DEVELOPMENT OF OPTIMAL RUNWAY FRICTION SYSTEMS FOR SOUTHERN AFRICAN INTERNATIONAL AIRPORTS

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ABSTRACT

The relatively short service life and typically low friction values obtained with conventional asphalt surfacings utilised on airport runways in Southern Africa justified an investigation into the formulation of regionally acceptable optimal runway friction systems. Three possible runway friction layer systems, which comply with ICAO standard, were investigated.

- Semi-Open Graded Ultra Thin Friction Courses (UTFC),
- Special Bitumen Rubber Asphalt Semi-Open Graded (BRASO) Surfacing Layers, and
- Antiskid Specialist Friction Courses.

Trials an implementation at Cape Town, OR Tambo and Sikhuphe International Airports have proved that the performance of both UTFC and BRASO mixes were superior (in terms of friction, surface texture, run-off efficiency) to conventional asphalt surfacing layers. It was concluded from the study that the BRASO friction system is the most cost-effective

1 INTRODUCTION AND SCOPE OF STUDY

This paper reports on a study done for Airports Company of South Africa (ACSA) and for the Swaziland Civil Aviation Authority to investigate and design an optimal runway friction layer/system solution for use on runway resurfacings or new runway construction projects in Southern Africa. The requirements of the new system was that it had to comply with ICAO friction standards (>0.74 for new runways, at 65 km/h Griptester criteria) and also had to reduce maintenance costs and tested to be safe and durable.

Initial worldwide best-practise studies identified three friction course products which were recommended for further study as optimal runway surfacing layers. These include:

- Dual Purpose Semi-Open Graded Ultra Thin Friction Course (UTFC) and Sealing Membrane Combination.
- Special Bitumen Rubber Asphalt Semi-Open Graded (BRASO) Surfacing Layer with enhanced surface texture and friction characteristics [similar to BBA French type mixes],
- Antiskid Specialist Friction Course, consisting of special elongated rock chippings (less than 5 mm size) embedded in a durable sealing binder.

Due to very high local cost of Antiskid trials, it was decided to rather assess the in-situ operational Antiskid layers at Amsterdam and Athens Airport instead of commissioning new trials. Two UTFC and two BRASO mixes were tested, initially on a heavily trafficked taxiway at Cape Town International Airport (CTIA), and later on runway trial sections at CTIA. Further detail testing and full scale application at OR Tambo International Airport (ORTIA) and Sikhuphe International Airport (SIA) followed. Development in Europe on similar BBA type mixes (similar to BRASO) used in latest runway overlay were also assimilated in the implementation study.

This paper reports further on the practical verification of the identified friction systems in terms of functionality and durability of the surfacing, but also in terms of cost effectiveness and lifecycle costs of complete upper pavement systems. Assessment of these friction products in combination with Long Life/Perpetual pavements is also reported on.

2 CONVENTIONAL FRICTION SYSTEMS, NEW BEST PRACTISE PRODUCTS AND OPTIMISING DESIGN CRITERIA

2.1 Conventionally Used Flexible Runway Surfacing Layers

Traditionally, conventional continuous graded asphalt surfacing mixes are used on South African airport runways. Friction measurements and recent maintenance history show costly grooving and rubber removals are frequently required to restore runway friction levels when non-compliant and/or borderline friction values are reached. Grooving of the surfacing layer and destructive “high water pressure” rubber removals also cause these conventional surfacing layers to age and disintegrate prematurely, eventually resulting in structural surfacing layer (and even base layer) damage and cracking failures which necessitate early resurfacing.

In the case of various runway surfacing (CTIA RW 01/19, ORTIA RW 03R/21L and others), it only provided an 8 to 10 year safe surfacing life at an estimated R2 million maintenance cost p.a. (mostly rubber removal, grooving and patching costs).

In addition to the costly annual maintenance effort, the fact that only 8 to 10 years life is obtainable from these traditional surfacing layers before major refurbishment is required, render it an extremely costly surfacing option. Also for new runways (and even resurfaced runways), the level of friction provided (0.45 – 0.65) by this conventional surfacing layers, is marginal when compared to the ICAO required minimum levels (0.74 target for new runway or 0.53 maintenance planning level) and this result in the use of either grooving and/or frequent rubber removal actions to maintain the minimum levels. [Note above friction levels referred to are Griptester (@ 65 km/h, 1 mm waterfilm) measured values and standards – all friction values referenced/stated in this paper will refer to friction values as measured with this methodology to this apparatus].

The other similar relative “smooth” surface layers (i.e. SMA, Semi-Gap mixes) which infrequently were used in the region, experienced the same problems reported above and also do need either destructive grooving or high-pressure water jet cutting.

The alternative surface systems offer significant benefits in terms of cost and safety. In the case of new runways, this will be essential in order to obtain the minimum friction standards for such runways (i.e. 0.74) and to comply with minimum surface texture values of 1 mm without costly or destructive grooving, water cutting or early-on frequent rubber removals

2.2 Essential design principles for optimal runway surfacing systems

The following essential runway safety, functionality and design principles, as identified from the ICAO requirements and other applicable international sources, were considered in the formulation of optimum surfacing layer/system types:

- The specialist friction course layer must increase friction values to consistently meet the ICAO standards for existing and new runways (Griptester >0.74 at 65km/h, etc.).
- These layers preferably should have 12 to 15 years lifespan to ensure that it is cost-effective while ensuring that the runway remains fully operational.
- Riding quality optimisation – the designed layer must accommodate the utilisation of best practise paving and construction methodologies as to obtain maximum final riding quality and transverse water run-off.
- Friction properties – skid resistance and surface texture, for crosswind loading grip and aqua-plane skidding prevention, to be obtained through special mix design and grading type (i.e. Semi-Open Graded, etc), including aggregate selection (Min. ICAO surface texture = 1mm).
- Optimal availability of runway – utilising long-life resurfacing products, state-of-the-art construction methodologies to accelerate construction, and ability to construct product under short occupation time periods should be worked into the optimum system.
- Long life pavement designs (perpetual and semi-perpetual asphalt base layers) need to be incorporated in the study if optimal cost-effective upper pavement systems to be formulated.

It was also noted that the suitability and cost-effectiveness of a friction layer should never be analysed in isolation from its immediate underlying substrata (normally a bituminous bound base or previous surfacing layer). In addition the expected aircraft volumes (i.e. 35 000 commercial/scheduled landings at CTIA p.a. and more than double that amount at ORTIA) also needs to be considered.

2.3 Identified Friction System Alternatives and Functional Mechanism

The key functioning mechanism of the three identified most promising friction system solutions, are summarised below:

- The Semi-Open Graded UTFC enables surface drainage through an open surface texture and through large inter-connected layer voids – two combinations of this product, one with rubber modified bitumen binder and one with straight penetration binder, were identify for further testing consideration.
- The Special BRASO Surfacing Layer enables drainage through a course surface texture resulting in high friction characteristics. This product is a recent developed asphalt product and is currently used with great success on RSA road surfaces. It is similar to the French BBA surfacing layer which is also used on various European Airport Runways.
- Antiskid Specialist Friction Course consists of elongated durable rock chippings which maximise wheel/surface grip. It was developed over the last 30 to 40 years in Europe and has been used with great success at various airports.

3 RESULTS OF LABORATORY AND FIELD PERFORMANCE STUDIES

Various friction course laboratory studies and field trial sections (both on taxiways at first and also three International Airport runways) were constructed and monitored over the last four years in order to develop these products for safe and optimal performance.

It should be noted that the Antiskid layer test section was aborted due to the high initial construction cost quoted by the patent holders of this product (Possehl). However, a thorough international track record of this product's performance exists and in-situ performance throughout Europe was incorporated in this study.

3.1 Results of initial taxiway trial and development study

Based on the initial laboratory and field mix study the following initial product development and enhancing initiative were noted:

- The bitumen-rubber modified UTFC mix appears to not be resistant enough against closing-up of the interconnected layer voids; it was not recommended for use in the runway trial sections.
- The straight pen binder UTFC mix showed better closing-up resistance; however the permeability tests done one month later indicate some closing-up. This guided the design of the follow-up runway trial to be constructed at a lower binder content and a more open-graded structure (higher single size stone content and lower mastic fines) as to obtain high inter-connected voids closing-up resistance.
- The BRASO mix appeared to perform very well under the aircraft loadings. The original after-compaction surface texture varied from ±1.2 mm (at CTIA) to 1.6 mm (SIA) on the runway sections paved. The use of unnecessary vibratory rolling at CTIA resulted in too much "closing-up" in the surface texture.

3.2 Mix criteria for runway trial sections

The following revised specifications were set for the trial section mixes (based on the literature and initial development study):

Table 1: Mix design criteria for friction layer runway trials

Mix Properties	UTFC Layer	BRASO Layer
• Marshall Voids-in-Mix	13% - 15% target	6 – 7% target
• Voids-in-Mineral Aggregate	22 – 27%	19 – 22%
• Binder Film Thickness	10 µm - 13 µm targets	8 – 10 µm
• Cantabro Durability	$\leq$20	N/A
• Grading	See below	As per RSA COLTO specs for Semi-open Bitumen Rubber Asphalt
• Maximum Aggregate Size	13.2 mm	13.2 mm
- % P6.7 mm Sieve	25% – 36%	
- % P2.36 mm Sieve	18% to 22%	

Mix Properties	UTFC Layer	BRASO Layer
- % P0.075 m – Sieve	5.0% target	
• Field Texture Depth	1.8 – 2.5 mm	1.2 – 1.7 mm
• Field Voids	22 – 25%	6 – 7.5%

(Notes: %P = %Passing; BRA = Bitumen-Rubber Asphalt)

3.3 CTIA Runway Trial Section Results and Performance to Date

The Maintenance Contractor at CTIA, Zebra Surfacings, constructed the runway trial sections in December 2007 on Runway 01/19. The surface condition of the sections are shown in Figure 1 with Figure 2 showing some comparative photo illustrations of the products as compared to the existing continuous graded asphalt surfacing (AC).

A strip of 5 m wide by 70 m long of each of the two products (UTFC and BRASO) was constructed at CTIA Runway 01/19 in the touch down zone in order to determine whether:

- The mix manufacturing process can be executed accurately and consistently.
- The layers can be compacted and laid at night during 6 hours closures to an acceptable standard (to ensure that future application on the runway will not present any risks).
- To assess the after compacted field properties of the product.
- To see how the product performs under aircraft traffic impact/loads.

The technical test results of the trial sections are listed in Table 2:

Table 2: Technical results of trial sections

Property		Unit	Product Type and Criteria		
			UTFC	BRASO	Control (Exist. AC)
Texture Depth:	after 3 months	mm	1.8 mm	1.4 mm	0.3 mm
	after 1 year	mm	1.75 mm	1.1 mm	0.3 mm
Griptester Friction	after 1 month	(μ)	0.82	0.8	0.62*
	after 1 year	(μ)	0.85**	0.8	0.47*
Thickness of Surfacing		mm	25 mm	35 mm	40 mm
LCS Inter-Connect Voids: after 5 months	after 5 months	% ICV	20%	N/A	N/A
	after 12 months	% ICV	18%	N/A	N/A
Field Voids		%	23%#	±8%	4 - 7%

Note: % ICV = % Inter-Connected Voids (LCS Permeability methodology)
Field voids based on experience with mix on N2 before; extraction of cores in-situ not successful
*Average values reported in 2008 and 2009 as measured in touchdowns

**Higher values of 0.85 (to 0.9) measured after 12 months – possible due to wearing of bitumen coating on surface

The visual assessment of these trial areas, done after three years afterwards, are summarised as follows:

Table 3: Visual assessment of friction layer trials on RW 01/19

Property	Product Type and Assessed Conditions		
	UTFC*	BRASO*	Control (Exist. AC#)
Aggregate loss:	None	None	None
Surface Texture Appearance	Rough/course texture; both surface and interlayer voids clearly visible	Rough/course texture; no interlayer voids but stone knuckles visible	Smoothest with low surface voids and no interlayer voids or meaningful stone knuckles visible
Rubber Build Up	None	None in texture	Build up on surface and inside texture in areas
Water Run-Off Efficiency/ Functionability	Run-off inside layer and through surface texture	Run-off through surface texture voids	Surface water mostly accumulate and run on surface

Note: *±12 months after construction
#±18 months after construction

The visual appearance of these product trial sections, placed on RW 01/19 at CTIA, is illustrated in Figures 1, 2.1 and 2.2

(a) Existing AC Surfacing (b) UTFC Layer (high Interconnected Voids) (c) BRASO (course and High Surface Voids)

Figure 1 A close view of the in-situ surface texture of the runway trials

The efficiency under wet conditions of the two alternative friction systems is clearly illustrated below:

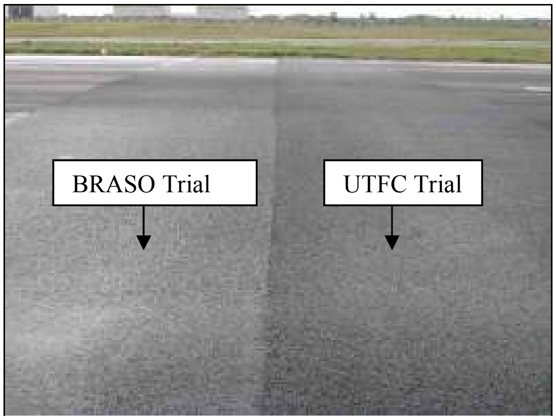

Figure 2.1 Water Run-off Illustrations (Under Rain Condition) of BRASO & UTFC

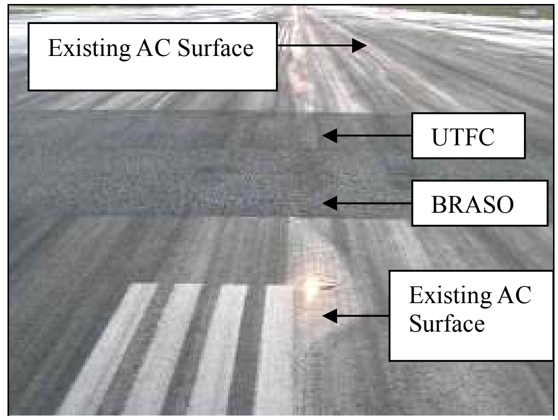

Figure 2.2 Water Run-Off Illustrations Comparison with Existing AC Surfacing

3.4 Sikhuphe International and ORTIA Runway Sections

Various BRASO and UTFC sections were placed at ORTIA (03R/21L) and at Sikhuphe International Airport over the past four years. Both these runways were eventually surfaced with UTFC but significant BRASO sections were done and are monitored. Texture depth values on BRASO mixes in excess of 1.5 mm were recorded at Sikhuphe International Airport and Griptester friction values of in excess of 0.7 (at 95 km/h) and in excess of 0.8 (at 65 km/h) were measured on average respectively. ORTIA (RW 03R/21L) Sections were measured to have texture depths of 1.2mm on average (in touch down zone).

4 SUMMARY OF PRODUCT EFFECTIVENESS AND COST-EFFICIENCY

Initial literature and international best-practise studies indicated that three friction systems should be investigated further.

Only two of the identified friction course products (UTFC and BRASO), were recommended as cost-effective runway friction systems and therefore tested under local conditions. Their in-situ performances were evaluated by means of initial laboratory mixes, taxiway trial applications and eventual runway trials. The trial section results and studies indicated that all three systems (including the costly Antiskid) are more effective, in terms of operationally and durability, than conventional Continuous Graded Asphalt surfacings (AC). A detailed performance comparison of the three products is summarised in Table 4.

Table 4: Comparison of various runway friction system types

Essential Factors & Aspects	Product/System Type			
	UTFC on new Bituminous Base/Surface	BRASO on Substrata	Antiskid on new AC	Control: Conventional AC
Essential Safety:				
ICAO Compliance (friction, other)	Fully compliant over life with μ ≥0.74 (value for new runways) attainable; some rubber removal might still be required over time	Compliant over life cycle with more frequent rubber removals (than UTFC) and possible grooving over end of design life needed;	Full compliant over life cycle; rubber removals required frequently but only at a later stage compared to AC conventional	Initial new runway friction value of 0.74 mostly impossible; later grooving/frequent rubber removals essential over full life
Other Benefits/ Risks	Water spray reduction and aqua-plane skidding risk largely eliminated	Low aqua plane skidding risk; good cross-wind landing grip	Very low aqua plane skidding risk (compared to control); high cross-wind landing grip	Some aqua plane skidding risk and cross-wind landing friction risk
Durability/Design Life:				
Duration	10 – 12 years	12 – 14 years	5 – 7 years (bit. based); 10 – 12 years (resin) in touch downs	7 – 9 years
End condition aspects	Ageing cracking and seal loss will necessitate “mill-removal” of UTFC and at least 10 mm - 20 mm of substrata	Layer might be resurfaced without any removal of BRASO layer	Removing of both Antiskid and substrata layer needed	Ageing cracking and break-up necessitate rehabilitation of surfacing and upper layers
Grooving impact on functional life	Not applicable/possible	Marginal reduction of ±2/3 years life if grooved	Not applicable/possible	Reduce life with ±4 years due to grooving/cleaning impact
Cost Aspects:				
Rubber build-up and removal costs	Low	Moderate	Moderate/High	High
Pavement maintenance	Moderate	Moderate to low	Moderate	Moderate/High
Runway availability	Lowest rubber removals of all systems (±$^1/_3$ to ½ of AC control systems)	Rubber removal approximately 60% to 80% of AC control	Rubber removal approximately 60% to 80% of AC control	Lowest availability due to most frequent rubber removals
	Moderate “end-of-life” maintenance repair occupancies	“End-of-life” surface repairs low due to rubber binder durability	Moderate “end-of-life” maintenance occupations	“End-of-life” surface repairs moderate to high

5.2 Other Technology Aspects to Consider in Friction System Comparison

The latest technology on longlife pavements, especially as utilised internationally on airport and other high performance pavements, was assessed and included in this study of optimum pavement friction systems for runways. It consists of the use of more durable, highly fatigue resistant, thicker pavements structures. This cost-saving technology (mostly developed by the North American Pavement Association or NAPA) is highly applicable to airport pavements and can be used very effectively in combination with runway friction courses to constitute highly cost-effective upper-layerworks systems.

Comparative Life Cycle analyses of typical longlife runway pavement structures (compared to conventional flexible asphalt structures) confirmed the significant cost-reduction (±30%) attainable through the use of these new long-life (40 years plus) pavement structures.

5.3 Life Cycle Costing Comparison of Various Friction and Upper Layer Systems

Table 5: 30 years life cycle cost analysis of various friction systems

Equivalent Friction System	UTFC Type		BRASO Type		Antiskid		Conventional	
Equivalent Friction System (placed on existing new bitumen substrata)	23 mm UTFC on 35 mm surfacing		35 mm BRASO		5 mm Antiskid on 35 - 40 mm AC		40 mm AC Surfacing	
Initial Construction Cost (P&G's, Design, Night Construction, all included)	R100 + R120≈ R220/m^2		R160/m^2		R250 + R130 ≈ R380/m^2		R150/m^2	
Rubber Removal Costs**:	R150/m^2/ 30 years		R240/m^2/ 30 years		R240/m^2/ 30 years		R300/m^2/ 30 years	
Maintenance Costs**:	R99/m^2/ 30 years		R47/m^2/ 30 years		R22/m^2/ 30 years$^{\#\#}$		R115/m^2/ 30 years	
Occupation Costs**:	R38/m^2/ 30 years		R23/m^2/ 30 years		R48/m^2/ 30 years		R60/m^2/ 30 years	
	Yr		Yr		Yr		Yr	
First Repair/ Replacement Cost:	12	R240m^2	14	R160m^2	9	R400m^2	9	R170/ m^2
Second Repair/ Replacement Cost:	24	R240m^2	28	R160m^2	18	R400m^2	18	R170/ m^2
Third Repair/ Replacement Cost:		N/A		N/A	27	R400/m^2	27	R170/ m^2
Unused End Value (Neg. Cost) Minus Structural Salvage Value in year 30:	- R120 + R20*/m^2 ≈ - R100/m^2		- R137 - R40$^{\#}$/m^2 ≈ - R177/m^2		- R266 + R*20/m^2 ≈ - R246		-R50+ R20 ≈ - R30m^2	
Life Cycle Cost (Undiscounted): 30 years	≈ R30/m^2/yr		≈ R20/m^2/yr		≈ R60/m^2/yr		≈ R37/m^2/yr	
Life Cycle Cost (Undiscounted): 20 years	≈ R30/m^2/yr		≈ R22/m^2/yr		≈ R50/m^2/yr		≈ R37/m^2/yr	

Note: *Removal cost of R20/m^2; #Salvage value = ¼ of initial thickness of BRASO; **from initial detail report/study

6 COST EFFICIENCY AND RECOMMENDATIONS

Combinations of trial sections and full scale application (ORTIA, SIA and CTIA) had prove that both UTFC and BRASO runway friction systems are safe, ICAO compliant, durable and cost-effective alternatives to either grooved or ungrooved conventional asphalt surfacings. It was further concluded from the study that the BRASO friction system, which is similar to the France BBA mixes used on European runways, is the most cost-effective solution at a comparative life cycle cost (30 years average) of approximately R20/m^2/year versus the UTFC and Conventional AC layers at approximately R30/m^2/year and R37/m^2/year respectively. The Antiskid layer at R60/m^2/year is, although an excellent product, not cost-effective for local Southern African application. Over a shorter life cycle comparison (i.e. 20 years), the UTFC and Antiskid layers are slightly more comparative with the BRASO, although still approximately 35% and 100% higher in cost; however, the full benefit of the BRASO system is not fully appreciated or encountered for over this shorter evaluation period. If local Antiskid product development proofs to be possible and performance verified, this might become the most effective system in time.

Only the UTFC layer may be recommended above the BRASO layer system due to its somewhat superior friction properties over the design life (±0.85 to 0.8μ initially, vs. 0.80 to 0.75μ initially for BRASO). However, both cost implications, life-cycle duration (10 to 12 years for UTFC vs BRASO's 13 to 15 years) and other special safety factors (downpour intensity at Airport, cross wind friction needs, etc) should be considered in line with both Table 5 and 6 in order to select the optimum friction system for each specific application. Both layers however satisfy the overall objective of complying with ICAO friction values, both initially and thereafter (over a meaningful life period) without costly frequent cleaning/grooving maintenance.

Overall it was found that the selection of optimal runway friction systems, together with a long life pavement technology application, could reduce the life cycle costs of major Southern African (or Sub-Saharan) airport runways (new or to-be-rehabilitated ones) by an estimated 30 to 40% or an equivalent of R200 million per runway over a period of 40 years.

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KEY WORDS:

Friction Layers, Runways, Ultra Thin Friction Course, Antiskid, Bitumen Rubber Asphalt Semi-Open Graded Surfacings