ACCELERATED LOAD TESTING OF ASPHALT MIX DESIGNS FOR HEAVY DUTY PAVEMENTS IN HOT CLIMATES

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ABSTRACT

Accelerated load testing in the laboratory has been done on heavy duty asphalt mixes in Australia and the Middle East. The mixes covered a range of asphalts including Australian and overseas airport mix designs and a wide range of existing and new Australian viscosity and overseas penetration binders, and modified binders.

Testing was done using the Model Mobile Load Simulator Mk3 (MMLS) and the Cooper wheel tracking machine used in Australia. The MMLS testing is scale testing and the laboratory rutting can be scaled to actual field rut performance. A fundamental analysis of the rutting performance of some mixes was done with due regard to actual aircraft type and loading, lateral wander, climatic conditions, tyre pressure and layer thicknesses. Results from the field showed a good correlation. The method has application for the design of new heavy duty asphalt mixes intended for high loads in hot climates.

INTRODUCTION

Asphalt has been used extensively for heavy duty pavements such as airports in Australia, the Middle East, and all over the world for decades with generally good performance. However problems on some Australian airports and a Middle Eastern airport prompted an investigation of binders and mix designs for heavy duty pavements. These investigations included accelerated load testing of asphalts in the laboratory, which provided the background to this paper. The focus is on heavy duty asphalt mixes for airports. The term asphalt as used in this paper may be called asphalt concrete, HMA or bituminous concrete elsewhere. Binder may be called bitumen or asphaltic cement, and if modified with the addition or polymers, called modified binder or PMB.

The problems identified at some Australian airports were groove closure and groove edge breaking of the grooved asphalt wearing course. Rutting of asphalt had generally not been a problem at Australian airports, which is due to the use of only thin asphalt layers over stiff pavements. Typical pavement construction consists of 50-60mm asphalt surfacing, over a very high density crushed rock base layer, over a lightly bound subbase layer. The binders in use on Australian airports can be Class 320 (unmodified bitumen), multigrade (1000/320), and polymer modified (A10E class; typically 5-6% styrene butadiene styrene (SBS) block copolymer additive). Relating these to the binders used in Dubai, the A10E binder is similar to a PG82 binder and slightly more modified than a PG76 binder; the Australian Class 320 is slightly harder than the Dubai 60/70 bitumen. Further details are described in Emery (2005a and 2005b).

Groove closure was apparent in a number of asphalts, predominantly made with A10E bitumen. The A10E was supplied by various manufacturers and the asphalt made by various contractors. It raised the question of the “stiffness” or the “resistance to viscous flow” of the mix, since field observations were that the asphalt was viscously flowing. The flow was linked, not surprisingly, to very slow moving aircraft and to hot weather. The asphalt specification, although not designed to be highly rut resistant, had remained unchanged for years, and so the investigation focus was on the binder.

With the assistance and cooperation of industry, a standard airport asphalt mix was made using a range of new and existing binders, and was tested. This testing included laboratory wheel tracking testing at Queensland Department of Main Roads, and accelerated loading laboratory testing using the Model Mobile Load Simulator Mk3 (MMLS) at SRT in Durban, South Africa.

Accelerated load testing of heavy duty asphalt mixes was also applied to material placed on Dubai International Airport (DIA). DIA is undertaking expansion and rehabilitation works. Part of the expansion works consists of pavement upgrade and construction works on runway 16R/30L and associated taxiway systems. The pavement construction consisted of deep lift asphalt pavement with a cement treated subbase layer. Within a few months of opening sections of the new pavements to aircraft traffic, rutting failures appeared with rut depths measured from 6 mm up to 34 mm. The rutting seen in the field was in areas of very slow speed trafficking, such as on aprons and around taxiway holding points. It had occurred in the hot Dubai summer. Cores were taken of the asphalt which showed a reduction in air void content from the time of construction to the time of sampling of up to 4.0%,. A considerable difference was measured between trafficked and non-trafficked sites, which suggests secondary compaction was occurring.

The DIA aircraft pavement structure consisted of six asphalt layers totalling 400mm thickness, and a cement treated subbase layer (Table 1). The wearing course comprised of a BC20 material (bituminous concrete, 20mm nominal stone size) with a PG76 Cariphalte Fuelsafe binder. A coarse grading was used for runway surfaces while a fine grading was used for all other pavements. Two BC20 intermediate layers contained PG76 grade polymer modified binder while three BC32 base course layers contained straight run unmodified 60/70 grade bitumen. The Cariphalte Fuelsafe binder is a mix of plastomeric and elastomeric polymers which provide for a stiff binder which is also resistant to hydrocarbons. The PG76 grade typically has 4-5% SBS polymer added. The PG76 binder is similar to, but slightly less heavily modified, than the Australian A10E, and the 60/70 bitumen is similar to, but slightly softer, than the Australian Class 320 bitumen.

Table 1 – Dubai Pavement Thickness Design

Description	Layer Thickness (mm)	Material (nominal stone size, binder)
Wearing	55	BC20 PG76 Cariphalte Fuelsafe – two gradings (coarse and fine)
Intermediate	65	BC20 PG76 SBS Modified Binder
Intermediate	65	BC20 PG76 SBS Modified Binder
Basecourse	70	BC32 60/70 Bitumen
Basecourse	70	BC32 60/70 Bitumen
Basecourse	70	BC32 60/70 Bitumen
Subbase	200	Cement Treated Fine Crushed Rock
Subgrade		Natural Sandy Subgrade CBR=15%

The performance, and especially the rut resistance, of the various asphalt mixes was tested along with new mix designs and a range of binders. This testing included laboratory refusal density testing at the central site laboratory in Dubai, binder testing at Shell research facility at Petit-Couronne in France, and accelerated loading laboratory testing using the MMLS at SRT in Durban and the MMLS at Stellenbosch University in South Africa.

2 LABORATORY ACCELERATED LOAD TEST EQUIPMENT

Accelerated load testing was done in the laboratory using two scale testing machines. This class of machine is intended for the evaluation and ranking of asphalt mixes prior to construction. As a tool, they rank above normal asphalt laboratory testing such as gyratory compaction, Marshall and refusal density. They sit below full scale testing in facilities such as the Canterbury Accelerated Pavement Testing Indoor Facility in New Zealand, and the substantial FAA National Airport Pavement Test Facility (NAPTF) at Atlantic City International Airport, New Jersey.

Scale testing machines can rate the performance of asphalt mixes in terms of rutting, fatigue and susceptibility to moisture damage in the laboratory and in the case of the MMLS in the field). The two machines used here were the Model Mobile Load Simulator Mk3 (MMLS) and the Coopers wheel tester (which is similar to the Asphalt Pavement Analyzer). The MMLS has the advantage of being more closely linked to real world loading and its results may be assessed in absolute terms. Various research efforts into the APA have only been able to establish it as a ranking tool (Kandhal and Mallick, 1999). The MMLS system has been used to evaluate asphalt sections at airports previously (such as Molenaar et al., 2004 and Jenkins et al., 2003). A comparison of the scale accelerated load testing machines is shown in Table 2.

Table 2 Comparison of scale accelerated load testers

Property	MMLS	Loaded wheel testers
Wheel	Four 300mm diameter inflated pneumatic wheel	Either solid rubber tyred wheel, or rubber hose loaded by a wheel running above it
Origins	Scaled model of full size Accelerated Pavement Testing Mobile Load Simulator (MLS) – a second generation Heavy Vehicle Simulator	Second generation loaded wheel tester (Georgia LWT, Hamburg LWT, Cooper LWT, Asphalt Pavement Analyser)
Typical test cycles	100,000	8,000
Typical wheel load	2.7 kN	up to 1.1 kN
Temperature range	-5 to 60 ^{o}C	4 to 72 ^{o}C
Typical speed	2.5 metres/sec (7,200 load applications per hour, which is scaled equivalent to 50 kph)	0.5 metres/sec
Absolute testing	< 1.8 mm after 100,000 cycles at critical temperature for airports; < 3mm for highways	Generally not possible (Kandhal and Cooley, 2003)
Users	15 machines globally. South Africa, USA, Japan, Switzerland (EMPA), China.	APA is widespread in USA and Canada; Hamburg loaded wheel tester in Europe; Cooper LWT in UK and Australia; Georgia LWT in USA.

MMLS

The Model Mobile Load Simulator Mk3 (MMLS) comprises the test bed, loading system and environmental control system. The MMLS can be used in the laboratory with the test bed, or in the field directly on a full scale pavement. The test bed comprises 9 specimens of which only the central 7 specimens are used for gauging performance. The briquettes are cut to a width of

105 ± 0.5mm. They are placed adjacent to each other, each fitted snugly into a restraining mould that provides circumferential support to the test specimens. Temperature is controlled within a band of ± 2˚C. The test bed is heated from below with a closed loop water system. Hot air is circulated across the test specimens prior to and during trafficking. Temperature is monitored by means of thermocouples that control the water and air temperatures. The temperature of the HMA specimens is measured independently as a control with an additional thermocouple.

The MMLS trafficking is by a four wheel system. The wheel load used in these studies was 2.9kN and tyre pressure was 700 kPa. No lateral wander was used in the laboratory since the briquettes are in a test bed and the wheels cannot wander. Test temperatures were selected according to the characteristics of the mix and the expected environmental conditions in the pavement. Trafficking can be done under dry conditions to assess rutting, as was done here. The MMLS can also be used under wet conditions to assess stripping potential of the mixture.

Tests were initially undertaken using the so-called Baton Rouge protocols (Hugo, 2004). These exist for evaluating MMLS results and using it as a tool for evaluation of rutting performance. They limit the dry rutting performance at critical temperature [50 °C or more] to:

- < 3.0 mm after 100,000 load applications for Highways or,
- < 1.8 mm after 100,000 load applications for Airports.

Testing is done at the critical temperature. This is taken as the pavement temperature in the hottest seven (7) day period in 30 years. It can be estimated from air temperature records using the Viljoen relationship (Kruger et al, 2004). The pavement temperature was adjusted as a function of asphalt depth using the work of Bissada (1980). Rut depth profiles were measured after trafficking intervals of 0, 5000, 10000, 25000, 50000 and 100000 load applications.

Loaded wheel tester

The loaded wheel tester used was the Coopers Research Technology, UK machine. Testing was done in accordance with Austroads AG:PT/T231 (2005). The standard test wheel loading is by solid tyre and is 0.70kN which equates to a contact pressure of 569kPa. The test bed comprises a compacted slab, of dimensions 300 mm x 300 mm x 75 mm deep.

Part of the wheel tracker testing was the measurement of groove closure. Grooving of runway pavements is essential for the safe operation of aircraft in wet weather. For this testing, grooves to the standard Australian configuration of 6 mm x 6 mm were cut transversely across the upper surface of each compacted specimen at 38 mm centre to centre intervals using a diamond saw. At the completion of 5000 cycles (10,000 passes of the loaded wheel), the rut depth, final groove depth and final groove closure were measured using vernier callipers to 0.1mm accuracy. The groove measurements are not quoted here.

ASPHALT MIXES TESTED

Australian airport asphalt

A standard Australian 14mm runway asphalt mix was used and samples manufactured with seven different binders in order to gauge binder performance within a standard asphalt mix. The airport asphalt philosophy is that of maximising the bitumen content consistent with achieving the specified design air voids content and the minimum Marshall stability (Emery, 2005a and 2005b).The mix design had air voids of 5.2%, binder content of 5.5%, Marshall stability of >11 kN, and flow <3mm. The design is based on 75 blow Marshall compaction using a 0.45 power Fuller curve maximum density combined aggregate grading.

The Australian asphalt with seven different binder types was tested in both the MMLS and Coopers Wheel Track machines. The asphalt materials were mixed and compacted in laboratory conditions. Slabs for the Coopers Wheel Tracking apparatus were compacted in the BP slab compactor and grooved, since part of the project was to examine groove deterioration. The MMLS samples were compacted in a gyratory compactor and tested without grooves so as to be able to apply the Baton Rouge protocols which were developed on ungrooved asphalt. For both the Coopers and MMLS apparatus, the samples were tested at 60°C and the speed was set at 106 and 120 passes per minute respectively. For the MMLS, this is 7200 load applications/hr which is the normal MMLS test speed and is the scaled equivalent to 50 kph. The Coopers machine applied 5,000 cycles to each sample while the MMLS applied 100,000 load applications.

Dubai airport asphalt

The Dubai airport asphalt was tested for a range of mix designs and binders. There were four original asphalt designs (Table 1), which had been optimised for stripping resistance rather than rut resistance. The wearing course layer had two gradings – a coarse grading for the runway with an increased surface macrotexture for skid resistance, and a fine grading for the taxiways. As well as testing these, new mixes were developed and tested.

A redesign of the BC20 wearing course was undertaken which followed the 0.45 maximum density Fuller curve for the combined aggregate grading, and the bitumen content was significantly reduced from 4.2% to 3.9%. The original asphalt specification allowed for high laboratory voids together with a wide envelope which is not typical for other airfield specifications. Laboratory air voids for 75 blow Marshall compaction for all pavement layers were originally specified as 4-7%. Typically FAA laboratory compacted voids are specified within the range of 3.0% to 5.0%.

Refusal density testing had been used to provide an indication of the potential air void content at the materials end life and an indication of the stability of the material. The original specification required that the asphalt achieve a refusal density voids value greater than 2.0%. When targeting 2.0% refusal voids, and a maximum 7.0% laboratory voids, the difference between these two values is considered to be large. For more stable asphalt mixtures the difference between such limits should be as close as possible.

In the initial refusal density laboratory testing, the basecourse materials were compacted in 100mm diameter Marshall moulds, which are now considered to be too small for the large aggregate size (up to 32mm nominal size). This is thought to have promoted early lock up of materials matrix against the side walls of the mould and therefore inaccurate results. A 300 blow Marshall compaction was used to measure refusal voids for BC20 mixtures and a design value of 2.8% was achieved. A 600 blow Marshall compaction was used to measure refusal voids in the BC32 basecourse layers and a 2.4% design value was achieved.

The adequacy of the 300 and/or 600 blow Marshall method and/or the British Standard (2003) Kango hammer method for refusal density (state at which the material can not compact further) design was considered. None of these exactly reproduces the mode of compaction which occurs under heavy traffic, however a TRL study of the methods preferred the Kango hammer procedure because it allows a degree of kneading of the mix which is more representative of field compaction and it is much quicker (Smith, 2001). This was introduced, and large size materials were later tested using 150mm diameter moulds.

MMLS testing was used to evaluate the material design changes on a performance basis. In order to measure the changes from existing materials and the new design, sample cores where extracted from existing coarse and fine surfacing materials and tested in the MMLS. For new mixes, 150mm diameter core samples were compacted in the laboratory and sent to South Africa for testing. There were variations in air void contents, bitumen contents and combined aggregate gradings of individual samples, and possible variations between cores cut from existing pavements and mix compacted in the laboratory. These variations had to be considered when drawing conclusions from the results.

MMLS test temperatures were selected from an analysis of expected pavement temperatures recorded with depth in the Dubai environment, using Dubai meteorological records and the Viljoen relationship (Kruger et al, 2004). This related well to measured pavement temperatures in Kuwait by Bissada (1980). The temperature of each asphalt layer was adjusted for thermal gradient in asphalt with depth. Thus the wearing course was tested at 65 ^{o}C, the next two (intermediate) layers at 60 ^{o}C, and the 3 basecourse layers at 50 ^{o}C, reflecting the thermal gradient. Since the focus was on asphalt rutting in summer, the low temperature performance of mixes was not considered in this study.

In the field, the rutting was much greater at slower speeds than at normal speed. The rutting at Dubai was occurring predominantly on the slow speed pavement sections such as taxiways and aircraft parking areas. Most of the trafficking had been in summer, and summer temperatures in Dubai are very high. Two testing speeds were used: 7200 load applications/hr which is the normal MMLS test speed and is the scaled equivalent to 50 kph; and 1800 load applications/hr which is quarter speed and equivalent to 12.5 kph. It was evident in the testing at faster loading speed, the deformation sensitivity of the mix at high temperatures was not being realized, with some samples passing the Baton Rouge protocol for airport pavement rutting, even though they showed extensive deformation in the field.

EFFECT OF BINDER TYPE ON RUTTING

The accelerated load testing enabled the effect of binder type on rutting to be examined. In the Australian testing, the ranking of the rut depth by binder type was generally as expected, with asphalts using modified binder performing clearly better in terms of rut resistance than those made with unmodified bitumen. Table 3 lists numerical results, and Figures 1 and 2 show these graphically. Both test methods showed little difference between the individual modified binders using SBS as the modifier. The benefit of multigrade bitumen over unmodified bitumen for rut resistance was also evident. The Class 450 bitumen (a non standard bitumen with a viscosity at 60 ^{o}C of 450 Pa.s, developed in NSW for improved rut resistance) showed an improvement over the Class 320 bitumen. It should be noted that rut resistance is only one factor in the choice of a binder; other properties include such as resistance to stripping, ease of handling, and stability.

Table 3: Wheel Tracking Results on Australian Asphalt.

Binder ID	**Binder**		**Final Rut Depth (mm)**	
	Description	**Softening Point (^{o}C)**	**Coopers WT**	**MMLS**
A	Proprietary elastomeric-plastomeric PMB	80	1.8	1.0
B	A10E (SBS elastomeric PMB)	99.5	2.2	1.1
C	SBS elastomeric PMB	62	1.9	1.0
D	C1000/320 (multigrade)	61	3.2	1.3
E	PBD elastomeric PMB	82	2.8	1.3
F	Class 450 (unmodified bitumen)	54	4.5	1.9
G	Class 320 (unmodified bitumen)	52	5.3	2.1

Both machines show the same trend of rut by binder type, and this reflected the result expected from other such studies. The rutting was deeper and more clearly differentiated with the Cooper machine than the MMLS, probably partly because of the loss of lateral support for the asphalt from the grooving, and partly because the Cooper machine is more aggressive. Although the Cooper machine seems to be a better discriminator of rut performance than the MMLS, it is a relative measure and does not discriminate between acceptable and unacceptable performance. In this respect, the Baton Rouge protocols for the MMLS give valuable guidance.

Applying these to the MMLS results, the asphalt with modified and multigrade binders (Binder IDs A to E) passed the Baton Rouge protocol for airport pavement rutting. The asphalt with unmodified binders (F and G) failed. The standard Australian airport asphalt mix has only modest rut resistance, and the results are not unexpected. At the busiest Australian airports, the asphalt mix typically uses a modified binder, while at less busy airports, unmodified binders are used. All the binders would have passed the Baton Rouge highway protocol.

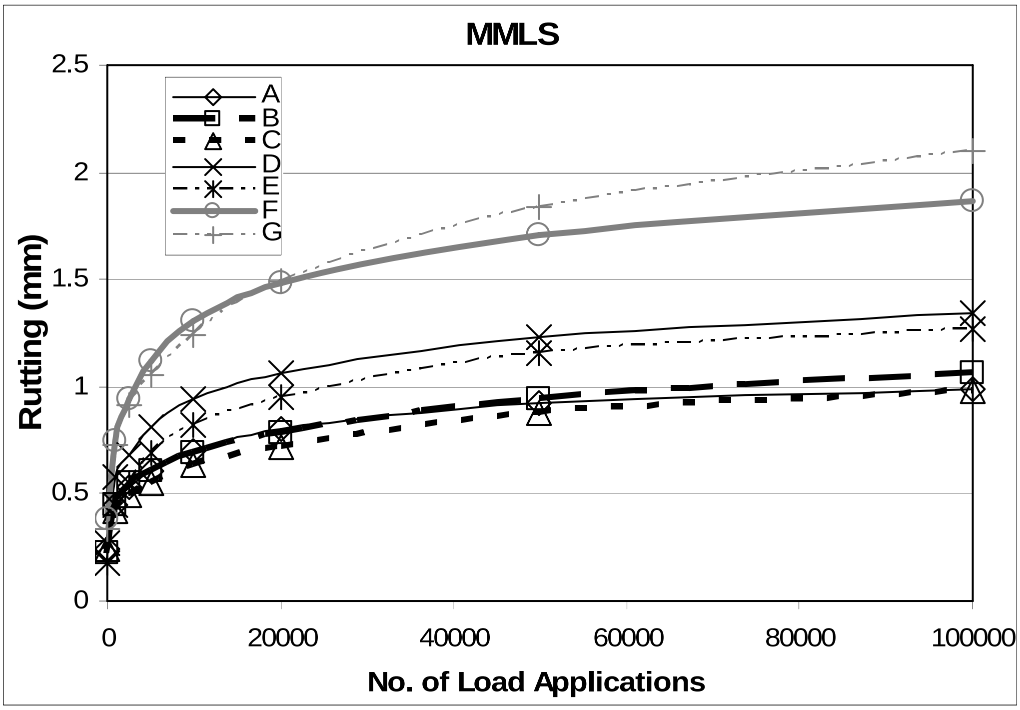

Figure 1: MMLS testing on Australian binders

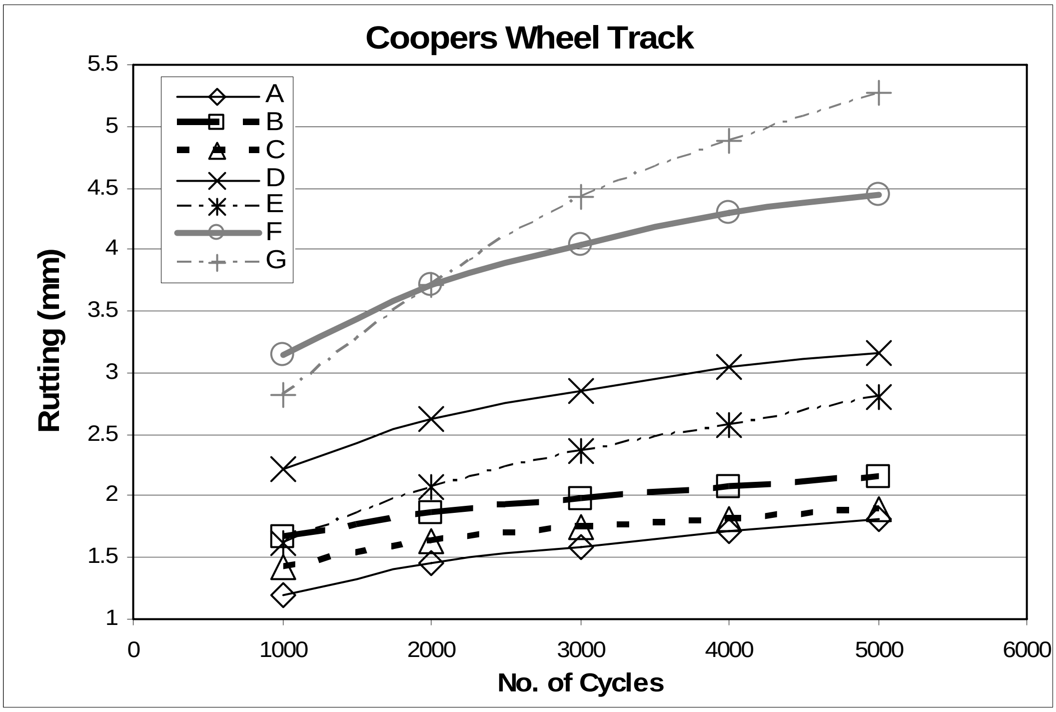

Figure 2: Coopers Wheel Track testing on Australian binders

In the Dubai testing, the effect of binder type on rut depth was seen most clearly with the intermediate BC20 layer. This was material originally specified using a PG76 binder. MMLS testing at slow speed and 60 °C showed that one of the three samples failed the Baton Rouge protocol with a final rut depth at 100,000 cycles of 1.90mm (Figure 3).

PG76 binder had been chosen using the Superpave and FAA systems. The Superpave binder selection is based on average 7 day maximum pavement design temperature (7MPT), and typically at 98% reliability. The Superpave selection algorithm does not extend outside North America. 7MPT was estimated from Dubai meteorological records, and with a small increase adjustment for 98% reliability, the preliminary binder choice would be PG70. The FAA (2001) guidelines make a high temperature adjustment to binder grade by bumping it up 1-2 grades for aircraft over 45 tonnes, hence the choice of PG76. The revised FAA (2006) asphalt guidelines superseded the 2001 guidelines, and now suggest 2 grade bumps. This would now suggest PG 82. MMLS testing was done on the intermediate BC20 asphalt with the PG82 binder, and it meets the Baton Rouge protocol (Figure 3).

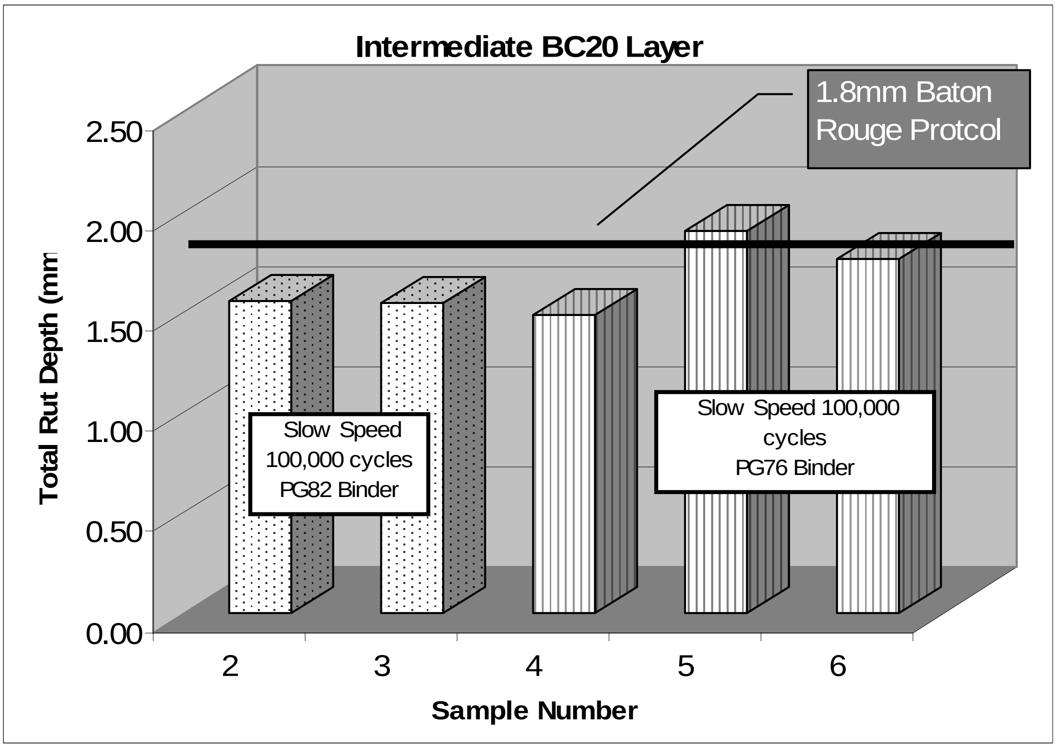

Figure 3: MMLS testing of Dubai BC20 intermediate asphalt layer.`

EFFECT OF ASPHALT MIX DESIGN ON RUTTING

In the Dubai testing, the effect of asphalt mix design on rutting was examined (partly in conjunction with binder type). The aircraft pavement structure had 400mm of asphalt over a cemented subbase. The FAA (1995) aircraft pavement designs require 125mm minimum thickness of asphalt wearing course for large widebody aircraft, and requires bound basecourse layers for aircraft over 45 tonnes. Both asphalt and cement stabilised materials are used for bound basecourse layers at DIA. The use of deep lift asphalt is common in airports due to the construction speed advantage. The 400mm thickness of asphalt used at Dubai however requires a higher level of rut resistance commensurate with use in heavy duty pavements and hot climates. This is as true for highways and industrial pavements as it is for airports.

Appropriateness of slow speed MMLS testing

Inspection of Dubai asphalt production results with Marshall testing initially suggested that the asphalt basecourse layers did not contribute to the pavement rutting. The 600 blow Marshall refusal density result of 2.4% voids significantly influenced this judgment, as did the initial MMLS tests at the standard speed of 7200 load applications per hour. However, since the rutting was clearly linked to very slow aircraft speeds, the MMLS testing on pavement core samples was then run at the slower speed of 1800 load applications per hour, and the results reversed this initial observation. At slow speed on the BC32 basecourse, a rutting result of 3.94 mm was obtained for pavement core samples at only 50,000 cycles; this rut depth was extrapolated to 4.10 mm at 100,000 cycles. The effect of test speed on rut depth is shown in Table 4.

Table 4: MMLS Test Results on Dubai Asphalts at Different Test Speeds.

Asphalt layer, grading and binder	**Final Rut Depth at 100,000 load applications (mm)**	
	Normal (7200 load applications/hr)	**Slow (1800 load applications/hr)**
Wearing course, BC20 fine grading, Cariphalte Fuelsafe PG-76 binder	1.40	1.70
Wearing course, BC20 coarse grading, Cariphalte Fuelsafe PG-76	1.27	2.14
Intermediate layer, BC20 fine grading, PG-76	1.45	1.82
Basecourse, BC32, 60/70 binder	1.48	4.10

The appropriateness of the 1.8mm Baton Rouge protocol at the MMLS slow speed was investigated by coring and testing a runway of known performance - the existing 12L/30R northern runway at Dubai. This pavement had been in operation for approximately 7 years. Only minor rutting has been observed and it was deemed to be an acceptable rutting rate with respect to the operating conditions. The test temperature was 60 ^{o}C and the speed was 1800 load applications/hour. The measured MMLS rut depths (Table 5) and known good field performance correlated to give confidence that the existing Baton Rouge protocols are appropriate at slow speed (1800 loads applications/hour).

Table 5: MMLS testing of Cores from Dubai Runway 12L/30R.

Parameter	**Wearing course**		**Basecourse**	
Binder	Plastomeric (PE blend)		PG76	
Sample	1	2	4	5
Air voids	4.6%	4.1%	7.0%	6.1%
Rut depth at 100,000 applications in MMLS slow speed (mm)	1.22	1.32	1.35	1.11

Specification for heavy duty asphalt for hot climates

The specification for the new asphalt mixes for heavy duty and a hot climate was then set. The Marshall flow requirement for all layers was limited to 3mm for this climate and load. Although the FAA specification for large stone size basecourse asphalt is a minimum Marshall stability of

8.1kN, in Australia the minimum Marshall stability requirement can be as high as 11.5kN. The minimum 75 blow Marshall stability was set as 11.5kN in view of the Dubai climate.

The wearing course and basecourse asphalt gradings were designed using the maximum density curve. The BC32 mix was redesigned to include an additional manufactured sand. The binder content was slightly reduced from 3.6% to 3.5% in an attempt to increase refusal voids, while both the original 60/70 grade binder and a PG76 grade binder were tested. Both the air voids and VMA were lowered by approximately 1.5% to form a more stable material. It was noted that the laboratory compacted voids reduced from 5.7% to 4.3% and refusal density testing using the British method returned voids of 2.7% which are quite acceptable for heavy duty pavements in hot climates.

The redesigned mixes were tested in the MMLS at slow speed (1800 load applications/hour). The improvement in rut resistance with the asphalt mix redesign is evident in Figure 4. The redesigned asphalt with 60/70 halved the rutting but still failed the Baton Rouge protocol. The same redesigned asphalt with the PG76 binder passed the Baton Rouge protocol.

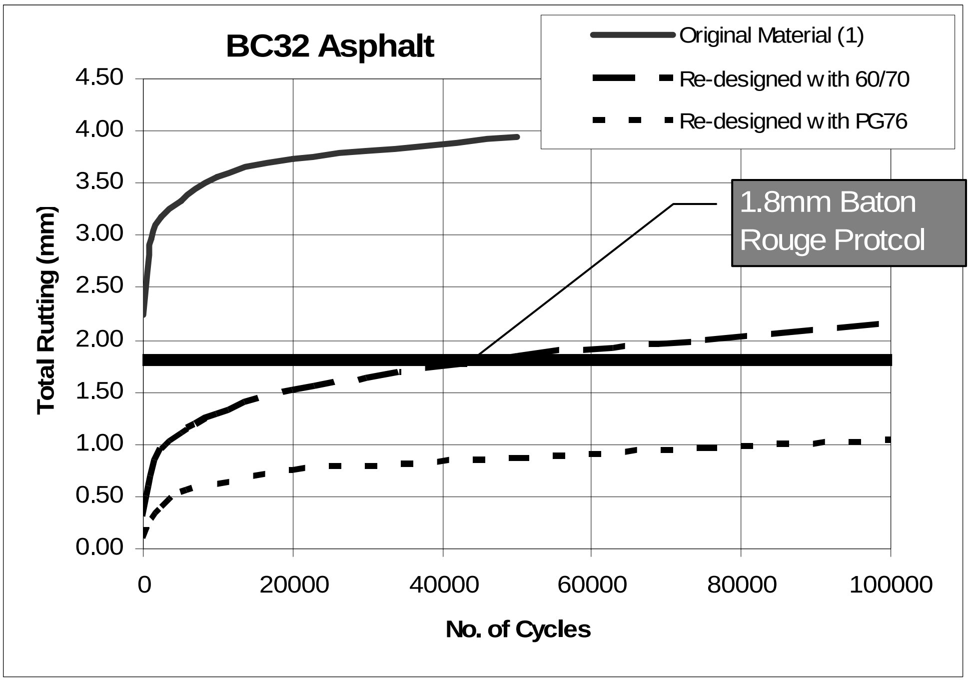

Figure 4: MMLS testing of Dubai BC32 asphalt basecourse.`

Value of MMLS testing

The value of MMLS testing can be seen in the results for the BC32 basecourse asphalt in Table 6. The original mix met the original specification in terms of Marshall stability and refusal density. At normal speed testing with the MMLS, it met the Baton Rouge protocol. However the combination of high temperature and slow speed in the MMLS was enough to cause severe rutting. This was the same severity of rutting seen in the field with very slow speed trafficking in the hot Dubai summer. It is possible that this rutting would not have occurred at combinations of higher speed, cooler temperature, and/or lower loading.

Table 6: Laboratory testing of Dubai asphalt basecourse.

Property	BC32 original		BC32 new	
	Actual	**Specification**	**Actual**	**Specification**
Binder content (%)	3.6		3.5	
Air voids (%)	5.7	4 - 7	4.3	4.0 - 4.5
VMA (%)	13.9	14 - 16	12.4	> 12.0
VFB (%)	60	50 - 70	66	65 - 70
Marshall stability (kN)	15.8	> 10	23.4	> 11.5
Marshall flow (mm)	2.25	2-4	2.4	< 3.0
Marshall 600 blow air voids (%)	2.4	> 2	n.a.	n.a.
BS Kango refusal density air voids (%)	n.a.	n.a.	2.7	> 2.5
Rut depth at 100,000 applications in MMLS normal speed (mm)	1.48	< 1.8	n.a.	< 1.8
Rut depth at 100,000 applications in MMLS slow speed (mm)	4.10	< 1.8	2.16 with 60/70 binder 1.03 with PG76 binder	< 1.8

LINKING MMLS RESULTS AND FIELD RUTTING

Given the scale effect of the MMLS, it is possible to link laboratory MMLS rutting with field rutting. Several studies served as benchmarks for the interpretation of the results of rutting performance under MMLS trafficking. In extensive studies (Smit et al, 2003, Epps et al 2002, and Walubita et al, 2002), the relationship between truck trafficking and MMLS trafficking was investigated. It was shown that it is reasonable to relate the rutting performance of the respective trafficking systems on a one-to-one basis, provided effective traffic volume, vertical stress due to load, load frequency, tyre pressure and temperature is taken into account. This process brings together the effect of temperature gradients in the asphalt (with the surface layers being tested at higher temperatures than the basecourse layers) and stress (with the greater stresses in the surfacing layers being reflected in the stress potential factor). The stress potential (SP) for each loading condition is the area under each respective maximum vertical compressive stress distribution curve to a depth of 75 mm, and is discussed in more detail in the papers referred to above than space permits here.

For the Dubai asphalt, the MMLS ruts were scaled up to calculated field rutting. This calculated rutting was then compared to actual measured rutting.

In the analysis, the stress potential, rutting under the MMLS, laboratory/field adjustment, and channelisation were considered. For stress potential, the vertical stress in each of the six layers of asphalt was calculated in terms of elastic layered theory. Each layer was sub-layered into four, and the vertical pressure bowl under the respective wheel loads and the contact pressure calculated for the MMLS and aircraft wheels. At Dubai airport, the Boeing 777-300ER is extensively used and was adopted as the design aircraft. This was modelled at 1533kPa tyre pressure and 269kN tyre load (equivalent to maximum takeoff weight). The MMLS was modelled at 700kPa and 2.9kN. This was used to determine the relative stress potential (SP) in Table 7 below.

The MMLS rut graph results enabled scale rutting to be established for any traffic level. The traffic movements of aircraft at each location were estimated from data in the Kubu Australia

(2006) report. The busiest taxiways such as M14 were estimated to have received 20,000 departing aircraft movements since their construction under a year previously. This would comprise a mix of aircraft. About a quarter were estimated to be aircraft with the highest wheel loading (mainly the Boeing 777-300ER), and these would be close to or at maximum takeoff weight. Each aircraft movement corresponds to three load applications on the surfacing for this TDT triple dual gear undercarriage. There would also be a contribution to rutting by other aircraft.

The MMLS at 20,000 load applications should be equivalent to the 20,000 aircraft movements experienced on those busy sections (such as Taxiway M14), after the adjustment for wander or channelisation as discussed below. Other areas have been subjected to much less trafficking due to traffic flows or due to a later opening, and 1,000 load applications should be equivalent to actual trafficking of the less busy pavements. The MMLS rutting (RutMMLS) in Table 7 below was found from the rutting during the MMLS test at the appropriate number of load applications.

The performance under MMLS3 trafficking is dependent on the degree of lateral constraint during trafficking. Field tests are the least constrained while gyratory compacted specimens are the most constrained. The effect on rutting performance has not yet been extensively studied, but trends have been observed in the Molenaar study (2004) as well as the MMLS study in Namibia (Hugo et al, 2004), and Molenaar's Table 7 was used for the laboratory/field constraint adjustment factor shown in Table 7 below.

A channelisation factor was used to allow for lateral wander during taxying, take-off and landing. For the analysis it was assumed that wander would reduce effective trafficking to 60 percent of the total aircraft movements on runways and short or curved taxiways, and 80 percent of total aircraft movements on long straight taxiways (due to the reduced wander along a straight taxiway). This is shown in Table 7 below. The scaled calculated rut depth was then calculated using these various factors in Equation 1 for the busiest Dubai taxiways such as M14 as shown in Table 7.

$$Field\_RUT = \left(\frac{RutMMLS \times LFC \times CF}{SP} \right) \qquad \text{Equation 1}$$

The scaled calculated rut depth was similarly calculated for long straight sections of busiest apron taxiways where only 200mm of asphalt was reconstructed (11.3 mm total rut), and for a less busy pavement representing a newly opened and short/curved taxiway (14.4 mm total rut).

Table 7 Calculated rut depth on busiest Dubai taxiway

Layer	Stress Potential SP	Measured MMLS rut depth (mm) RutMMLS	Laboratory/ field constraint LFC	Channelisation factor CF	Calculated rut depth (mm) Field_RUT
Wearing	0.317	1.16	1.25	0.8	3.7
Intermediate	0.341	1.36	1.3	0.8	4.2
Intermediate	0.406	1.36	1.3	0.8	3.5
Basecourse	0.523	3.73	1.3	0.8	7.4
Basecourse	0.710	3.73	1.3	0.8	5.5
Basecourse	0.973	3.73	1.3	0.8	4.0
				Total Calculated Rut Depth (mm)	28.3

Table 7 shows that although all layers are rutting, 60% of the rutting in the 400mm deep asphalt can be attributed to the three 60/70 BC32 basecourse layers. Even though these layers are in cooler conditions than the surfacing layers and are subject to less loading stress, the MMLS testing makes it clear that the 60/70 bitumen is too low in performance (effectively it is too low in viscosity), and a harder bitumen or a modified bitumen is required to improve the performance.

These scaled calculated ruts compare well to the actual measured field ruts of:

- Busy sections: (a) northern side of reconstruction runway 12R30L. Taxiway M14 – ruts of 34mm and 32mm. (b) 2m North of Southern runway 12R30L edge line within coarse graded material and runway 12R30L strip – rut depth 16mm and 32mm within gear wheel tracks and 8mm between gear wheels – no heaving. (c) Taxiway K11 18m south of Southern runway 12R30L edge line - rutting at 28mm and 11mm.
- Busy apron taxiways: Taxiway Z opposite Taxiway F parking Bay 10 – measured at 16mm depth 6m south of centre line and 13mm depth 6m North of centreline over 1 m straight edge.
- Less busy sections: (a) Taxiway K7 – general rut measurement of 4mm depth on eastern side of centreline – this taxiway was open for 8 weeks only and servicing primarily landing aircraft i.e. aircraft that are not fully loaded and not necessarily moving slowly. (b) Taxiway M11 south of Northern runway 12L30R - rut depth measured at 6mm and 13mm.

CONCLUSIONS

The accelerated load testing of asphalt mixes in the laboratory provides additional performance information which is important for heavy duty asphalt pavements in hot climates. Both the loaded wheel tester and the MMLS give guidance into the relative performance of binders in a given asphalt. Both machines show the same trend of rut depth with asphalt type, and the limited results correlate with a Pearson r of 0.95. When testing a standard Australian 14mm runway asphalt mix, both test methods showed the benefit in terms of rut resistance of modified binders and multigrade bitumen over unmodified bitumen. Asphalt made with Class 450 bitumen showed an improvement in rut resistance over Class 320 bitumen. It should be noted that rut resistance is only one factor in the choice of a binder; other properties include resistance to stripping, ease of handling, and stability.

MMLS testing gives yet more insight into the performance of asphalt, and protocols exist to quantify laboratory measured rutting performance. The value of MMLS testing was seen here in the results for the BC32 basecourse asphalt. The original mix met the original specification in terms of Marshall stability and flow, and Marshall refusal density. At normal speed testing with the MMLS, the asphalt met the Baton Rouge protocol. However a combination of high temperature and slow speed in the MMLS apparatus resulted in severe rutting of the sample. This was the same severity of rutting as seen in the field after slow speed trafficking in the hot summer.

MMLS testing is scale testing, and the laboratory rutting can be scaled to actual field rut performance. In the process, the stress potential, rutting under the MMLS, laboratory/field adjustment, and channelisation are considered. This brings together the effect of temperature gradients in the asphalt (with the surface layers being tested at higher temperatures than the basecourse layers) and stress (with the greater stresses in the surfacing layers being reflected in the stress potential factor). For the DIA asphalt, the MMLS ruts were scaled up to calculated field rutting. The Boeing 777-300ER was adopted as the design aircraft, modelled at 1533kPa tyre pressure and 269kN tyre load (equivalent to maximum takeoff weight). The scaled calculated rut depths compared well to the actual measured field rut depths.

For accelerated load testing of heavy duty asphalt pavements in hot climates, good results were found using the MMLS for low speed applications with a test protocol of 2.9kN load and tyre pressure 700kPa, 100,000 load applications, critical asphalt layer temperature (of 50^{o}C or higher), and a new test speed of 1800 load applications/hour. The Baton Rouge limit of < 1.8mm rutting for airports under this test protocol was validated by testing an existing runway with known good rutting performance. The results suggest that the Baton Rouge protocols be updated to consider the loading rate.

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