EARLY IDENTIFICATION OF DURABILITY AND STRIPPING ISSUES IN ASPHALT BASES AND SURFACINGS

E Horak[1], P Olivier[2], S Emery[3] and P Pretorius[4]

1.Kubu Consultancy (Pty) Ltd, 68 Molopo Avenue, Doringkloof, Centurion 0157, South Africa

2. Jeffares and Green (Pty) Ltd, P.O. Box 1109, Sunninghill 2157, Gauteng, South Africa
3. Civil and Environmental Engineering, University of Witwatersrand, Private Bag 3, Wits 2050, Gauteng, South Africa
4.Bakwena Platinum Corridor Concessionaire, Postnet Suite 151, Private Bag X26, Sunninghill 2157, Gauteng, South Africa

Abstract

Some asphalt surfacings and bases on airports have shown stripping related distress. Asphalt stripping on roads is normally associated with high traffic and wet climates. Airport pavements have much less traffic on their central keel areas than on roads, and virtually no traffic on the outer edges. Yet stripping has been found on some runways and in arid regions. The stripping was undetected by normal visual and instrument surveys. Detailed investigations are needed to identify the early signs of stripping. Coring information was reviewed and proved to be valuable to identify this hidden problem. Aspects such as void content, film thickness, porosity, permeability measurements and core observations can also be used to arrive at a credible quantification of the problem.

1 INTRODUCTION

Moisture damage in asphalt layers on roads and airfields is often obscured and not clearly identified via normal pavement management system (PMS) survey information or even at project investigation level investigations (Olivier et al, 2010). The distress evaluation can be obscured by normal structural parameters, such as cracking and deformation observations, and resultant calculations of degree and extent with direct focus on structural corrections via overlay strengthening, etc. If moisture damage distress is not observed in this process (such as ravelling on the surface), the extent and mechanism of moisture distress, such as stripping, is often overlooked. Some recent airfield and road projects are considered where stripping was not properly evaluated initially due to the focus and commission of work, and now these are reviewed to better understand the moisture related damage.

This paper is geared towards the practical evaluation of moisture damage such as stripping, which has a significant effect on durability. 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.

The comprehensive state of the art work by Caro et al (2008a and b) on the mechanisms of moisture distress was therefore used to give guidance on possible practical analysis techniques which were applied retrospectively on various observances of stripping in airport and road pavements. They broadly defined the moisture damage mechanisms as:

- <u>Moisture transport</u>: processes by which moisture in either a liquid or vapour state infiltrates the asphalt mixture as well as the asphalt binder or mastic and reaches the asphalt binder – aggregate interface. The main processes are:
  - infiltration of surface water (water permeability)
  - capillary rise of subsurface water and
  - permeation or diffusion of water vapour.
- <u>Response of the system</u>: changes in the internal structure leading to a loss of load carrying capacity of the material. The main responses are:
  - detachment/debonding
  - displacement
  - dispersion
  - film rupture/micro-cracks
  - desorption
  - spontaneous emulsification

These illustrate how complex this moisture damage phenomenon is, and that it actually goes through various stages and exhibits various characteristic responses which make it difficult to use a single measure or test to define the presence or extent of moisture damage. The theories are clearly useful to understand the fundamental aspects related to the aggregate-binder interface, but have limited current practical measuring techniques. For that reason the most practical and available tests and investigation technologies have been identified and are demonstrated in this paper by way of summarized case studies.

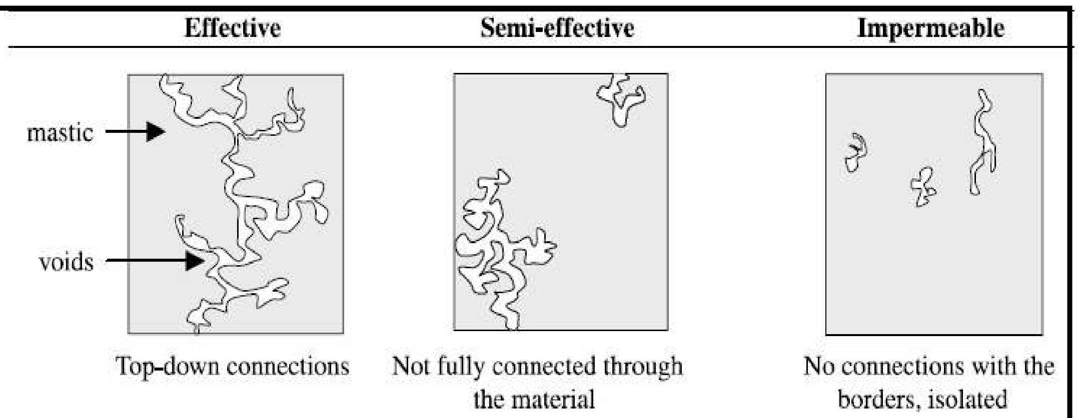
2 MEASURABLE MOISTURE DAMAGE FACTORS

2.1 Main factors affecting moisture damage

A Pareto type analysis of factors affecting moisture damage is not always needed as intuition, prior knowledge and therefore normal asphalt mix specifications identify air void content in the mixture as a fundamental factor that influences porosity, permeability and therefore moisture movement and associated damage in asphalt mixtures. As confirmation an analysis of cores with stripping damage from pavements in California (Lu and Harvey, 2006) showed that air voids content, pavement structure, rainfall and pavement age have the highest influence while repeated loading and cumulative truck traffic have a marginal effect.

A helpful practical guide was suggested by Chen et al (2004) which classifies air voids and their connectivity as observed in asphalt mixtures via core surface observance into three categories which are illustrated in Figure 1:

- effective,
- semi-effective and
- 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 1: Classification of air void connectivity in mixtures (adapted from Chen et al., 2004)

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, but this is only an indication of in situ water permeability as this apparatus is prone to instrument handling and installation problems (Visser et al, 2002). An upper limit of <1.0 l/hour is usually applied to surfacings (Taute et al, 2007). 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.

Indirect measures often make use of other material factors and can be used to get an estimate of permeability value. An equation (Eq. 1) for the water permeability of coarse-graded Superpave asphalt in the field using the NCAT field permeability device tester is given by Cooley et al, (2002) (R^2 = 0.66). It shows the inter-related nature of density, lift thickness, and permeability:

$$Ln(k_{field}) = -1.787 + 0.592(V_a) + 0.196(NMAS) - 0.23(\frac{t}{NMAS}) \qquad \text{(Eq.1)}$$

where k_{field} is the field water permeability of the mixture in 10^{-5} cm/s,
V_a is air void content (expressed in percentage points)
NMAS is the nominal aggregate size (mm)
t is the asphalt layer thickness (mm)

As density decreases (in-place air voids increase), permeability increases exponentially. At some point within this relationship, small changes in density lead to large increases in permeability and this defines the point where excessive permeability begins. As Eq. 1 shows, larger mix sizes require higher density (lower air void) values to ensure impermeability. Standard practice assumes 8% air voids as the cut-off point for conventional dense-graded asphalt whereafter such mixtures become excessively permeable. Coarsely graded mixes can become excessively permeable above 6 % air void contents.

There is also a relationship between permeability and t/NMAS and NCHRP (2006) found that even though there was a lot of scatter within and between projects, most field results support the finding that higher t/NMAS ratios generally provide lower air void levels. Grading is not specifically addressed in Eq.1, but NCHRP also concluded that coarse-graded mixtures generally have higher permeability values than the fine-graded mixtures for a given air void level.

2.2 Testing for asphalt stripping potential

Testing for asphalt stripping potential usually compares test results for dry or control specimens to the same parameter(s) derived by testing moisture conditioned specimens. The goal of the moisture conditioning process is to simulate the detrimental effects of moisture on the material during a short period of time.

The tests that can be used to assess and quantify moisture damage potential in asphalt mixtures range from visual assessment to empirical tests which assess moisture damage (in loose or compacted samples) using a quantifiable performance parameter; these are summarised in Airey and Choi (2002). Such tests include the boiling water stripping test, Riedel and Weber test, Hamburg wheel-track test, modified Lottman test (AASHTO T 283), methylene blue test, Marshall wet/dry stability (immersion test), and Tensile Strength ratio.

These tests are normally simple and easy to conduct, but they do not provide information regarding the causes of damage, making it difficult to propose effective remediation actions for poorly performing mixtures. In addition, the results from the majority of these tests do not correlate well with the field performance.

Caro et al (2008b) express the view that it is extremely difficult to find a single parameter that can be used to successfully characterise and predict moisture damage. The main reason for the need to use multiple parameters to characterise moisture damage is that a single material property cannot simultaneously account for the physical, mechanical, and chemical changes that occur in the materials during the development of moisture damage. As a result, the effort to develop a multiple-parameter approach derived from analytical methods has gained momentum.

At the practical level, the MMLS protocol for moisture damage uses a multiple parameter approach of residual semi-circular bending tensile strength and fatigue rations, and the spectral analysis of surface waves residual stiffness (Hugo et al, 2004). New analytically-based approaches are being developed at the research level to characterise moisture damage, which consider multiple material properties derived using fracture mechanics, continuum mechanics, thermodynamics, and/or micromechanics. These lie beyond the scope of this paper, which is focussed on practical issues of detecting stripping in existing asphalt pavements.

3 REVIEWED CASE STUDIES

3.1 Background

The preceding section gave a synoptic overview of the complexity of moisture damage phenomenon, stripping and durability. As stated some of the techniques are at the research investigation level. The practical engineer is often left with less sophisticated techniques to help identify moisture damage. In most cases stripping is just one of the modes of distress of an airport or road pavement. As it is not always visible from the surface this distress mechanism is often pushed to the background and other related forms of distress which are more easily measurable gets the attention. The focus in practice is also often on immediate repair and rehabilitation with the result that structural evaluation and associated testing take the lead and the actual extent and mechanism of stripping tend to become evidence only of general distress that has already occurred and tend to lack proper definition and quantification of the moisture damage. In this section case studies on airports and road projects were reviewed with practical test and survey information to help quantify the moisture damage on these projects. These reviews were done in hindsight and helped to better quantify and identify moisture damage that was previously obscured.

3.2 Moisture damage on an airport in a moderate climate

OR Tambo International Airport (ORTIA), Johannesburg, is in a moderate climate (Koppen climate classification Cwb: temperate dry winter. Annual rainfall 863mm). The main runway of ORTIA 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 inner keel area of the runway showed less pronounced signs of distress. Deformation was encountered within the inner 8m 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. The presence and extent of stripping in the pavement layers could not be seen based on the available survey methodology relying on visual surveys and instrument surveys. It needs tobe acknowledged that jet fuel spillage and heat from turbine engines often causes a camouflage effect for other environmentally related distress forms. Careful examination of evidence is needed to prevent possible misdirection of cause of distress or extent determination.

Coring indicated that the existing asphalt surfacing comprises a typical combined thickness of 100mm, mainly comprising an Open Graded Friction (OGF) course as final wearing course and two lower layers comprising of various asphalt wearing course trial sections including Stone Mastic Asphalt (SMA) and Open Graded Asphalt (OGA). In the keel section, the ageing and brittle OGF was replaced in 1997 by a continuously graded dense asphalt wearing course.

Dynamic Creep, Resilient Modulus and Indirect Tensile strengths were used as indications of the structural integrity of the combined asphalt layer. Indications were that substantial weakening of the bottom layer in the keel section had taken place. Resilient Moduli and Indirect Tensile Strengths of respectively 1000 MPa and less than 1000 kPa were reported for the keel area sections. Test results for off-keel areas were in excess of 3500 MPa and 1300 kPa respectively, indicating a reduction in strength of at least 50% in the keel area.

It was the initial intention to remove the full depth of asphalt over the keel section in order to replace the lower supporting asphalt layer. However, a cross-fall correction was also to be achieved with the new overlay which led to a significant increase in thickness (over 90mm) in the overlay operation over the keel area which tapered off at the keel area edges. This increase in thickness added significant structural strength which limited the milling operation to 65mm to ensure that the OGA layer was removed over the keel area prior to replacement and the 90mm overlay addition.

The off keel area could have received only an overlay due to the limited trafficking in that area. It was feared that if the aged and brittle existing OGA friction course was covered by an overlay, this OGA layer will become a porous interlayer, that could become a water reservoir ultimately causing moisture related damage to the surrounding asphalt in the form of stripping and loss of adhesion. The decision was therefore made to mill out 35mm full thickness of the OGA and in areas of structural strengthening at turnouts and the new rapid exit taxiway (RET) to mill out to 65mm prior to overlay and fill-in operations. The coring information was therefore used mostly to monitor and determine depth of milling and not to further quantify the moisture induced damage at that stage.

The available core information was 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 basis to convert it to the Chen et al (2004) description of Effective stripping, Semi-effective stripping and Impermeable classification shown in Figure 1. 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 1. Only the summary as percentages per area identified and stripping extent classification are shown here.

The results clearly show that 56% of the cores on all areas were impermeable. It showed that 44% of the cores on all areas showed some signs of effective (31%) and semi-effective stripping potential (13%). The off–keel area showed 20% and the keel area 11% of the total area respectively had classifications of effective stripping. The off-keel area is normally not associated with traffic induced moisture movement. This is significant as Cooley et al (2007) clearly indicate that even the keel area of some of the busiest airports in the world have up to 10 times less traffic than a busy highway. Therefore the conclusion could be made that the evidence of stripping on this main runway was not strongly associated with traffic induced moisture movement and it was not clearly evident from the surface condition.

Table 1: 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

Limited modified Lottman tests were done on the cores as a matter of routine, but not evaluated for the reasons given before. The average value reported for the wet/ dry ratio values was 76.6%. Even though the sample size is small the significance lies in the fact that it corroborates the core observations and classification done and confirming a significant potential for stripping of the OGA asphalt surfacing layer.

In Figure 2 the Base Layer Index (BLI) parameter of the FWD survey at 172kN loading is shown as an isograph with benchmark indications of red, amber and green (RAG) to indicate respectively benchmarked severe, warning and sound structural conditions (Horak and Emery, 2009). The base layer index (BLI) parameter correlates well with the structural condition of the surfacing and base materials. In this case it clearly illustrated that the asphalt surfacing combination layer was almost all in a warning state with isolated peaks venturing into the severe state. This BLI isograph does not specifically identify the OGA layer as the asphalt material with structural inadequacies, but rather the combined asphalt layers. It nevertheless corroborates the observations made earlier regarding loss of structural integrity of the OGA layer.

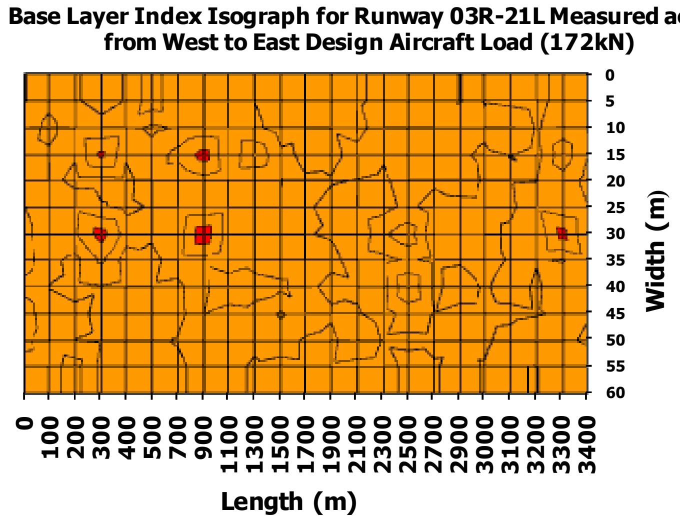


Figure 2: Base Layer Index isograph on ORTIA main runway prior to overlay

3.3 Comprehensive application of investigation tools on Australian airports

Emery (2005) reported on the performance of asphalt surfaces on Australian airports. Part of the investigation was the analysis of the observations and test results of a national airport asphalt coring programme. The Australian airport asphalts are dense graded to a common specification (given in that paper), with the addition of 1% lime to reduce stripping (lime has been since discontinued with multigrade bitumens due to a concern about its neutralisation by polyphosphoric acid). The climates ranged from dry to wet (Koppen BWh, BSh, Csa, Cfa, and Csb).

The coring programme found that stripping of airport 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 the modified Lottman test (RTA T649 test method, discussed in Brizga et al., 2000). It involves significant testing of the aged asphalt, and a complex multi-faceted analysis. 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 airports. In road terms, the "within wheeltrack" trafficking on many airports 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 airports, but not for many airports. This argument was also made regarding the traffic situation described by Cooley et al (2007) 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 binder on stripping was confounded by both the effect of rainfall on stripping and the fact that different binders were being used in different climates. The individual binders clearly perform differently in their resistance to stripping in wetter climates (mean annual rainfall > 1000 mm).
  - asphalt made with unmodified bitumen (Class 320, similar to 40/50 pen) was more likely to be stripped,
  - asphalt made with multigrade bitumen (Class 1000/320) was less likely to be stripped,
  - asphalt made with PMB (A10E, in the 6% SBS class) was slightly more likely to be stripped.
  - In the drier areas (mean annual rainfall < 1000mm), asphalt made with unmodified bitumen appears less likely to strip.
  - The PMB result was somewhat surprising in view of previous anecdotal comments about the resistance of PMBs to stripping. Most PMB cores were from Sydney Airport, and there are known difficulties there with stripping that may have influenced the results. However if PMB was as good in resisting stripping as is supposed, a different result should have been seen.

3.4 Review of a South African road

The N1 dual carriageway (sections 22 and 23) from just north of Pretoria to Bela Bela (the old Warmbaths) is 83 kms in length and forms part of the Bakwena N1N4 Toll Road. The climate is Koppen humid subtropical, with a dry winter and hot summer. The annual rainfall varies from 541-676mm. This road was constructed in sections in the mid 1970's with an asphalt base and surfacing. It has a well known history due to the fact that it traverses long sections of clay subgrade, and subsequent to its construction in the mid 1970's, undulations and longitudinal cracking on the outer edges manifested. In the early to mid 1980's these distresses were extensively studied in terms of swell and cracking behaviour and rehabilitation measures were implemented. The recent detailed investigations found that the past rehabilitations largely achieved the goal of ensuring a constant moisture regime in the subgrade and prohibited further clay subgrade related distress, but that additional sub-surface and surface drainage measures were suggested to improve the drainage of the upper pavement layers whilst keeping the moisture regime in equilibrium in the subgrade.

This road is regularly surveyed via the active pavement management system (PMS) processes. The surveys in 2009 consisted of visual condition assessment, instrument measurements (IRI and Rutting) and structural measurement (Falling Weight Deflectometer) coupled with mechanistic analyses. These investigations were in more detail than is normally associated with a rehabilitation investigation due to the complexity of the derived pavement and its condition and causes for distress. However, it was very evident in the interaction of various parties involved that the usual PMS trend analysis can hide actual detail of distress in spite of the apparent performance measures detail available (Olivier et al, 2010). The real extent and cause of distress became evident only after an expert panel had identified (without any factual supporting evidence) a growing suspicion as to a-typical pavement performance and behaviour. This triggered a series of progressively extensive and invasive investigations culminating in the very detailed design investigation.

If this investigation had relied purely on “surface measured” information together with some pavement test pits, the conclusion would have been merely that “a lot of crocodile cracking with pumping is present on both the N1-22 and the N1-23, especially in the northbound carriageway, with some isolated deformation”. The stripping of some of the asphalt layers was well hidden and it is only via a coring investigation which sought to investigate the thickness of the asphalt layers that this distress mechanism was observed.

The description of the observed moisture damage aspect only is highlighted and reported on in this paper. Other very complex and intriguing distress modes and unique materials behaviour and distress mechanism were also analysed and quantified in detail, but are not mentioned here purely to limit possible confusion due to the complexity and detail.

The detailed design report stated on a portion of the entire route that inspection of numerous cores indicated a substantial amount of stripping of the bituminous binder of the original (1970’s) thin semi gap graded asphalt surfacing layer (now overlaid) on top of the original asphalt base was clearly evident. The focus on the structural aspect is clearly evident from the statements that this stripped layer has an extremely brittle appearance and is forming a “biscuit’ layer variable and with weak support. Yet the only evidence on the surface was isolated deformed areas.

The extensive coring investigation was originally intended to determine the depth of milling as part of the rehabilitation operations and not to quantify the distress further or the possibility for further distress. The original isolated cores carried out were 150mm diameter cores. These were only to determine asphalt layer depths and obtain as much material as possible for further testing of binder condition. However, experience from the airport investigations as detailed in this paper suggested that a much closer look was needed at asphalt stripping.

The complexity of mechanisms causing stripping mean that there is no single evaluation criteria or test to best quantify stripping or the potential for stripping. It was decided to take cores using different core barrel diameters, thinking that a smaller core barrel diameter would place more stress from the cutting face on the asphalt, and so better identify stripping, or at least the potential thereof. Hence an extensive coring exercise was carried out using a 52mm coring barrel diameter. In the cases where complete stripping was identified, a further core using a 102mm diameter barrel was taken to confirm the severity of the stripping. Cores were taken done at 50m, 100m and 200m spacing, and on the shoulders of the road.

The evaluation of the cores in this case focused on the stripped layer and the condition or degree of stripping or disintegration thereof to determine such depth of proposed milling. In this evaluation therefore the semi gap graded layer showing effective and semi-effective air void connectivity classification was identified to be milled out, while the impervious sections were left in place. In some cases the asphalt base layer below was also stripped (using the same evaluation criteria), and was milled out as deep as 250mm.

The original visual survey information was then correlated with the core positions, as was the instrument measured data. Distress observed from the visual survey was summarized in terms of distress observations, such as cracks, crack type and visible pumping. Roughness (IRI), Rutting and Radius of Curvature (ROC) calculated from the FWD data was also correlated to the areas where stripping was evident from the cores and where no stripping was identified. Of the 350 cores drilled over this first N1-22 section, 223 showed signs of stripping (63.7% of the cores). What makes this significant is that for only 9 of the 223 cores showing stripping, did the visual survey information at that spot identify stripping being observed as a distress mechanism from the surface! Almost all the stripping would have gone undetected if the coring was not used to identify it.

4 CONCLUSIONS

Moisture damage of asphalt, and specifically stripping and its effect on durability, is a complex process. The distress mechanism starts with the transport of water within the asphalt mixture matrix, leading to various complex chemical, mechanical, thermodynamical and other processes. None of the theories can singly explain the phenomenon of stripping due to the variability in materials, environment, construction practices, and evaluation methods.

Pavement engineers are aware of the fact that moisture damage is influenced by the aggregate and bitumen properties in presence of water, and on roads stripping can often associated with high traffic and wet climates. On airports, stripping has been found in very low traffic areas and in dry climates. Analysis of cores with stripping damage from various pavements has found that air voids content, pavement structure, rainfall and pavement age have the highest influence, while repeated loading and cumulative truck traffic have a marginal effect.

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. Examples of these problems from practice are discussed, include a national survey of airports which found stripping to be much more widespread then previously suspected. For rehabilitation design in all climates and traffic levels, it is not adequate to rely on visual and PMS data to reveal stripping, and detailed investigations including coring are needed to identify the early signs of stripping and reveal its extent in the pavement.

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KEY WORDS

Asphalt, stripping, moisture, runway, taxiway, roads, coring