		95.9	0.03	0.1	
D1D	APRON	B	Impermeable		95.8	0.03	0.1	
D1E	APRON	W	Permeable	8.2	92.6	2.07		0.72
D1F	APRON	W	Permeable	7.5	93.1	1.85		
D2A	APRON	W	Permeable		93.5	1.09	375	
D2B	APRON	W	Permeable		93.4	0.82	330	
D2C	APRON	W	Permeable	5.9	94.4	0.23		
D2D	APRON	W	Permeable	5.5	94.3	0.18		0.43
D2E	APRON	B	Semi-permeable	5	95.3	0.03		
D2F	APRON	B	Impermeable		95.6	0.03		0.61
D2G	APRON	B	Impermeable	4.2	95.8	0.03		0.82
D2H	APRON	B	Semi-permeable	4.3	95.8	0.03		
D2J	APRON	W	Permeable		91.8	5.84	495	
D3A	RWY 08-26	W	Permeable	9.8	91.2	5.93		
D3B	RWY 08-27	W	Permeable	9.9	91.1	6.35		0.42
D3C	RWY 08-28	B	Impermeable		96.2	0.03	0.1	
D3D	RWY 08-29	B	Impermeable		96	0.03	0.1	
D4A	APRON	W	Permeable	7	90.8	0.25		
D4B	APRON	W	Permeable	7.9	92.9	0.95		0.81
D4C	APRON	B	Semi-permeable	4.8	95.3	0.03		
D4D	APRON	B	Semi-permeable	5.3	98.2	0.04		0.66
D4J	APRON	W	Permeable		90.3	22.39	2235	
D5A	TAXIWAY	B	Permeable	10.2	90.8	1.04		
D5B	TAXIWAY	W	Permeable	14.4	85.9	31.2		
D6A	TAXIWAY	B	Permeable	13.9	87.2	21.66		
D6B	TAXIWAY	W	Permeable	14.1	88.1	43.32		0.72
		Key	Impermeable	x < 4.5	x < 95	x < 0.04	x < 0.5	x > 0.8
			Semi-permeable	4.5 < x < 6	95 > x > 93	0.04<x< 5	0.5 < x <100	0.8< x < 0.70
			Permeable	x > 6	x< 93	X > 5	x > 100	x < 0.7

Air voids in the AC does seem to correlate or benchmark well with the visual classification. It is admitted that the ranges for the RAG classification may change for HMA on other projects or even between keel and off-keel areas. It means that more data is needed to help refine this RAG classification for voids coupled to the visual classification, but it is clear that the combination of voids and visual classification is already a better evaluation tool than merely voids alone. The voids do not correlate as well as expected with actual air and water permeability values. It appears the reason for this can be in the connectedness of the voids which is better described by the visual evaluation than merely expressed as a void percentage. The suggested range tolerance values described above is based more on a combination of subjective feel and the specification used and this uncertainty may also contribute to this lower correlation. However, it is clear that both density and voids used in combination with the visual classification can improve the current focus on the former two quality control criteria to provide a better indicator of durability aspects of the constructed HMA layer with no additional specialised testing.

Ultimately water permeability and air permeability values are more directly measured indicators of durability aspects of the HMA (1,2,5, 6 & 14) Therefore, in benchmark comparison of the visual classification with the actual permeability values measured, it clearly indicated that the extremes of visual classification as permeable or impermeable tend to correlate well, but the semi-permeable situation has a lesser correlation. It is noted that the range of water permeability values are limited and hampers the actual benchmark effectiveness, but the visual classification does seem to rather identify potential permeability problems as a severe or red category while it may in effect only be semi-permeable according to the air permeability values.

It therefore confirms that a visual classification can in effect be used as a more conservative indicator of potential permeability problems which can be followed up with laboratory tests for such flagged areas with water and air permeability tests. The actual air and water permeability values may also suffer from bias as the majority of the cores, even on sound spots (black) may not have shown up with white deposits purely due to local micro geometry issues which dictated the leaching and deposition of the white deposit.

The Tensile Stress Ratio (TSR) results based on the modified Lottmann tests are often identified as one of the more direct tests for stripping potential (6). The TSR results obtained and RAG benchmarked show a lesser correlation with the visual classification of permeability as well as with the RAG classification of actual water and air permeability values. Caution must be taken when assigning value to the TSR results, as its variability is too high, particularly from field samples. Admittedly TSR testing is destructive and based on cores only in close proximity with a relatively small sample used in this limited investigation. Therefore TSR as a higher level test cannot be ruled out as having value.

The data provided in Table 3 was analysed in more detail and depicted in the graphs to follow. The validity of correlations between various data sets provided was determined. In Figures 4 to 7 the scatter diagrams for a number of factors are shown. These diagrams are interpreted by determining the R^2 or coefficient of determination for each set of data. A high R^2 value indicates a very good linear correlation between the two parameters with possible values ranging between 0 and 1.

Figure 4 shows that voids in the mix versus density obtained from cores have a good correlation with R^2, or coefficient of determination, of 0.89 for the data set. The high R^2 value indicates that there is a very good linear correlation between the voids and the density. This conclusion is logical as lower density is mostly due to higher voids in the mix.

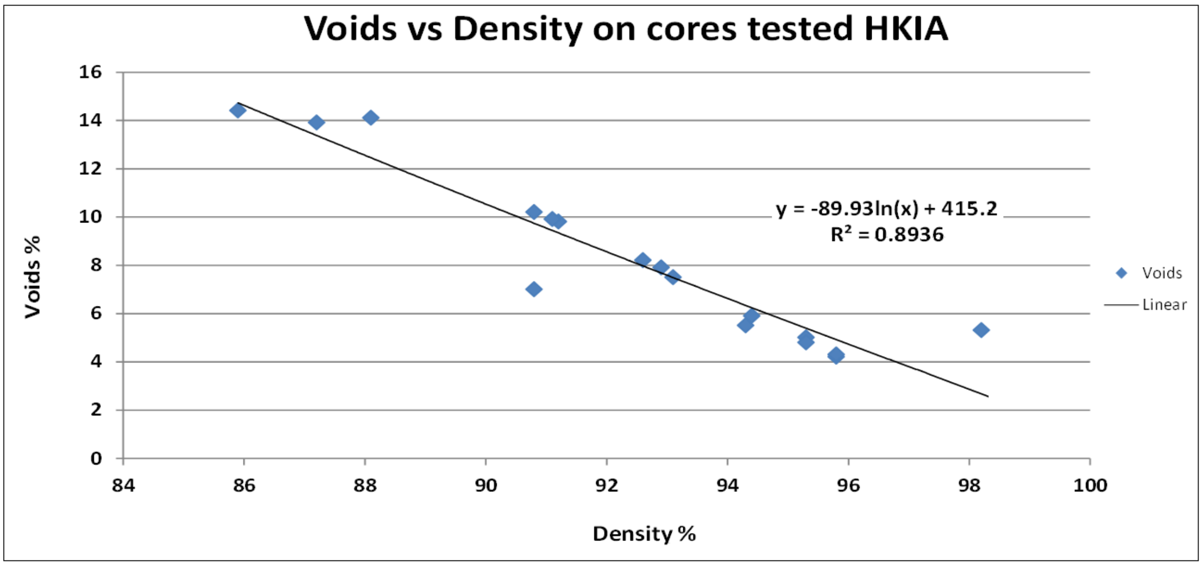


Figure 4. Correlation between voids in the mix and density determined from cores.

The scatter diagram for density versus water permeability is shown in Figure 5 for the data set available. The logarithmic function fit to the data set has a R^2 value of 0.8, which is high and indicate that the correlation has a high confidence value. The interpretation is that as soon as the density drops below 93% the permeability increases significantly and below 92% it accelerates to even higher permeability values. This conclusion is also as expected and in line with correlations and conclusions drawn from previous work (4).

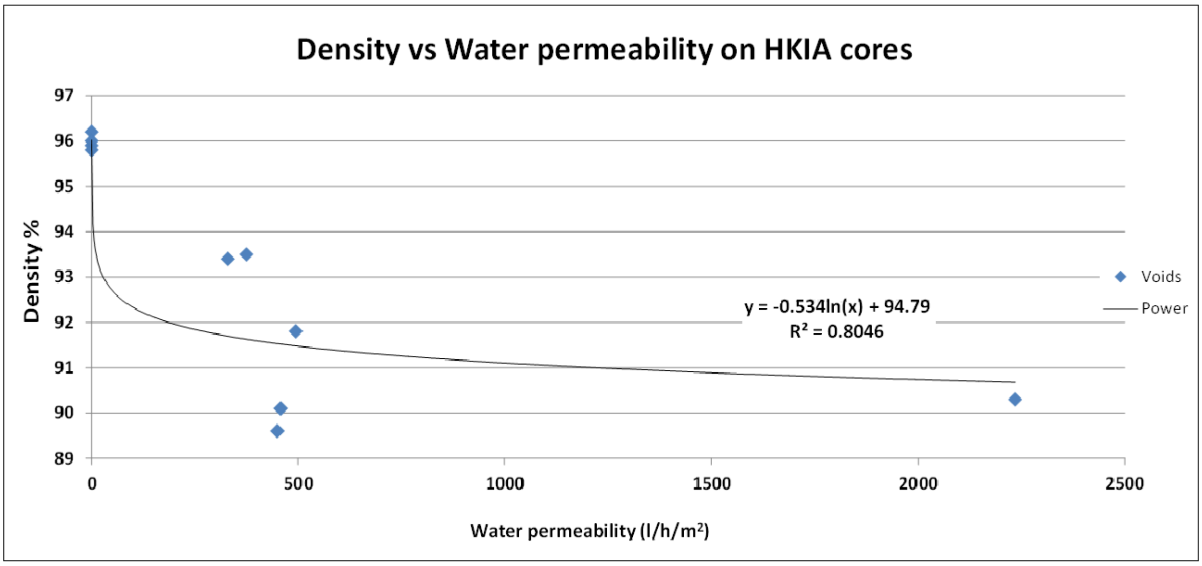


Figure 5. Correlation of Density versus water permeability.

The air permeability versus density on Figure 6 shows a similar good correlation with a logarithmic function fitted with a R^2 value is 0.84. This fit is even better than that determined for the water permeability.

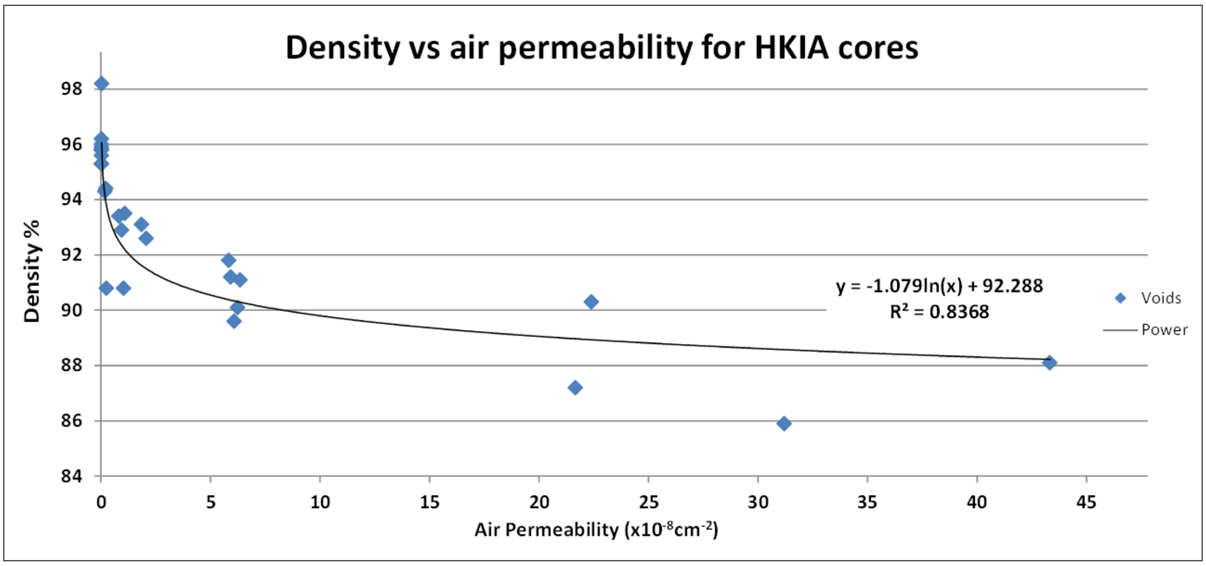


Figure 6. Correlation between air permeability and density

Literature elsewhere shows that if air voids increase above the threshold value of 7% that permeability will increase significantly. (4, 15). In Figure 7, this threshold value is confirmed with air permeability values and shows an exponential increase in air permeability beyond 8% voids. This correlation between air voids and air permeability has a very good R^2 value of 0.94.

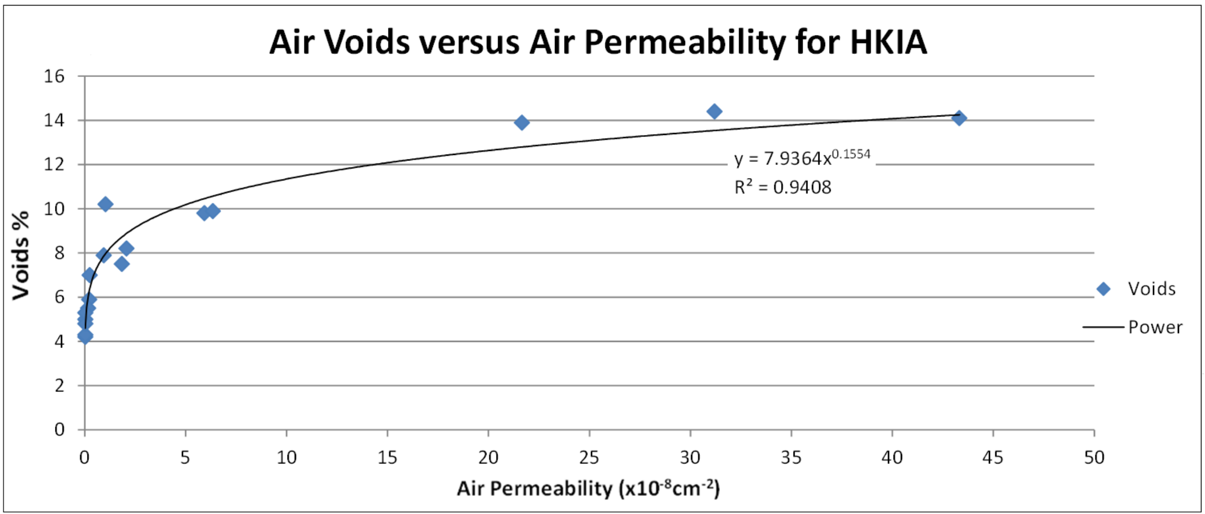


Figure 7. Correlation between air permeability and air voids

The RAG benchmarking based on Table 2 concluded that the wet/dry Lottman test results (TSR values) are not a good indicator of probable stripping or permeability potential. The correlation between TSR and voids are very low (not shown here) which confirms that for this limited data sample the TSR is probably not a good indicator of permeability problems as linked to voids in the mix. TSR also has a weak correlation with density (not shown here) and the same conclusion can be reached as before.

4 CONCLUSIONS

Stripping and ravelling are durability type distress often observed on airports. This form of distress is often linked with areas with no traffic and can also be associated with arid as well as wet regions. Stripping can easily go undetected and can lead to de-bonding of asphalt layers which, like in the case of HKIA, can cause delamination with serious safety threats associated with loose objects on the airside surfaces (FOD). Stripping and other durability types of distress were observed to often originate at longitudinal joints.

The current asphalt mix design procedures in Southern Africa tend to focus on rut and cracking prevention and have a strong roads design bias. The result is that specifications and quality control procedures also tend to focus on mainly density and voids control. The bias is also enhanced by the focus on the lane mat quality and lesser attention given to the longitudinal joint quality. It is acknowledged elsewhere that densities in the close vicinity of longitudinal joints often are allowed to be 2% lower than the densities on the lane mat.

Hosea Kutako International Airport (HKIA) was recently rehabilitated by milling out the delaminated and stripped thin asphalt overlay (50mm). It was built up with an asphalt inlay and improvements of the cross fall. Due to various factors, initial attention to longitudinal joint quality suffered some lack of detailed attention. After a change in management on site the correct attention was given and within the roads' biased specification, an attempt was made to correct the focus on the joint construction quality. Coring on joints previously uncut confirmed that densities were below specification and voids also too high. Remedial work was done where the mat densities were also failing to meet specifications. Analysis of density results on this project determined afterwards that the average density between the mat and the paired joint densities were as high as 5%, and the joint densities were as low as 3% below accepted specification limit. However, the fact that joint densities are analysed with the rest of the mat (with higher than specification densities) often resulted in acceptance of the paved lane. Corrective action was to apply a rich fine slurry rejuvenator to the joint area.

Abnormally high rainfall caused a break of 6 months in the construction of the various asphalt layers. The heavy rain infiltrated the pavement layer work and caused a white deposit on the surface of the airside asphalt surfacing. Most of the white deposit concentrated on the longitudinal joints or other areas suspected of lower permeability. A detailed laboratory analysis found that the white deposit was due to salt in the aggregate in the older under lying structural layers which was leached out due to water permeating through the asphalt layers. The white salt deposit thus tended to show up and confirm the porous nature of the longitudinal joints.

A coring program enabled cores to be taken at areas with the white deposit, as well as apparently sound (black) areas. In an attempt to find a practical way to shift the density and voids control to actual permeability indicators, the cores were rated or classified visually in terms of inter-connectedness of voids observed on the core samples. This classification was followed up with normal quality control type density and voids determination. Specialised tests not provided for in the specification included air and water permeability, as well as Modified Lottmann Tensile Stress Ratio (TSR) determination.
A Red, Amber, Green (RAG) benchmark comparison of all tests provided valuable practical guidance to correlate existing density and voids testing with actual durability related aspects of permeability. It was found that density and voids in combination with the

visual permeability rating showed good correlation with actual air and water permeability values. It was found that TSR did not correlate well with the same permeability information. More detailed analyses showed and confirmed very good correlation between density and voids, density and permeability (air and water), voids and permeability (air and water) and that TSR had virtually no correlation with any of the permeability related values.

5 REFERENCES

1. 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.
2. 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.
3. Chen JS, Lin KY and Young, SY., 2004 **Effects of Crack Width and Permeability on Moisture-Induced Damage of Pavements**. J. Mat. in Civ. Engrg. Vol 16, Issue 3, pp. 276-282.
4. Cooley LA, Prowell, BD and Brown ER., 2002 **Issues pertaining to the permeability characteristics of coarse- graded superpave mixes.** Journal of the Association of Asphalt Paving Technologists, Vol 71, pp 1-29.
5. Cooley LA, Ahlrich RC, James RS, Prowell, BD and Brown ER., 2007. **Implementation of Superpave mix design for airfield pavements**. 2007 FAA International Airport Technology Transfer Conference. Atlantic City, New Jersey, USA.
6. Emery S. 2005. **Asphalt on Australian Airports**. Australian Asphalt Paving Association. Pavement Industry Conference, Surfers Paradise, Queensland, Australia.
7. FAA (1983) **Airport Design**, Advisory Circular, 150/5300-12, Federal Aviation Administration, Washington, DC
8. Horak E, Emery SJ and Mihaljivic I. 2011 b. **Balancing asphalt rut resistance with durability and safety requirements on runway rehabilitations.** PIARC conference on Pavement Design, September 2011, Mexico City, Mexico.
9. Horak E, Emery SJ, Maina JW and Walker B. (2009a) **Mechanistic Modelling of Potential Interlayer Slip at Base Sub-base level.** Proc. 2nd Bearing Capacity Conference for Roads Railways and Airports, Champagne Illinois, USA.
10. Horak E, Maina J, and Emery SJ .2009b. **A case study: Quantification and modeling of asphalt overlay delamination on an airport pavement**. Proceedings of the Bearing Capacity of Roads, Railways and Airports (BCR2A), April 2009, Champagne, Illinois, USA.
11. ICAO (1983) **Aerodrome Design Manual, Part 3-Pavements, 2nd ed**. Reprinted 1997, Incorporating Amendments 1 and 2, Doc 9157, International Civil Aviation Organization Montréal, Canada.
12. ICAO (2004). **Standards and Recommended Practices for Aerodromes. Annex 14 to the Convention on International Civil Aviation, Volume I**: **Aerodrome Design and Operations**, Fourth Edition. International Civil Aviation Organization Montréal, Canada.
13. ICAO (2006) **Aerodrome Design Manual, Part 1 – Runways**, 3rd Edition 2006 International Civil Aviation Organization Montréal, Canada.
14. Lu, Q and Harvey, JT., 2006. **Field investigation of factors associated with moisture damage in asphalt pavements**. 10th international conference on asphalt pavements (ISAP), Quebec, Canada pp. 691–700.

15. NCHRP., 2006. **Relationship of Air Voids, Lift Thickness and Permeability in Hot-Mix Asphalt** Pavements NCHRP report 531, National Centre for Asphalt Technology,. Auburn University, USA
16. Obika, B. 2001. **The prevention and repair of salt damage to roads and runways.** Botswana Roads Department Guideline No 6, Gaborone.
17. Olivier PA, Emery S, 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.
18. Taute A, Pretorius D, Marais M and Grobler J., 2007 **Hot mix asphalt quality control** 9th Conf Asphalt Pavements Southern Africa, Gaborone, Botswana.
19. Visser A, Long F, Verhaeghe BMJA and Taute A., 2002 **Provisional validation of the new South African hot-mix asphalt design method** 9th Int Society Asphalt Pavements, Copenhagen, Denmark.
20. 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.
21. Morton B , Horak E , van Niekerk G and van Aswegen E. 2011. **Holistic pavement design incorporating environmentally friendly material utilization on a sinkhole prone runway reconstruction.** Paper accepted for presentation at 2011 Conference of Asphalt Pavements in Southern Africa (CAPSA), Champagne Castle, South Africa.
22. 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.
23. 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.

KEY WORDS

Asphalt, stripping, moisture, runway, coring, ultra-thin surface friction course, longitudinal joints, permeability