PAVEMENT SUSTAINABILITY AND PERFORMANCE IMPROVEMENT: CASE STUDIES

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ABSTRACT

French asphalt materials have been introduced in the UK airport sector to improve durability, sustainability and cost. This paper presents the recent findings on the performance monitoring of the French Airfield Asphalt Concrete (BBA, *Béton Bitumineux pour Chaussées Aéronautiques*) surface course that have been successfully laid and constructed on five UK airport runways since 2006. Workshops promoting the use of BBA surfacing have been organised in the UK with positive responses and interest received from stakeholders, such as consultant designers, regulating bodies and airport users and authorities. The surfacing material offers high performance, speedy construction and ease of maintenance. This paper also presents a sustainability case study of using the BBA surfacing on the runway and taxiway pavement rehabilitation and strengthening project at Isle of Man airport. To meet the technical and financial requirements of the Contract, two alternative pavement designs incorporating BBA surface course were adopted, specifically a Repave process and a full depth cold in-situ recycling. The recycling option delivered a sustainable solution with substantial reductions in cost (40%), energy consumption (44%) and carbon dioxide emissions (32%), when compared against the conventional design.

1. INTRODUCTION

Airfield pavements in the UK historically use Marshall Asphalt (MA) surface/binder course and Dense Bitumen Macadam (DBM) base until recently when the BBA surface/binder course started being used. BBA is the standard airfield asphalt surfacing in France [1] and has been used in almost all airport pavements in France, including the two runways at Paris Charles de Gaulle, and Toulouse (where the A380 is being built), with a track record of over 25 years. A relative comparison between UK and French approaches on the mixture and pavement designs have been published elsewhere [2,3,4].

Since May 2006, BBA surfacing materials have been used at five UK airports, specifically Sumburgh and Tiree Airports in Scotland (Highlands & Islands), Ronaldsway Airport (Isle of Man) and Jersey Airport (Channel Islands) and London Southend Airport.

- Sumburgh Airport: resurfacing of the main runway 09/27 plus extension by 250 metres to the East and by 90 metres to the West using grooved 0/10mm BBA surface course. The project included reclamation of 4.2 hectares of land from the sea and the resurfacing work was completed in May 2006.
- Tiree Airport: resurfacing runway 05/23 and part cross runway 29/11, plus extending and resurfacing the existing Apron using grooved 0/10mm BBA surface course. The resurfacing work was completed in September 2007.

- Isle of Man Airport: resurfacing, re-profiling and strengthening the existing runway 08/26 and taxiways using grooved 0/10mm BBA surface course. The work was started in August 2008 and completed in 2009.
- Jersey Airport: resurfacing, re-profiling and strengthening the existing runway 09/27. Grooved 0/10mm BBA surface course was used together with 0/14mm BBA binder course. The resurfacing work was completed in December 2008.
- London Southend Airport: resurfacing and re-profiling the existing runway 06/24. Ungrooved 0/14mm BBA surface course was used together with 0/14mm BBA binder course. The resurfacing work on the existing runway was completed in March 2011.

Despite the normal practice for not grooving BBA surface course in France, the BBA surface course used at the above airports (with the exception of London Southend) were specifically grooved at the request of the airports' owner. In this case, the mixture gradations were modified to give closer surface texture to receive grooving and consequently a 0/10mm BBA mixture design was selected. In no particular order, the type of materials used in the completed resurfacing work of some of the above airports is summarised in Table 1. As stated above, London Southend airport was resurfaced with ungrooved 0/14mm BBA and at the time of writing this paper, ungrooved BBA is being adopted for runway resurfacing at Manchester International airport.

Table 1 - Class and type of BBA materials

Material ID	MAT-01	MAT-02	MAT-03	MAT-04	MAT-05
Mix	AC10-BBA D	AC10-BBA D	AC10-BBA C	AC14-BBA D	AC10-BBA C
Nominal Aggregate Size	0/10mm	0/10mm	0/10mm	0/14mm	0/10mm
Type of Grading	Discontinuous	Discontinuous	Continuous	Discontinuous	Continuous
Layer	Surface Course	Surface Course	Surface Course	Binder Course	Surface Course
Binder	Pen $40/60^+$	Pen $40/60^+$	Colflex N	Pen $35/50^+$	Colflex N
Class	3	3	3	2	2
Design Level	3	2	3	3	3
Coarse Aggregate PSV	66	58	55 – 60	48	60
Fine Aggregate PSV (parent rock)	66	65	55 – 60	53	48

Note: adhesion promoting agent was used in the binders Pen $35/50^+$ and Pen $40/60^+$; a high performance polymer modified bond coat Colbond 50 was also used.

2. LENGTH OF RUNWAY POSSESSION DURING CONSTRUCTION

In accordance with CAP 781 [5], a decision about Temporary Total Ungrooved Runway Length (TTURL) during a runway construction should be made to ensure aircraft will be able land and stop within the available stopping distance, unless grooving or improved friction course has been applied. The current practice allows a temporary surfacing or exposed binder course to be open for traffic by aircraft but limited to a maximum TTURL length, which although not mandatory, has been typically 100m. This practice effectively limits the speed of construction and consequently prolongs the completion of the work and may ultimately increase the construction cost. It is understood that this limitation has been developed from the experience with MA surfacing which, as later shown by the data presented in this paper, generally has low initial wet friction value prior to grooving.

Indeed, the primary reason for grooving closed texture asphalt surfacing (such as MA having typical texture depth less than 0.5mm) is to create rapid discharge of surface water runoff, to facilitate a ‘dry’ surface condition, to reduce skidding risk during wet weather. More open texture surfacing materials (e.g. Porous Friction Course and BBA) have inherently higher surface texture depth which, without the need for grooving, allows water to dissipate into the texture and/or rapidly discharge to the collective drains by gravity. This section presents how grooving may also contribute to some improvement on wet friction of a closed texture asphalt surfacing but not as much on that of higher texture surfacings.

2.1 Early Life Friction Characteristics of Marshall Asphalt (MA)

Recently, surface characteristics (macrotexture and wet friction tests) of 0/14mm MA surface course (designation: Marshall AC 14 surf 70/100) prior to grooving has been determined by Colas during an airport resurfacing work in England; hereafter the material is identified as AC14-MA (MAT-06). The coarse and (parent rock of) fine aggregates used in the AC14-MA material has a PSV value of 63 (declared as PSV_{60}).

The wet friction tests were carried out by using a Grip Tester (at 0.25mm water depth) on 90m ungrooved sections; these relatively short test sections were due to the restriction on TTURL (Note: this particular contract specified a maximum TTURL of 99m). The results are summarised as follow:

- Mean Texture Depth (MTD) = 0.3mm (before grooving) and 1.1mm (after grooving);
- Mean wet friction coefficient = 0.59 (before grooving) and 0.74 (after grooving);
- A minimum wet friction coefficient for each 90m run of 0.43;
- 9 of 16 individual test runs showing wet friction coefficients below 0.55.

The above suggests that most of the ungrooved MA test sections were below the Minimum Friction Level (MFL), thus from an operation point of view, these sections may be deemed as ‘slippery when wet’ prior to grooving. These results may also partly demonstrate the reason behind the restriction on TTURL on ungrooved MA surface course. After grooving, however, the friction value significantly improved and exceeded the MFL.

2.2 Early Life Friction Characteristics of BBA

Observations of the surface friction, before and after grooving, have been made over a 27 month monitoring period using Continuous Friction Measurement Equipment (CFME) at the four airports in the UK and Jersey where the respective BBA surface courses were laid and grooved. The measured wet friction values, tested at 65 km/h using either Mu-meter or Grip Tester in accordance with CAP 683 [6], and the measured texture depth are summarised in Table 2. Data of an ungrooved BBA binder course is also presented. Most of the friction data were supplied by the respective airport owners apart from the friction data obtained during the construction of MAT-04 and MAT-05 (prior to grooving only), which were supplied by Colas.

Table 2 - Early Life Surface characteristics

Material ID	MAT-01	MAT-02	MAT-03	MAT-04	MAT-05
Mix	AC10-BBA D	AC10-BBA D	AC10-BBA C	AC14-BBA D	AC10-BBA C
Layer	Surface Course	Surface Course	Surface Course	Binder Course	Surface Course
Mean Texture Depth as Laid	0.8mm	0.6mm	0.5mm	1.0mm	0.5mm
Mean Texture depth after grooving	1.0mm	1.0mm	0.9mm	*see Note	1.0mm
Groove Dimension (mm x mm x mm)	4x4x25	4x4x25	3x3x25	*see Note	4x4x25
Continuous Friction Measurement Equipment	Mu-meter at 0.5mm water depth		Grip Tester at 0.25mm water depth		
Average friction results prior to grooving	Not available	0.63	0.68	0.73	0.72
Average friction results after grooving	0.63	0.66	0.69	*see Note	0.72
CAA CAP 683 Requirements	MFL = 0.50, MPL = 0.57, DOL > 0.72		MFL = 0.55, MPL = 0.63, DOL > 0.80		

Note: *there was no requirement to groove the BBA binder course MAT-04.

In the UK, specification requirements for wet friction coefficient (measurement by Mu-meter and Grip Tester) are generally in accordance with CAA CAP 683 [6] and the following definitions have been used:

- Minimum Friction Level (MFL) is the friction level below which a runway shall be notified as 'may be slippery when wet'.
- Maintenance Planning Level (MPL) is the friction level below which a runway maintenance programme should be undertaken in order to restore the friction level.
- Minimum Design Objective Level (DOL) is target friction level to be achieved on a new or resurfaced runway within one year.

Table 2 shows that the discontinuous AC10-BBA D provided an initial texture depth higher than the continuous AC10-BBA C; and whilst direct comparison between the two different CFME (friction) test results cannot be made, all the above materials met the wet friction test criteria set out by the CAA guide [6]; specifically they were all well beyond the respective MPL values. These data are considered to be good initial values which, with the anticipated improvement in friction during the first year (as the excess binder is worn away by trafficking to expose the aggregate), increases the likelihood of achieving the respective minimum design objective (DOL) values within the first year in service. It is also worth noting that changes in the early life friction values, before and after grooving, appeared to be relatively small. This suggests that the contribution of grooving to any increase in wet friction of a good quality surface course could be relatively small, consistent with those reported by Toan [7]. The friction values presented in Table 2 were measured within 24 hours of laying and/or grooving.

The above table also shows that:

a) Grooving application increased the mean texture depth (MTD) of the material but the AC10-BBA C (MAT-05) data shows comparable wet friction value after grooving is applied although the minimum friction value had increased following the grooving;

b) The friction test results on the ungrooved AC14-BBA D (MAT-04), having higher MTD, are generally higher than those of the AC10-BBA C (MAT-04) before grooving;

c) The friction test results on the ungrooved AC14-BBA D (MAT-04), having similar MTD, are comparable to those of the AC10-BBA C (MAT-05) after grooving;

The above points (a) and (b) suggest that higher MTD increased the chance to obtain higher friction value overall; but on the other hand, point (c) suggests the correlation between MTD and friction value may not be linear. The latter may be related to the effect of different patterns in the surface texture i.e. the coarser texture inherent in the AC14-BBA D and the grooved pattern in the AC10-BBA C.

It has been mentioned previously that in these UK airports, the 0/10mm BBA surface course mixture designs were modified to have a closed texture in order to receive grooving. If grooving were not required, the “normal” BBA surface course (which will be used ungrooved) would have been designed to have more open texture in order to satisfy the MTD requirement, and consequently greater MTD could have been expected which might ultimately yield a higher friction value.

The 0/14mm binder course presented in this study would be representative of an ungrooved BBA surface course being used in France. Table 2 shows that the BBA binder course MAT-04 which has been designed, laid and tested ungrooved, showed relatively high immediate texture depth (1.0mm) and high initial friction value (0.73) comparable with the grooved BBA surface course MAT-05, complying with the CAA requirement (CAA, 2008a).

This suggests that, when used as a running surface, the ungrooved AC14-BBA D binder course may be expected to provide surface friction characteristics as good as those of grooved AC10-BBA C surface course. As mentioned previously, the resurfacing London Southend airport runway with ungrooved AC14-BBA D surface course was completed in March 2011. At the time of writing this paper, initial friction tests are being conducted and the results are not yet available; subject to approval from the respective authorities they will be published in the future.

5.3 Comparison between MA and BBA Surfacing

A comparison between the friction test results of ungrooved MA and those of the BBA materials is illustrated in Figure 1; all these materials were tested within 24 and 48 hours of laying and grooving for the BBA and the MA surfacing respectively.

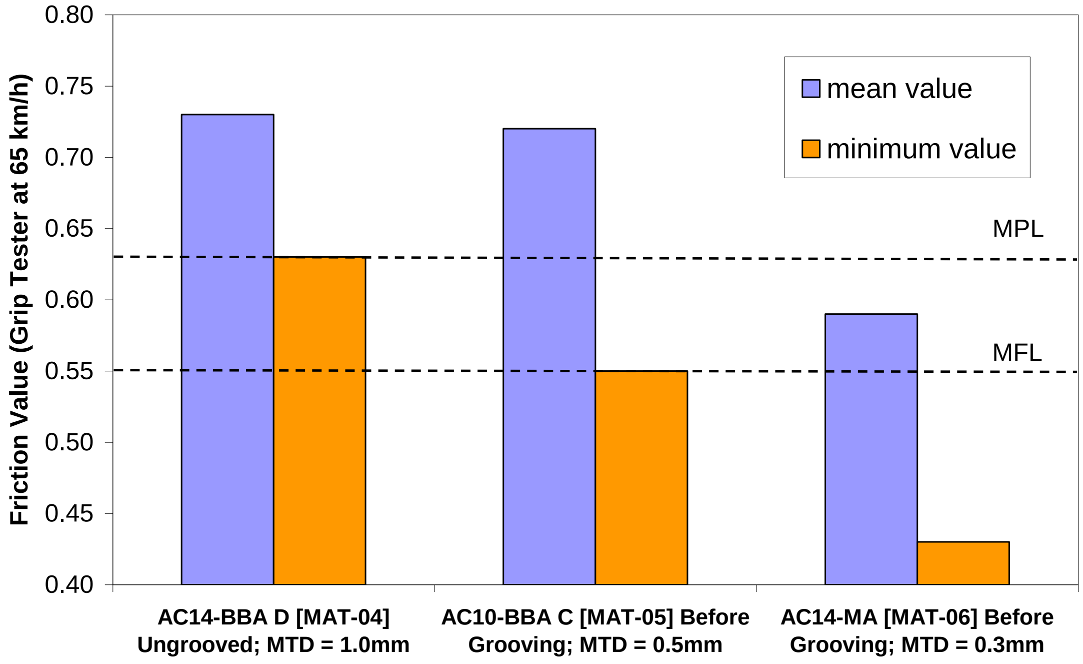

Figure 1 - Wet Friction Values of Ungrooved Asphalts measured by Grip Tester at 0.25mm Water Depth

The above figure shows that:

- For surfacing materials designed to be grooved, i.e. AC10-BBA C (MAT-05) and AC14-MA (MAT-06), the initial, ungrooved, texture depth (MTD) of AC10-BBA C was slightly higher than those of AC14-MA albeit the larger nominal aggregate sizes of the latter;
- For surfacing materials designed to be grooved, the initial, ungrooved, wet friction values of AC10-BBA C were over 22% higher than those of AC14-MA;
- For surfacing materials with the same nominal aggregate size, i.e. AC14-BBA D (MAT-04) and AC14-MA (MAT-06), the initial, ungrooved, texture depth (MTD) of AC14-BBA D was significantly (over 3 times) higher than those of AC14-MA;
- For surfacing materials with the same nominal aggregate size, i.e. AC14-BBA D (MAT-04) and AC14-MA (MAT-06), the initial, ungrooved, wet friction values of AC14-BBA D were over 24% higher than those of AC14-MA.

The above results demonstrate the superiority of ungrooved BBA over ungrooved MA on the initial (macro)texture and wet friction coefficient. In the above example, the TTURL of ungrooved MA was restricted to 99m maximum. However, in the recent resurfacing works at UK airports, a longer runway possession length (TTURL) has been allowed due to the use of BBA materials, specifically:

- On the Sumburgh, Tiree and Isle of Man airports, up to 1000m length of runway surfaced with ungrooved AC10-BBA surface course have been used for aircraft traffic, until the grooving was subsequently applied in the following days;
- On Jersey airport, the full runway length (1400m) surfaced with ungrooved AC14-BBA D binder course was used for aircraft traffic, prior to the surface course layer.

The final runway surfacing may be grooved or ungrooved. This section presents some findings on the wet friction value of the studied surfacing materials. The results are summarised in Figure 2.

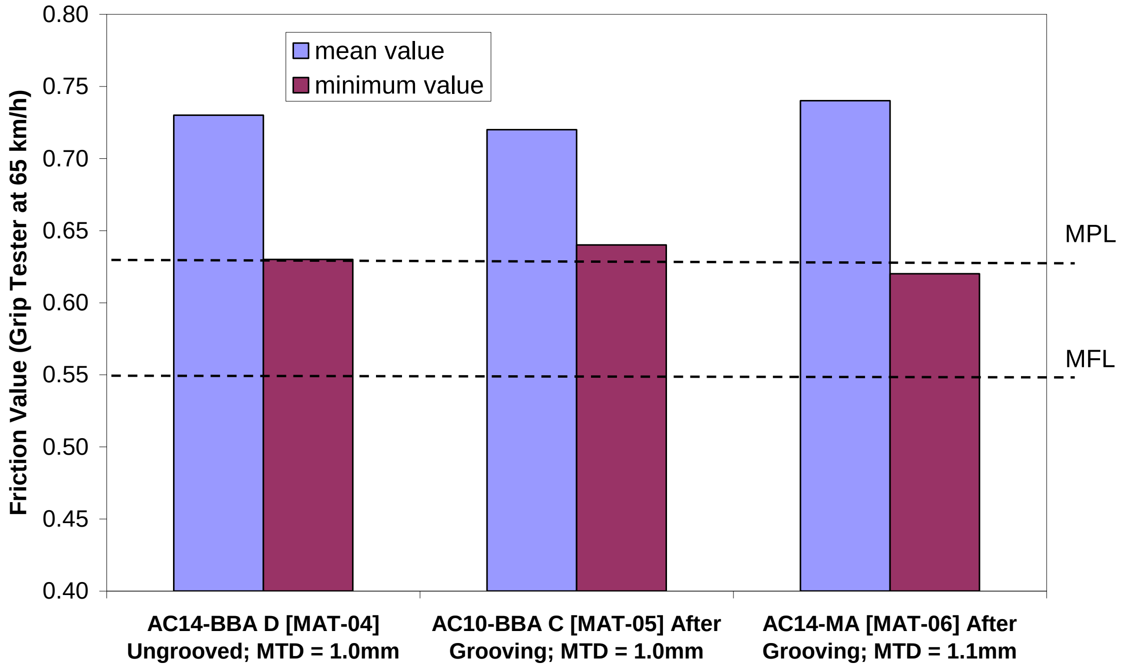

Figure 2 - Wet Friction Values of Grooved Asphalts and an Ungrooved BBA measured by Grip Tester at 0.25mm Water Depth

After grooving application, the wet friction coefficient of the studied MA surface course (MAT-06) increased by 25%. Figure 2 shows comparable macrotexture and wet friction values between the three different surfacing types, ungrooved AC14-BBA D, grooved AC10-BBA C and grooved AC14-MA. These results suggest that:

- Grooved AC10-BBA C has comparable macrotexture and initial wet friction values to grooved AC14-MA;
- Ungrooved AC14-BBA D has comparable macrotexture and initial wet friction values to grooved AC14-MA.

As stated in the previous papers [2,3], these BBA material offers enhanced mechanical properties enabling better retention of the groove, and the opportunity for earlier grooving. For clarity, the improved resistance to groove failure of BBA over MA is reproduced in Figure 3. The wheel tracking test was carried out at 60^{o}C under a 520N wheel load moving at a rate of 42 passes per minute; details can be found in [2].

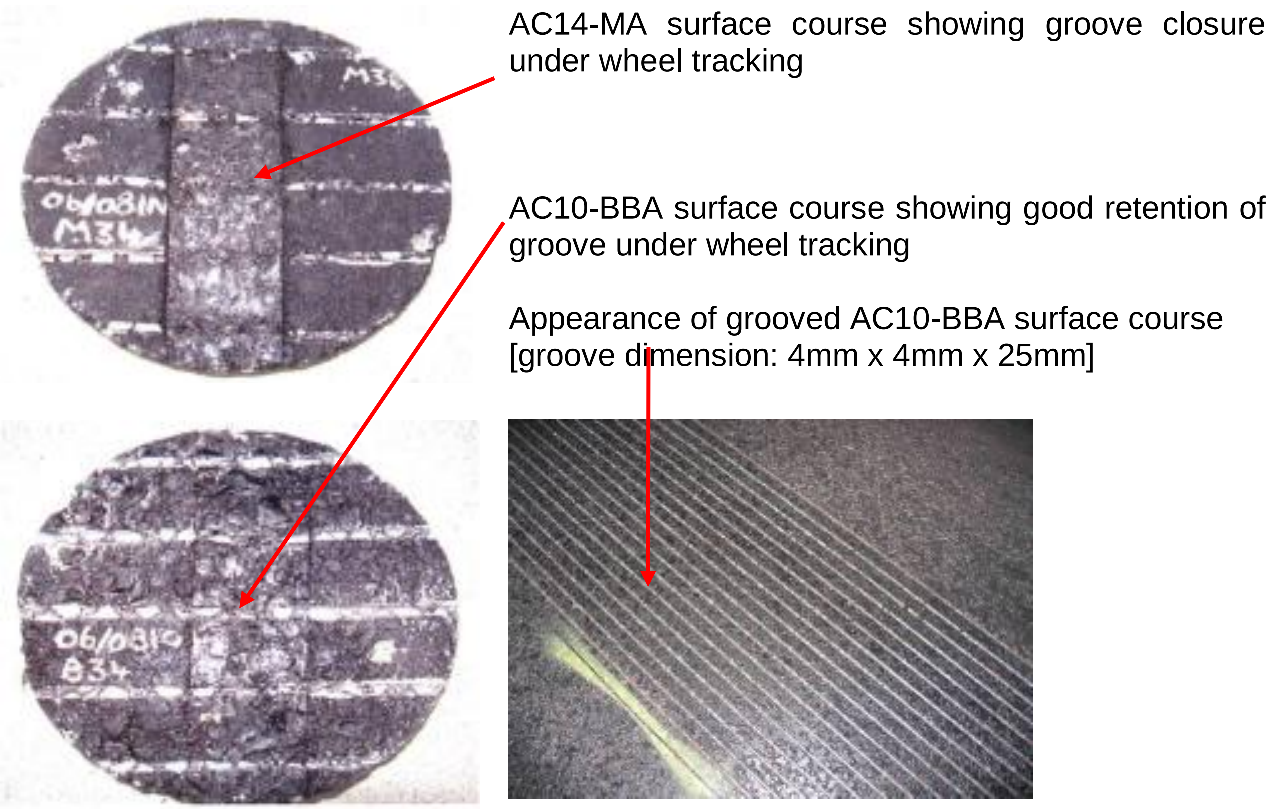

Figure 3 - Improved Groove Retention of AC10-BBA in Comparison with AC14-MA

Based upon the above results and the experience gained during this study, BBA material is considered to have the potential for use as an alternative to AC14-MA and, furthermore, suitably designed BBA materials may be left ungrooved on runways, either as temporary or permanent running course.

3. IN SERVICE CHARACTERISTICS OF GROOVED BBA

It is widely expected that the friction value increases with age, as the binder coating the aggregate at the surface has been rubbed off by aircraft trafficking, revealing the microtexture and macrotexture of the surfacing material; the speed at which binder is rubbed off will be related to the traffic levels. This trend has been observed on the BBA materials used in these airports, as illustrated by Figure 4 for MAT-01 and MAT-02 (measured by Mu-Meter) and Figure 5 (measured by Grip Tester) for MAT-03.

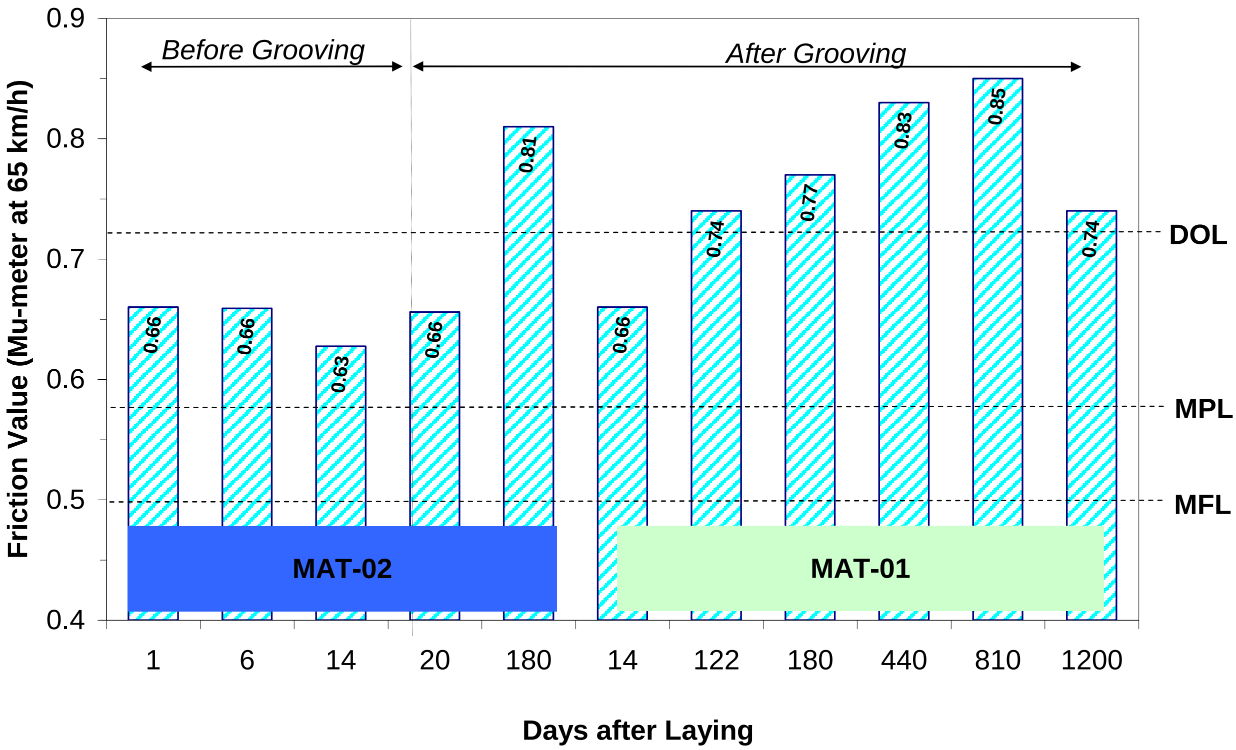

Figure 4 - Changes in Friction Value with time, measured by Mu-Meter at water depth of 0.5mm, for MAT-01 and MAT-02 surfacings

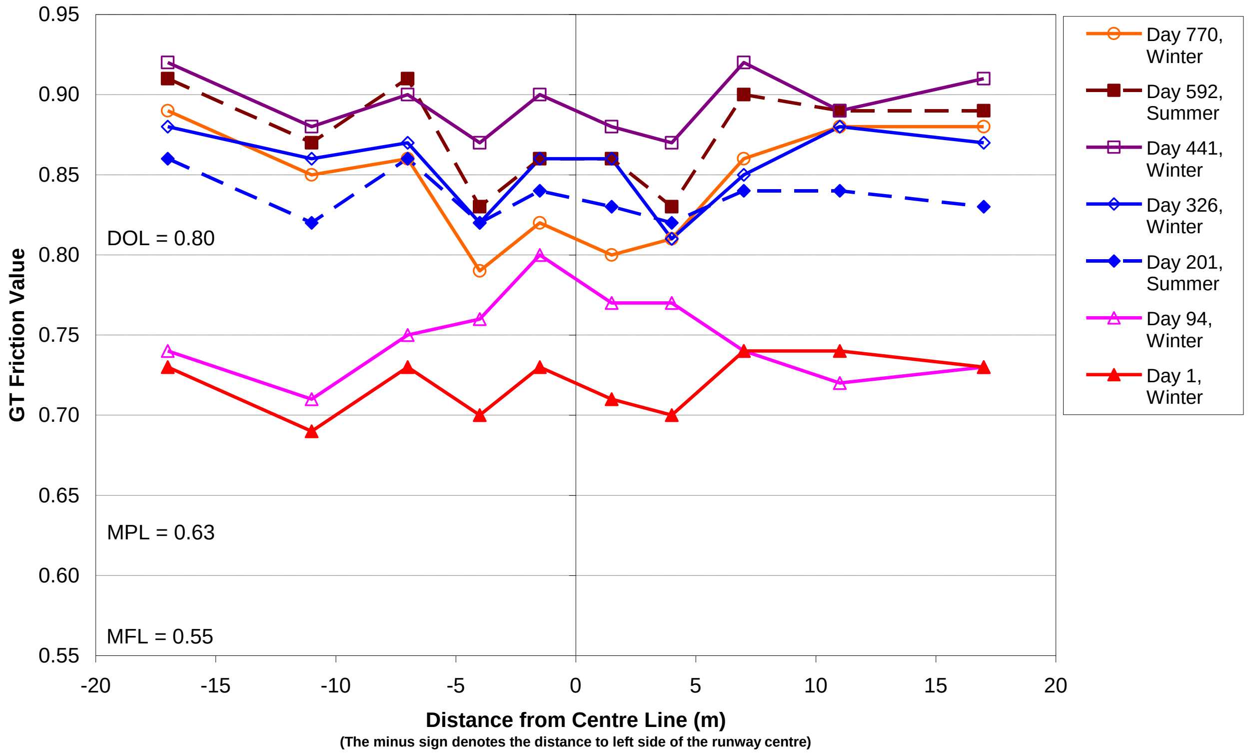

Figure 5 - Changes in Friction Value with time, measured by Grip Tester, at 0.25mm water depth, MAT-05 surfacing

As previously stated, the high early life friction value provided a good starting point to achieve the DOL within the first year spent in service. This has been evidenced from all the four resurfacing projects and examples were presented in Figures 1 and 2. These figures generally show continuous improvement in the surface friction values during the first 2-3 years in service. However, there was a trend of reduction in some friction values during the summer months and/or after 2 years in service. At the time of writing this paper, no rubber removal has been carried out to this BBA surfacing (thus partly explains the reducing friction value as the rubber deposit building up) but in each case all friction values remain exceeded the DOL.

5. SUSTAINABLE PAVEMENT SOLUTION: CASE STUDIES

The four completed BBA projects were located in remote islands. The biggest challenge with construction in remote islands is to deal with issues related to material sourcing, transporting construction plant and equipment, logistics, and the main construction. The construction plant and equipment were transported and shipped from the mainland UK and/or France (in case of Jersey Airport). On-site asphalt production and local material were incorporated in these projects (Sumburgh project specifically used 100% local material). This does not only mean greater control over quality and supplies but also minimised airport disruption and environmentally and socially beneficial as it avoided the impact of, for example, some 1100 lorry movements on local roads that otherwise would have been experienced for the Sumburgh project.

In the above projects, the asphalt materials were produced by continuous type mobile asphalt plants with production capacity rated up to 350tph. Improved workability and speed of construction of the BBA materials were observed in these projects. Grooving was able to commence within 24 hours of laying the BBA surface course which is a major operational benefit. Details about these projects can be found elsewhere [3,8,9]; some important records on sustainability are highlighted here.

5.1 Hot Ex Situ Recycling incorporating Reclaimed Asphalt Pavement (RAP)

The BBA standard [1] permits the introduction of recycled content in both binder course and surface course, being determined by pavement traffic category. This standard requires performance of mixtures incorporating recycled content to be verified during the laboratory mix design process prior to the construction phase. In the Jersey airport project, RAP materials have been added in the new BBA binder course and surface course, respectively thereby allowing premium surface course aggregate from the existing runway surface to be re-used.

5.2 Repave Hot In Situ Recycling

Repave hot in situ recycling was adopted on a number of taxiways at Isle of Man airport, where only small strength increase or non structural treatment was required. The Repave recycling process involved reheating and scarifying the existing pavement surface, followed by adding a new thin (30mm) layer of BBA and subsequently applying compaction on both layers at the same time. This process was able to create a full bond between the recycled and the new (added) BBA materials, without the need for tack coat. Saving to the environment was achieved by minimising asphalt planings that otherwise might have to go to landfill and by reducing import of new materials (being construction on a island this was a major cost saving).

5.3 Full Depth Cold In Situ Recycling

This process makes use of aggregate from the existing pavement and mixes it with additional binders to produce a material with different properties to the original layer. At the Isle of Man Airport, the existing asphalt material was excavated and mixed with a hydraulic binder to produce a Hydraulically Bound Material (HBM) which would perform as the new pavement base layer. This layer was subsequently overlaid by heavy duty macadam

(HDM) binder course and BBA surface course. This recycling process was adopted for areas in need of structural strengthening.

A summary of different recycling options topped by application of BBA surface course on the Isle of Man airport taxiways is presented in Table 3.

Table 3 - Pavement Design Options and Actual Treatments

Taxiway	**Conventional Design**	**Recycling Design**	**Actual Treatment Performed on Taxiway**
Bravo South	No structural treatment required.		Repave 30mm BBA.
Charlie South Delta East Delta West	Remove 160mm existing pavement materials and replace with 50mm surface course on 110mm HDM binder/base.	Remove 365mm existing pavement materials and replace with 100mm surfacing on 265mm cold recycled H1 HBM material.	Remove 365mm existing pavement materials and replace with 100mm surfacing (comprising 40mm BBA surface course on 60mm HDM binder course) on 265mm cold recycled H1 HBM material.
Echo East Echo West	Overlay with 40mm BBA surface course after repairing cracks and defects.	N/A	Repave 30mm BBA.
Foxtrot North	No structural treatment required.		Overlay 45mm BBA.
Foxtrot South	Remove 160mm existing pavement materials and replace with 50mm surface course on 110mm HDM binder/base.	Remove 350mm existing pavement materials and replace with 100mm surfacing on 250mm cold recycled H1 HBM material.	Remove 365mm existing pavement materials and replace with 100mm surfacing (comprising 40mm BBA surface course on 60mm HDM binder course) on 265mm cold recycled H1 HBM material.

Based upon the construction record taken from the Isle of Man project, the recycling option delivered a sustainable solution with substantial saving in cost (40%), energy consumption (44%) and carbon dioxide emissions (32%), when compared against the conventional design (i.e. planing and replacing with new materials). Breakdown details regarding these cost savings and environmental benefits have been published separately [9].

6. CONCLUSIONS

BBA materials have been successfully used on the runways of four UK airports; these runways were surfaced with grooved AC10-BBA C or AC10-BBA D and one of the airport incorporated AC14-BBA D binder course. Further developments in 2011 will see the use of ungrooved BBA as the final runway surface in the UK.

Grooving application increases the mean texture depth and generally increases the wet friction. However the contribution of grooving to any increase in wet friction of a good quality surface course (such as AC10-BBA C) appeared to be relatively small; this is consistent with those reported by others.

The mean texture depth and wet friction coefficient of ungrooved AC14-BBA D, having larger nominal aggregate size, are comparable with those of grooved AC10-BBA C. This suggests the potential for use of AC14-BBA D as an ungrooved runway surface course (as in France), in addition to being a high performance binder course.

The grooved AC10-BBA surfacings and ungrooved AC14-BBA binder course laid on the four studied UK airports exceeded the wet friction Maintenance Planning Level within 24 hours of laying. These suggest very good early life friction characteristics of the BBA materials. The wet friction coefficient of the grooved AC10-BBA surfacings increases with time and exceeded the Design Objective Level as early as within 1 month after laying.

Longer temporary total ungrooved runway lengths (TTURL) have been successfully adopted in Sumburgh, Tiree, Isle of Man and Jersey airports, without any issue associated with the surface friction. The benefits from using BBA materials presented in this study warrant reconsideration of the following issues:

- Ungrooved asphalt (other than porous asphalt) such as BBA can be designed to provide similar level of friction as grooved asphalt. Thus consideration should be made to allow the use of this material on runways (ungrooved BBA was later adopted in the runway resurfacing at London Southend and Manchester International airports);
- TTURL may be extended up to the full length of runways as long as the laid BBA satisfies the minimum wet friction criteria

The use of BBA offers cost saving and minimising airport disruption. It is also environmentally and socially beneficial. By incorporating suitable recycling techniques, further cost savings and environmental benefits can be maximised.

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