EARLY LIFE AND IN SERVICE FRICTION CHARACTERISTICS OF RUNWAY SURFACE

I. WIDYATMOKO
URS Infrastructure & Environment UK Limited
Daru.Widyatmoko@urs.com
C. FERGUSSON
Colas Limited, UK
Carl.Fergusson@colas.co.uk

ABSTRACT

This paper presents friction data gathered from seven regional and major international airports in the UK, covering different surface courses, from the time of installation to in service. The wet friction monitoring at these airports was carried out by using Continuous Friction Measurement Equipments (CFME) over 4 years in service. Some materials showed reduction in the wet friction values during a few days after installation but then followed by a steady increase in the values, even without traffic; this demonstrated the importance of having a good mixture design and binder selection to ensure the early life friction remains above the specified minimum friction level. Longer temporary total ungrooved runway lengths have been successfully adopted at several UK airports where the authors were involved in the resurfacing work, without any issue associated with the early-life surface friction; this resulted in early completion, reduced airfield down time and cost saving. Records to date, demonstrating the ability of well designed surfacing material to maintain very good friction characteristics since the opening of the runways, are also presented.

1. INTRODUCTION

There are two main criteria for surface characteristics of airport runways: texture depth and wet friction characteristics.

Annex 14 of ICAO (International Civil Aviation Organization) recommends a minimum average texture depth of 1mm [1]; a similar requirement is also specified by CAP 168 of CAA (Civil Aviation Authority) for licensing airfield surfacing in the UK [2]. In addition to the texture depth, there is a requirement to measure the (longitudinal) wet friction coefficient, which is probably the most important criterion during licensing and routine maintenance. This coefficient can be measured using Continuous Friction Measurement Equipment (CFME), such as Mu-Meter and Grip Tester which are commonly used in the UK. For completeness, the specification requirements for wet friction coefficient (measurement by Mu-meter and Grip Tester) in accordance with CAA CAP 683 [3] and Table A-1 of the ICAO Annex 14 are reproduced in Table 1.

Table 1 - CAA [3] and ICAO [1] Criteria for wet friction value at 65 km/h

Continuous Friction Measuring Equipment	Minimum Design Objective Level (DOL)		Maintenance Planning Level (MPL)		Minimum Friction Level (MFL)	
	CAA	ICAO	CAA	ICAO	CAA	ICAO
Mu-meter	0.72	0.72	0.57	0.52	0.50	0.42
Grip Tester	0.80	0.74	0.63	0.53	0.55	0.43

CAA specifies water depth of 0.5mm and 0.25mm for the wet friction assessment using Mu-meter and Grip Tester respectively, whilst ICAO specifies water depth of 1mm for these tests.

The following definitions have been used by CAA:

- 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.

If a survey indicates that the runway surface friction characteristics have deteriorated below a specified MFL, that runway will be notified via NOTAM (**No**tice **T**o **A**ir**m**en) as ‘may be slippery when wet’. According to CAA’s **F**light **O**perations **D**ivision **Com**munication (FODCOM) 28/2007, when a runway is notified simply as one that ‘may be slippery when wet’ with no other accompanying substantive information, take-offs or landings in wet conditions should only be considered when the distances available equal or exceed those required for a slippery or icy runway, as determined from the approved information in the Aeroplane Flight Manual. If the friction level is significantly below the MFL, the aerodrome operator should withdraw the runway from use for take-offs and/or landings when wet and inform the CAA.

If the friction level is below the MPL, maintenance should be arranged to restore the friction level, ideally to a value equal to or greater than the MPL.

It has been known that runway condition will have significant impact to the required stopping distance of aircraft during landing. A combination of rainfall rate, wind, runway surface texture and design (e.g. grooved or ungrooved) determine the runway surface condition at a particular moment.

There are a number of recommendations describing the impact of the runway surface condition on braking distance of aircraft. However, different agencies or bodies use different definitions regarding runway surface condition.

ICAO uses the terms: Damp, Wet, Water Patches, Flooded.

JAR OPS 1 (**J**oint **A**viation **R**equirement for the **Op**eration**s** of commercial air transport within European Union, Section 1); specifically Section 1.480 [4] uses the terms: Dry, Damp, Wet, Contaminated (Water Patches or Flooded), which have been defined as follows:

- A **DRY** runway is one which is neither wet nor contaminated with slush, snow or ice. Reports that the runway is dry are not normally passed to pilots;
- A **DAMP** runway is one which shows a change of colour due to moisture. However, if there is sufficient moisture to produce a surface film or the surface appears reflective, the runway will be reported as **WET**;
- A **WET** runway is one which is soaked but no significant patches of standing water are visible. Standing water is considered to exist when water on the runway surface is deeper than 3 mm;
- A **WATER PATCHES** runway one which is considered to be contaminated by having more than 25% of the surface area (whether isolated or not, within the required length

and width being used) covered by surface water more than 3mm deep, or by slush or loose snow equivalent to more than 3mm of water.

- A **FLOODED** runway one which is considered to be contaminated by having more than 50% of the runway surface area (whether isolated or not, within the required length and width being used) covered by surface water more than 3mm deep, or by slush or loose snow equivalent to more than 3mm of water

The airport operators normally describe the surface condition in every third length of the runway. For example WET DRY DRY means the first 1/3rd section of the runway is in WET condition and the last 2/3rd sections are DRY. For wet runways, an allowance should be made by increasing the stopping distance. In this case, the landing distance available should be at least 115% of the required landing distance, determined in accordance with JAR–OPS 1.515.

According to JAR OPS 1, ***paved runways which have been specially prepared with grooves or porous pavement may be considered as having "effectively dry" braking action even when moisture is present, but provided that it is not contaminated*** (i.e. no WATER PATCHES or FLOODED).

JAR-OPS 1 specifically requires account to be taken of the conditions of the surface of the runway from which the take-off or landing will be made. Consequently, in the absence of approved contaminated runway performance data, operations from contaminated runways are not permitted.

Unfortunately the above guidelines may appear to have previously discouraged the use of ungrooved surfacing, other than porous surface course, in runways. Furthermore, grooving is not a requirement for runway surfacing in certain other European countries. This paper demonstrates that ungrooved asphalt surfacing can also provide wet friction characteristics at least as good as grooved asphalt since the early days after the construction.

2. NEW SURFACE COURSE FOR UK RUNWAYS

Until 2008 the material that was predominantly used to surface most UK runway pavements was grooved Marshall Asphalt (MA) although grooved Hot Rolled Asphalt (HRA), Porous Friction Course (PFC) or Slurry Seal are also in use. An update in the 2008 CAA guide CAP 781 [5] permitted the use of French airfield asphalt concrete material BBA (Béton Bitumineux pour chausées Aéronautiques).

BBA is the standard airfield asphalt surfacing in France [6] and has notably been used in the two primary runways at Paris Charles de Gaulle, Orly, Toulouse (where the A380 is being built and tested) and has a track record of over 25 years. To date, BBA has been used on seven UK airports, four island based being Sumburgh (Shetland Islands), Tiree, Ronaldsway (Isle of Man), Jersey; and more recently in 2011, at three mainland airports being Southend, Perranporth and Manchester [7]. Apart from the project at Southend, the mix design and production for all these schemes was undertaken by Colas who also acted as the surfacing contractor.

Despite the normal practice for not grooving BBA surface course in France, the BBA surface course used at each of the four 'island' airports were specifically grooved at the request of each airport operator to comply with requirements prevailing at that time. 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. On the other hand, the mainland airports at Southend, Perranporth (trial section) and Manchester were resurfaced with ungrooved 0/14mm BBA. In no particular order, the type of materials used in the completed resurfacing work of the above airports is summarised in Table 2.

Table 2 - Materials Description

Material ID	MAT-01	MAT-02	MAT-03	MAT-05	MAT-04	MAT-07	MAT-08	MAT-09
Material ID	AC10-BBA D	AC10-BBA D	AC10-BBA C	AC10-BBA C	AC14-BBA D	AC14-BBA D	AC14-BBA D	AC14-BBA D
Nominal Aggregate Size	0/10mm	0/10mm	0/10mm	0/10mm	0/14mm	0/14mm	0/14mm	0/14mm
Type of Grading	D	D	C	C	C	D	D	D
Layer	S/C	S/C	S/C	S/C	B/C	S/C	S/C	S/C
Binder	Pen 40/60^{+}	Pen 40/60^{+}	PMB N	PMB N	Pen 35/50^{+}	PMB O	PMB S	PMB S
Class	3	3	3	2	2	3	3	3
Design Level	3	2	3	3	3	3	3	3
Coarse Aggregate PSV	66	58	55 – 60	60	48	62	60	62
Fine Aggregate PSV (parent rock)	66	65	55 – 60	48	53	62	60	62
Mean Texture Depth as Laid	0.8mm	0.6mm	0.5mm	0.5mm	1.0mm	1.2mm	1.3mm	1.2mm
Treatment	Grooved	Grooved	Grooved	Grooved	Not Grooved	Not Grooved	Not Grooved	Not Grooved
Mean Texture depth after grooving	1.0mm	1.0mm	0.9mm	1.0mm	n/a	n/a	n/a	n/a

Note: C and D denote continuous and discontinuous grading respectively.
S/C and B/C denote surface course and binder course respectively.
PMB denotes proprietary polymer modified binder.

3. EARLY LIFE FRICTION CHARACTERISTICS OF MARSHALL ASPHALT (MA)

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. The coarse and (parent rock of) fine aggregates used in the AC14-MA material has a PSV value of 63 (declared as PSV60).

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 Temporary Total Ungrooved Runway Length (TTURL). 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 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.

4. EARLY LIFE FRICTION CHARACTERISTICS OF BBA SURFACE COURSE

Unlike the traditional MA surface course, the surface characteristics inherent to BBA negate the need for grooving; therefore, BBA surface course can be ready for trafficking as soon as the material is compacted and has cooled down. Furthermore, BBA has another practical advantage in that it can also be laid as binder course. Due to its good wet friction characteristics, this permits aircraft to land on sections of BBA binder course that may be used 'exposed' or as temporary running surfaces during runway refurbishment works.

There are four types of BBA material: Continuous (C) and Discontinuous (D) graded and each grade can be produced using with 0/10mm and 0/14mm nominal aggregate sizes. There are three classes of BBA specified, based on the frequency and weight of aircraft, to give the aggregate type and asphalt mix needed. A review of the mechanical properties, designs and other benefits associated with the use of this material has been published in Asphalt Professional No. 26 and No. 27 [8, 9].

Current CAA guidance regarding the refurbishment of runways is set out in CAP 781 [5]. This permits a temporary surfacing or exposed binder course to be open for traffic by aircraft but limited to a maximum TTURL length. Although not mandatory, this has typically been set at around 100m. This restriction was made to ensure aircraft will be able land and stop within the available stopping distance, unless grooving or improved friction course has been applied. This practice effectively limits the length of runway that can be resurfaced at any one time. This not only adversely affects the speed of construction, but it ultimately prolongs the length of the project and increases the construction cost. It is understood that this limitation has been developed from the experience with MA surfacing which, as previously presented, 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. Table 3 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 surfacing.

Table 3 – Surface Characteristics of Airfield Surface Course

Material ID	**MAT-01**	**MAT-02**	**MAT-03**	**MAT-05**	**MAT-04**	**MAT-07**	**MAT-08**	**MAT-09**
Material ID	AC10-BBA D	AC10-BBA D	AC10-BBA C	AC10-BBA C	AC14-BBA D	AC14-BBA D	AC14-BBA D	AC14-BBA D
Nominal Aggregate Size	0/10mm	0/10mm	0/10mm	0/10mm	0/14mm	0/14mm	0/14mm	0/14mm
Mean Texture Depth as Laid	0.8mm	0.6mm	0.5mm	0.5mm	1.0mm	1.2mm	1.3mm	1.2mm
Treatment	Grooved	Grooved	Grooved	Grooved	Not Grooved	Not Grooved	Not Grooved	Not Grooved
Mean Texture depth after grooving	1.0mm	1.0mm	0.9mm	1.0mm	n/a	n/a	n/a	n/a
Groove Dimension	4mm x 4mm	3mm x 3mm	3mm x 3mm	4mm x 4mm	n/a	n/a	n/a	n/a
Approximate age at grooving	min 3 days	min 14 days	4 - 15 days	20hrs	n/a	n/a	n/a	n/a
CFME	Mu Meter	Mu Meter	Grip Tester	Grip Tester	Grip Tester	Grip Tester	Grip Tester	Grip Tester
Average friction results immediately after laying	n/a	0.63	n/a	0.76	0.73	0.75	0.70	0.76
Average friction results prior to grooving	n/a	0.62	0.68	n/a	n/a	n/a	n/a	n/a
Average friction results after grooving	0.63	0.68	0.80	0.72	n/a	n/a	n/a	n/a
CAA CAP 683 Requirements	MFL = 0.50, MPL = 0.57, DOL > 0.72		MFL = 0.55, MPL = 0.63, DOL > 0.80					

Table 3 shows that the initial mean texture depth (MTD) of ungrooved AC-14 BBA D meets the CAA requirements of 1mm minimum texture depth [3]; a typical surface appearance is illustrated in Figure 1.

Figure 1 – A Typical Surface Texture of Ungrooved AC-14 BBA D

The above data is 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 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 was relatively small, consistent with those reported by Toan [10]. The friction values presented in Table 3 were measured within 24 hours of laying and/or grooving.

The above table also shows that:

a) Grooving application increased the MTD of the material but the AC10-BBA C 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, having higher MTD, are generally higher than those of the AC10-BBA C before grooving;
c) The friction test results on the ungrooved AC14-BBA D, having similar MTD, are comparable to those of the AC10-BBA C and AC14-MA 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 or AC14-MA.

5. IN SERVICE FRICTION CHARACTERISTICS OF GROOVED BBA SURFACE COURSE

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, but eventually reduces as rubber deposit (from the aircraft tyres) builds up. The speed at which binder is rubbed off and/or the rate that rubber deposits are built up will be related to both traffic levels and the affect of weathering. This trend has been observed on the grooved BBA materials, as shown in Figures 2 and 3.

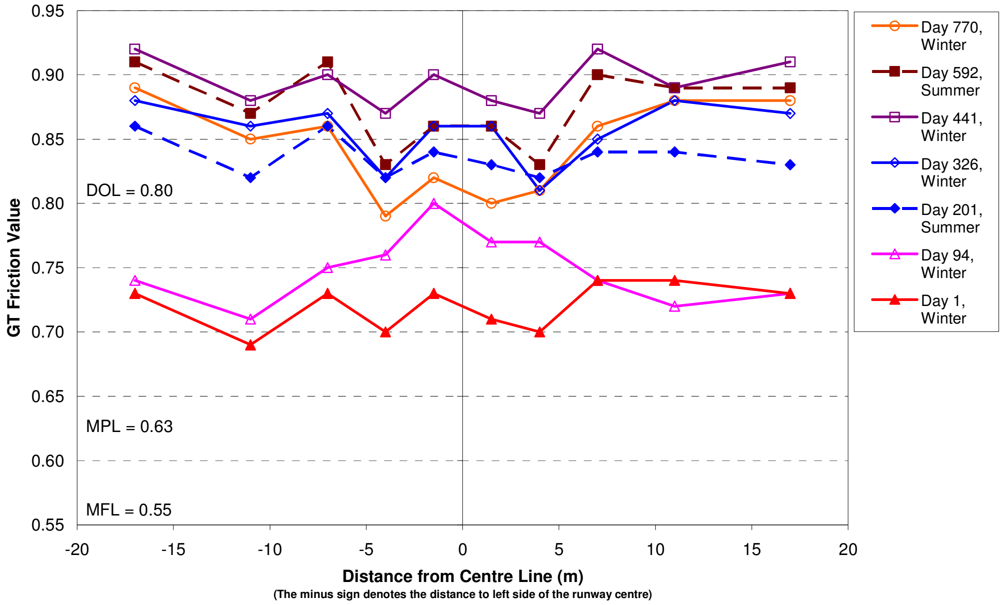

Figure 2 – Changes in Friction Value with time, measured by Grip Tester, at 0.25mm water depth

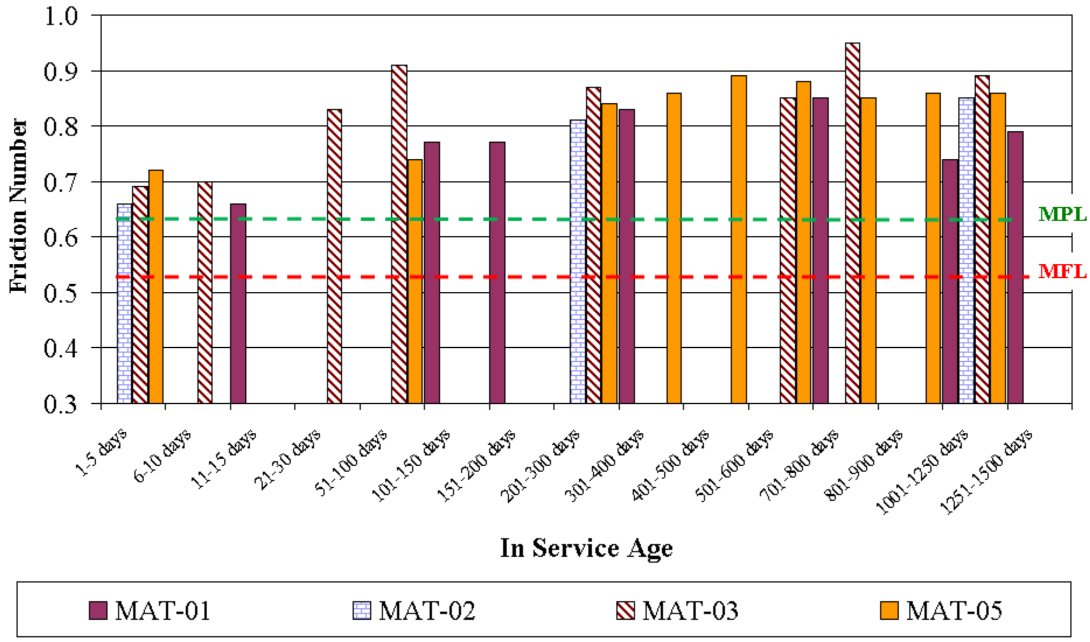

Figure 3 - In Service Friction Values for Grooved BBA

Figure 2 shows 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 this paper was being drafted, no rubber removal has been carried out to this BBA surfacing; this partly explains the reducing friction value as the rubber deposit building up as illustrated in Figure 4. In any case all friction values remain exceeded the DOL.

Figure 3 demonstrated that the surface friction increases with age and remains significantly above the MFL even after 4 years in service. Rubber removal would have been carried out when the friction level was approaching MFL, therefore from the financial point of view, the lack of (or reduced) rubber removal may be seen as good cost-saving in maintaining the runway operation.

(a) Surface area generally in good condition (b) Localised rubber deposits

Figure 4 - Surface Appearance after 3 years in Service

6. CHARACTERISTICS OF UNGROOVED BBA SURFACE COURSE

As previously stated, three UK mainland airports have adopted ungrooved BBA on their runways. The work was completed by Colas with satisfactory wet friction values of the surface course since the opening of these runways to date; a summary is presented in Figure 5. The wet friction values have always been above the MFL immediately after laying. The general trend shows a steady increase in friction value with time and for these three runways, the DOL was achievable within the first 30 days from laying. These results further demonstrate that these ungrooved BBA materials have provided very good wet friction values since the early days and may be regarded as a sound alternative to grooved MA as runway surface course.

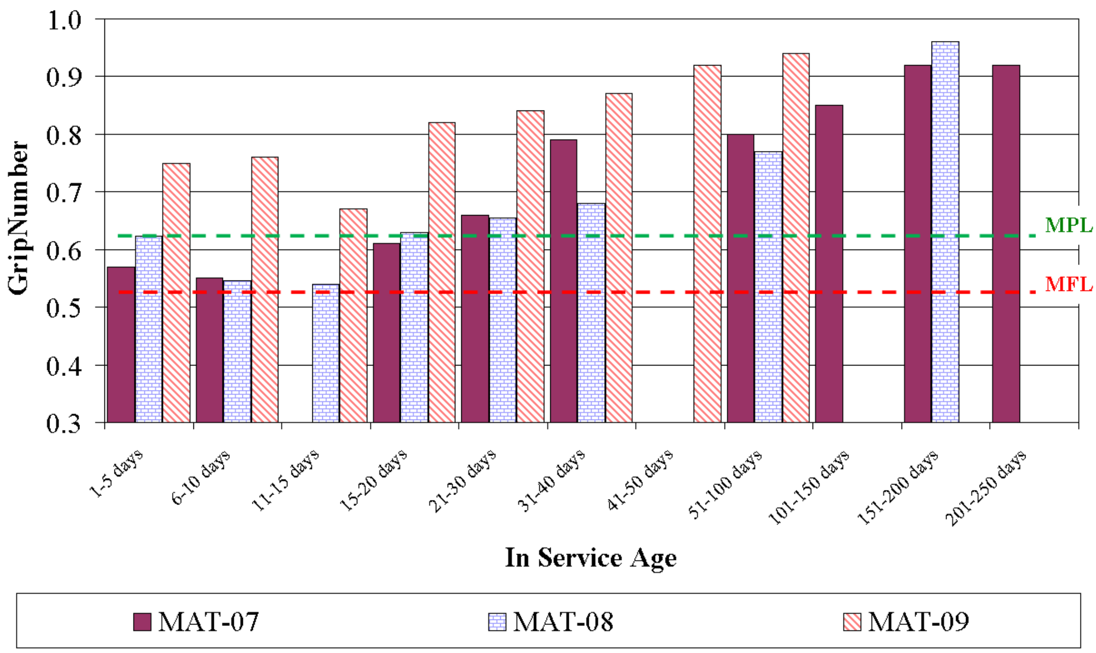

Figure 5 – In Service Friction Values for All BBA (ungrooved) to Date

The most recent work at Manchester Airport 05L/23R (Runway 1) may be seen as a good example how this material is able to carry heavy aircraft traffic in a busy airport and has enabled a further data to be gathered and a better understanding obtained regarding the early life and in service friction characteristics of ungrooved BBA under UK construction practices and climatic conditions. The material was designed and produced by Colas to meet the technical specification devised by URS on the behalf of Costain, the main contractor of this project. The decision to use ungrooved BBA was made by Manchester Airports Group (MAG) after careful and detailed consideration of all the available facts regarding its properties and advantages over 'traditional' MA. This process involved holding workshops with the main stakeholders (e.g. MAG maintenance and operational staff, pilots representatives, main based carriers, regulators, etc) and discussions/exchange visits with Aeroport de Paris and a comparative study on different material options, specifically between grooved MA and ungrooved BBA. Technical, financial and operational aspects for adopting new material were high on the agenda

The database of BBA performance has been continuously developed for those UK airports where it is in service. A number of airport owners, including MAG, have carried out trials of ungrooved BBA and subsequently adopted this material for their runways. There was also a common agreement regarding the potential financial benefit by adopting this surface course. This has been proven through the ease and speed of laying , the less demanding mix design, better strength (it can be laid as thick layer), maintenance requirements (less onerous) and durability (longer life). The laying operation is illustrated in Figure 6.

Figure 6 – Laying and compaction of BBA surface course at Manchester Airport (Courtesy of Costain) [11]

The technical specification adapted the current good practice in designing and laying MA surface course, together with additional performance requirements for the laid material. The specified material was BBA 0/14D Class 3, designed in accordance with NF 98-131 to the Level 3 requirements, to carry high traffic frequency (250000 coverages over 15 years) and unlimited aircraft tyre pressure. In an attempt to anticipate the possible effects of global warming, such as wetter summers and more severe winters, the requirements for resistance to moisture and de-icing liquid were specified for the mix design. This involved assessments of tensile strength of the material after being subjected to freeze thaw cycles in water and in de-icing solution.

For thin overlay with thickness less than 50mm, the presence of good bond between the new surface course and the existing layers is one of the key factors to promote durability of the new overlay. In this case, bond strength test between these layers was also specified.

In summary, the key additional performance requirements included:

- Design stage: stiffness modulus and resistance to moisture and de-icing liquid.
- Construction stage: tensile strength and inter-layer bond strength.

In order to meet the above technical requirements, Colas have used their own proprietary polymer modified binder in the BBA mix design and in the bond coat.

The submitted construction records demonstrated compliance of the materials with respect to mixture volumetrics and composition, performance criteria, surface texture and wet friction characteristics.

The recent resurfacing work at Manchester has enabled a further data to be gathered and a better understanding obtained regarding the early life and in service friction characteristics of ungrooved BBA under UK construction practices and climatic conditions. Calibrated water friction measurements were carried out at regular time intervals during the work both by Colas and MAG (both using Griptester Continous Friction Measuring Equipment), and after the completion of the resurfacing by MAG; these are summarised in Figure 7 [11].

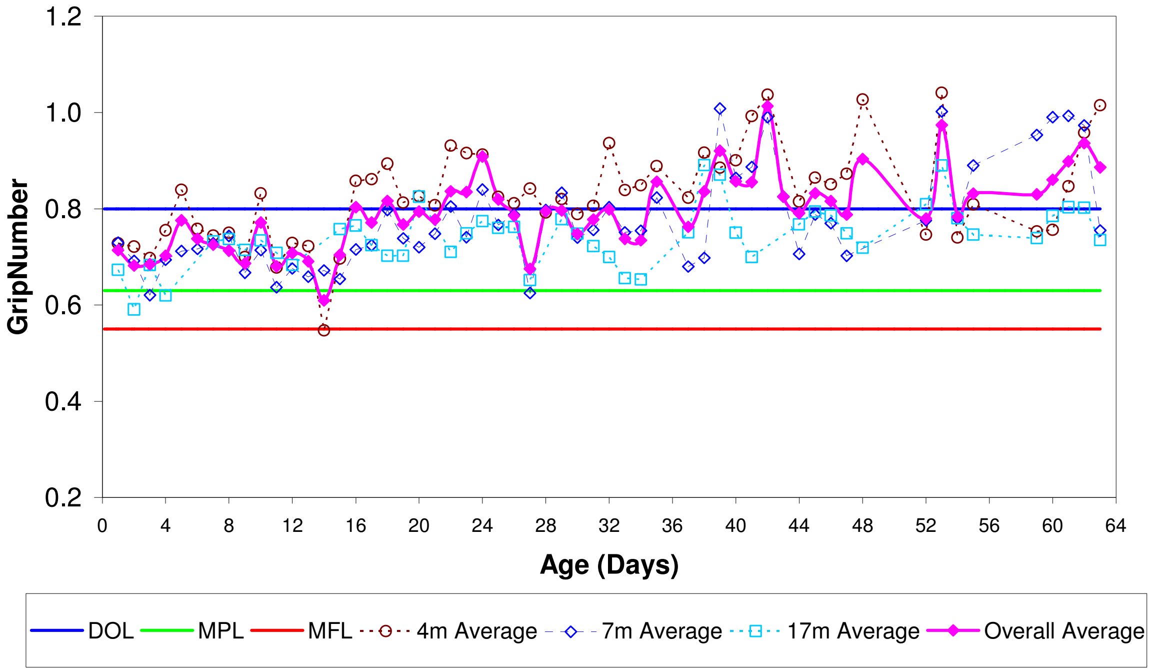

Figure 7 – The Lowest Minimum 100m Rolling Average Friction at 4m, 7m and 17m Offsets [11]

The above results demonstrate rather similar trends as those found on the grooved BBA where the initial friction values exceeded both the MFL and MPL, followed by gradual 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. As shown by the line for the overall average of the lowest mean 100m rolling average friction values (the ‘pink curve’), the DOL was exceeded within the first 18 days. Whilst the general trend in Figure 7 shows a steady increase in friction value with time however, prior to the start of the resurfacing works there were some concerns within MAG about the possibility of the friction falling below the MFL of 0.55 and the impact this would have on operations, particularly in relation to consequential restrictions that would be placed on aircraft take-off weights. Hence, in order to prevent this situation from happening MAG set a minimum ‘trigger’ friction value of 0.6, below which remedial action to improve the friction level would be considered if it were found that any significant area had fallen below this level.

Overall, the above findings demonstrate that the BBA surfacing in all areas of the runway has successfully delivered very good “early life” friction values.

Since completion of the surfacing works, continued regular monitoring of friction levels has been continued by MAG and this has confirmed that the BBA is providing excellent friction characteristics. When compared against the grooved MA on R23L/05R (Runway 2), the ungrooved BBA surfacing appears to exhibit a slower rate of run-off. However, this could have also been contributed by any variation on the general geometry and/or crossfall slope of the two runways. Overall operationally the surfacing continues to meet the required performance criteria.

As a result of the unusually mild early winter, at the time this paper was written there have only been a small number of instances when it has been necessary to apply anti-icing media. In each occasion, the spread rate has been in accordance with the manufacturer’s recommendations for the anticipated weather conditions.

Notwithstanding the long (over 20 years) service life in France, with continued regular monitoring it is anticipated that an increased understanding of the materials behaviour in its later life will be obtained with view to potential future BBA utilisation in the UK.

7. CLOSURES

During the introduction of BBA material to UK airfields, the respective authorities have been very supportive in supplying factual information regarding in service friction data of this material. This has allowed a considerable database of BBA surface characteristics to be developed.

In accordance with CAP 781, a decision about TTURL during runway construction should be made unless grooving or improved friction course has been applied. This paper presents that BBA has offered an alternative and, in ungrooved condition, provided improved surface characteristics enabling further extension of TTURL up to the full length of runway; hence maximising the construction output and faster completion time. Furthermore, this paper also demonstrates how favourable BBA can be over MA, including the versatility and flexibility of BBA material to be designed as either grooved or ungrooved surfacing. The latter may also carry more benefits in terms of whole life cost savings.

It took approximately 5 years to reach the position where ungrooved BBA is now considered as a viable alternative to grooved MA in the UK. Indeed, the recent projects at Southend Airport and most notably at Manchester’s principal runway could be considered as a breakthrough. This project clearly demonstrated its many advantages including high stability, performance and wet friction characteristics, together with the ease of production and laying which helped to maximise output - and thereby significantly reduce costs - and the minimum impact on runway operations that occurs whilst the resurfacing works are being carried out.

ACKNOWLEDGEMENTS

The views presented in this paper are of the authors; they do not necessarily reflect the opinion of the organisations they represent. The authors gratefully acknowledge the support from all parties for supplying the information presented in this paper: Costain, Capita Symonds, Jacobs, Manchester Airports Group and the Authorities for Highland Islands Airports, Isle of Man and Jersey airports.

REFERENCES

1. ICAO (2004), Aerodromes: Volume I, Aerodrome Design and Operations, International Civil Aviation Organization (ICAO) Annex 14, 4th Edition.
2. CAA (2007). Licensing of Aerodromes, CAP 168, Civil Aviation Authority, London.
3. CAA (2008a). The Assessment of Runway Surface Friction for Maintenance Purposes, CAP 683, Civil Aviation Authority, London.
4. JAA. (2007). JAR–OPS 1 Commercial Air Transportation (Aeroplanes), Joint Aviation Authorities, Saturnusstraat, The Netherlands.
5. CAA (2008b). Runway Rehabilitation, CAP 781, Civil Aviation Authority, 20 June, London.
6. AFNOR (2004). Enrobés hydrocarbonés – Bétons bitumineux pour chaussées aéronautiques (BBA). NF P 98-131. Association Française de Normalisation. Saint-Denis. France.
7. Widyatmoko, I., Hakim, B. and Fergusson C. (2011). Pavement Sustainability and Performance Improvement: Case Studies, XXIVth PIARC Congress – Airfield Pavement Seminar, Mexico, 27-30 September.
8. Hill, C.L., R.C. Elliott, C. Fergusson and J.T.G. Richardson (2007). Assessment of European airfield surface course materials, Asphalt Professional No 26. Journal of the Institute of Asphalt Technology. ISSN 1479-6341
9. Widyatmoko, I., B. Hakim, C. Fergusson and J.T.G. Richardson (2007). Introduction of European Asphalts to UK Airfield Pavements, Asphalt Professional No 27. Journal of the Institute of Asphalt Technology. ISSN 1479-6341
10. Toan, D.V., (2005). Runway Friction Performance in New Zealand, International Conference on Surface Characteristics, Christchurch, 1-4 May.
11. Widyatmoko, I., Fergusson, C., Cant, S., Gordon, J and Wood, J. (2012). French Airfield Asphalt Concrete at Manchester Airport. Asphalt Professional No 51. Journal of the Institute of Asphalt Technology. ISSN 1479-6341