

INNOVATIVE MATERIALS AND PAVEMENT DESIGN INCLUDING THE USE OF ENVIRONMENTALLY SUSTAINABLE PRODUCTS: CASE STUDY AT OR TAMBO INTERNATIONAL AIRPORT

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ABSTRACT:

KEY WORDS: Airport Pavement, Sustainability, Environment, Asphalt

This paper reports on the use of innovative design methodology including the use of environmentally sustainable products at OR Tambo International Airport (ORTIA) over the past eight years. As supported by various cases studies presented herein, this innovative design approach has been verified by the excellent performance of various pavement structures over this 8 year period (e.g. heavy duty taxiways, haul roads, aprons etc). It is also shown that the use of proven (e.g. Reclaimed Asphalt) and new (e.g. Carbon Black) environmentally sustainable products, combined with innovate designs, offer significant cost advantages ($\pm 20\%$) when compared to the conventional products and design methods. Additional benefits included $\pm 25\%$ reduction in CO₂ emissions and a considerable saving in virgin construction materials.

1 INTRODUCTION

This paper discusses aspects of the innovative materials design criteria and specifications, including the use of recycled materials and innovative volumetric mix designs, that were developed for airfield pavement applications (runways, taxiways, service roads and aprons). These criteria and specifications have been verified over the last 8 years through their successful performance in trial sections and completed projects. Specific reference is made to the use of environmentally sustainable materials.

In addition to these successfully completed projects and trials sections, future investigations into new technologies, through new and existing trial sections, are also being undertaken in conjunction with ACSA.

An essential part of a pavement and materials design is the identification of alternatives and the selection of the most appropriate solutions in terms of cost effectiveness and more recently the environmental benefits of each alternative. The correct methodology to evaluate the environmental benefits is essential, as production suppliers of environmentally friendly products tend focus only on the advantages of the products. This paper discusses how the environmental benefits for each alternative could ideally be calculated – similar to a cost comparison.

Case studies of cost effective and sustainable asphalt products in various stages of development (proven performance, successful field trials and current developments) are presented in the paper. Two of these case studies show how innovative thinking and optimized design on shorter term or non-permanent works can result large savings for the client.

2 BACKGROUND

Historically, entrenched asphalt mix design methodologies and specifications limited the use innovated design practices (e.g. use of high VIMs mixes combined with very coarse continuous gradings), resulting in the use of expensive modifiers to achieve required performance criteria, in particular resistance to deformation. This paper deals with design practices and criteria, that deviate from standard airport asphalt mixes design criteria and that high performance mixes can be designed with high VIMS ($\pm 5,5\%$) given that appropriate controls is in place (e.g. stringent density specifications and layer thickness control).

Prior to 2005, the Airports Company of South Africa (ACSA), as in the case of many road authorities, primarily used virgin construction materials in all their reconstruction, rehabilitation and new construction of pavements. In the past, many road authorities had entrenched design methods and were reluctant to allow the use of reclaimed asphalt (RA), especially in asphalt designs, thereby limiting the opportunity for innovation in this field. Waste materials (i.e. mill asphalt material) were mostly spoiled or used as unbound selected materials during road and airport pavement rehabilitation works. In the past 5 years however, ACSA has encouraged consultants to be more innovative in their pursuit of more cost effective design solutions. More recently, ACSA have also embarked on a drive to encourage innovation that leads to more environmental friendly and sustainable solutions.

Future development plans at ORTIA, which allow for a significant amount of new airfield infrastructure (up to 2 million tons of new asphalt and concrete pavement on taxiways, aprons and runways over the next 10 years), are therefore an ideal opportunity to implement the successes of the past five years and to continue the research for more cost effective and sustainability enhancing materials and designs.

3 DESIGN PRINCIPLES, CRITERIA AND SPECIFICATIONS

Airfield pavements, and in particular asphalt mix designs for use on airfields, are a specialized area. In many cases, mix designs used for road construction are totally inappropriate in airfield applications. Unique loading conditions, ranging from high static loads on aprons to non-trafficked areas such as shoulders exist on airfields and each condition requires a unique solution in order to maximize the life of the pavement.

The use of modified asphalt mixes for heavily loaded airfield pavements is usually specified in order to meet the stringent durability and deformation resistant properties required for such pavements. However, innovative materials design, where modifiers are only used as a last resort (once it has been proven that the performance specifications cannot be met with un-modified mixes), and where the use of 15% to 20% RA is specified, can and has been successfully used to ensure cost savings for the client and to reduce environmental impacts. In too many cases, modifiers are specified too easily before exploring these other pioneering material design alternatives.

Based on extensive in-house research, full scale field trials and from the results of successful asphalt projects, various specifications have been developed for ACSA for the use in different loading conditions such as runways, taxiways and non-trafficked surfaced shoulder areas. The specifications, as used over a period of 8 years) for typical asphalt base and wearing course mixes for application in a code F taxiway are illustrated in Table 1.

The enhanced pavement life performance and durability criteria required for a taxiway for example can, as mentioned, be met without the use of expensive modifiers through using the following innovative asphalt mix design principles, which, in many cases, deviate from previous design approaches.

- 1) Resistance to deformation of a wearing course, as required by the MMLS rutting criteria, can, in most cases, only be achieved with unmodified mixes when the Marshall Voids in Mix (VIM's) is 5% and higher together with a continuous grading that targets the coarse side of the standard COLTO medium grading envelope. The material passing the 2,37mm sieve is typically 37% and even lower.

Table 1: Typical Design Criteria Required

Property	Unit	BTB		Wearing course	
		Min	Max	Min	Max
Target voids in mix	%	4.7	5.2	5.0	5.5
Filler/bitumen ratio	-	1.3	1.6	1.3	1.6
4 Pt Beam fatigue repetitions to failure at 5°C at 350µ (100% Marshall)	200 µ	2400k	-	2400k	-
	350 µ	200k	-	200k	-
VMA	%	15	-	16	-
Indirect tensile strength @ 25°C	kPa	1000	-	1000	-
Average Micron strain deformation per cycle in the Dynamic creep test in the 2000 – 3000 cycle range	Microns / cycle	-	0.4	-	0.4
MMLS Rutting (100k repetitions, 93% RICE briquettes, Dry, 50°C)	mm	-	1.3	-	1.3
Binder film thickness	Micron	7.0	-	7.0	-
Marvel Penetration on joints (before refusal)	Liter/h	-	3.0	-	3.0
Voids in mix @ 300 gyrations of the Superpave Gyrotory Compactor	%	3.0	-	3.0	-

Note: Modifiers only to be used if above criteria cannot be achieved with standard penetration grade bitumen.

- 2) With the high VIMS and coarse gradings, proper field compaction is essential in order to achieve the required durability and fatigue requirements. A minimum compaction of 93% maximum theoretical density (Rice density) is strictly enforced and statistically controlled during construction. To achieve this density a minimum layer thickness of 50mm is generally required. Also the correct rollers/compaction equipment, paving methods and the accurate control of the temperature of the mix are essential to achieve the high minimum density specifications.
- 3) Permanent deformation is also controlled by enforcing an upper field compaction limit of 96% of Rice density to prevent over-compaction. This is seldom a requirement in project specifications and most deformation problems (in particular at slow moving application and static loads) can be related to very high in-situ density (over compaction) of asphalt.
- 4) Tighter tolerance specifications, such as a tolerance of plus or minus 0.2% for binder content and plus or minus 1% for VIMS (usually 0.3% and 1.5% respectively) are also specified to ensure a consistent mix is produced.

4 COST AND ENVIRONMENTAL BENEFITS OF INNOVATIVE MIXES

The cost and environmental benefits of various pavement design options, and particularly with new technologies, must be calculated very carefully to ensure that the correct decision regarding their application is made.

Cost benefits of a specific pavement design must be calculated over the design life of the product using standard financial models (e.g. net present value) that take into account the total cost of construction and future maintenance requirements. In practice however, it is often difficult to motivate a better long-term solution, with higher immediate capital expenditure requirements, under financial budget constraints and the need immediate repairs/upgrading.

The environmental impact of a particular solution can reasonably accurately be estimated during a design process using published embodied energy and emission values of various construction materials.

These published embodied energy and emission values are indicated in Table 2.

The impact of various pavement design options can then be calculated. Using a similar approach as in the case pavement design options (costs/m²) calculations, the total embodied energy and emission can be determined by taking the amount of material used times the units energy and emission values. Illustrated examples are shown in Table 3.

Table 2: Typical embodied energy and emission value of construction materials

	Embodied energy	Emissions
	MJ/kg	kgCO ₂ /kg
Aggregate ¹	0.15	0.008
Bitumen ²	44.7	1.5
Cement ²	7.9	0.8
Fuel ²	43	2.7
Asphalt ¹	2.41 (0.8 [#])	0.14
Concrete ¹	1.24	0.127
Steel ¹	19.7	1.72

G Hammond et Al (2006)

Note 1: To be used in pavement design estimates/

Note 2: To be used when more detail is required

When asphalt is used as waste product i.e. RA incorporated in the mix

Table 3: Embodied energy and emission per m² of various broad pavement design options.

	Unit	Asphalt	Asphalt with 20% RA	Warm Mix Asphalt	HiMod Asphalt	Concrete	UTCRCP*
Thickness of layer		120mm	120mm	120mm	80mm	330mm	50mm
Total energy/m ²	MJ/m ²	694.1	555.3	680.2	462.7	1059.9	459.1
Emission/m ²	kgCO ₂ /m ²	40.3	35.0	39.5	26.9	107.4	42.3

Note: Ultra Thin Continuously Reinforced Concrete Pavement

Environmental benefits of new products, e.g. “warm mix asphalt”, need to be carefully calculated and compared to existing product by impartial/objective industry bodies. Promoters or manufacturers might not give the full picture when promoting new products. Although warm mix asphalt does have its place and certainly does offer advantages, it is important to evaluate the entire manufacture, transport, construction and life cycle of a new product when calculating costs and environmental benefits. For example, many promoters of warm mix asphalt additive emphasized the energy savings that can be obtained during manufacture, i.e. a 10% saving in fuel due to the lower temperatures at which warm mix asphalt can be constructed. However this translates to only a 2% saving in the total embodied energy of asphalt (taking into the energy values of bitumen, aggregate and transport) without taking into consideration the environmental impact of the manufacturing and transport of the additives.

5 CASE STUDIES; CODE F TAXIWAY ASPHALT MIXES

Innovative materials design and the effective use of RA and carbon black has been used with success in the following heavy-duty code F taxiway projects:

- Echo taxiway (2005) – rehabilitation and widening
- Hotel taxiway (2006) – rehabilitation and widening
- Yankee taxiway (2007) – rehabilitation and widening
- Alpha, Brava, India, Charlie taxiways (2008) – rehabilitation and widening
- Papa taxiway and Extension of Charlie Taxiway (2009) – new construction

5.1 Innovative designs

By optimizing the mix design through using the specifications and innovative volumetric designs previously discussed, the use of modified mixes was limited only to when the performance criteria were not being achieved. Based on a total volume of asphalt placed of 200,000 tons and a saving of about R40/ton for not using modifiers, a saving of R6.5 million for ACSA was achieved over the last 5 years.

Optimum pavement material selection and pavement designs in combination with stringent construction specifications, in particular asphalt joint construction, also resulted in the implementation of more cost effective pavement designs with the same expected design life for new heavy duty Code F Taxiway. The new pavement structure used on the extension of Charlie Taxiway is given below as an example.

- 100 mm of asphalt
- 150 mm G1 quality crushed stone base,
- 250 mm C3 quality cement stabilised subbase,
- 300 mm of selected subgrade (150 mm G9 lower, 150 mm G7 upper).

5.2 Effective use of Reclaimed Asphalt (RA)

The use of RA in the pavement projects at ORTIA was intensively researched through an international best-practice study. This also involved intensive investigation into advanced methods and technology application. Various product trial sections were installed to verify product performance over the past 5 years where between 10% and 20% by mass of mix of RA was used. Successful implementation of RA containing asphalt mixes was then carried out and has resulted in a saving of 38 000 tons of new aggregate and 1 200 tons of new bitumen at a cost saving of R12 million for ACSA. This saving and lower impact on

the environment was gained without having a detrimental effect on the quality of the final asphalt product or the expected pavement design life.

5.3 Long life shoulder mixes

Because the shoulder mix is not subject to constant heavy aircraft loads, (although a certain structural strength is still required as they are used by heavy vehicles such as fire trucks, and construction equipment) they become dry and brittle and start to crack, which accelerates the failure of the shoulder surfacing.

The successful introduction of the innovative carbon black modified mixes on taxiway shoulders has extended the shoulder areas' life by 50% compared to standard asphalt. Further innovative pavement design, based on low traffic volumes, together with the use of salvaged materials from adjacent sites has seen a successful cost saving reduction in the pavement structure for the shoulders. The following pavement design has been used for the construction of new shoulders on taxiways:

- 45 mm asphalt using a 10% carbon black modifier
- 125 mm G3 quality crushed stone base, obtained from salvaged/recycled layerworks on adjacent sites and/or from commercial sources
- 125 mm G5 quality Subbase obtained from salvaged/recycled layerworks on adjacent sites and/or from commercial sources
- 300 mm of selected subgrade (150 mm G9 lower, 150 mm G7 upper)

The use long life carbon black modified mixes is about 3% higher in terms of initial construction cost, but will results in savings of $\pm 35\%$ over time (on a discounted net present value base) and effective saving 50% materials usage (aggregate and bitumen) over the long term.

6 CASE STUDIES: SHORT TERM PAVEMENT STRUCTURES/TEMPORARY WORKS

A number of pavement structures requiring a shorter design life were also constructed. The use of innovate designs focusing on the use of recycled materials resulted in cost savings to ACSA and had the added advantage of the environmental benefits associated with the use of recycled materials.

6.1 Reclaimed asphalt heavy duty haul road (5 years)

As part of the new airport developments, a heavy-duty haul road was required to transport up to 1.1 million tons of new construction materials to the airfield. Due to pressure from the local community, the residential roads leading to the airfield accesses could not be used. A new dust free road, 1,5km long, therefore had to be constructed to carry the construction vehicle traffic.

After a number of trials sections (that included various methods of stabilization of the reclaimed asphalt), the following method was effectively implemented.. First a 150mm gravel base layer was constructed. This was covered by a 150mm un-compacted RA layer and was graded to level. The RA layer was sprayed with an emulsion at a rate of $2l/m^2$ and compacted with steel wheel rollers and then immediately subjected to heavy-duty construction traffic.

Apart from small isolated areas where poor subgrades existed, the performance on the haul road over a one-year period was excellent and limited maintenance was required compared to a standard gravel haul road. Potential also exist to use this approach in the mining sector.

6.2 Apron of aircraft maintenance facility (5 years)

Due to the extension of the Charlie taxiway, the adjacent aircraft maintenance tenets required a new apron for code C planes. The following pavement design was used:

- 50mm layer of recycled concrete block pavers (that can again be reused later)
- 200mm C3 quality cement stabilized base layer
- 150mm G6 selected fill layer

The approach compared to standard 330mm thick concrete pavement structures resulting in a saving to ACSA in excess of 250%.

6.3 Taxiway bypass (8 months)

Due to the construction of an underpass under Hotel taxiway, and due to the heavy air traffic demands along the Hotel Taxiway route, a taxiway bypass was required for an 8-month period. A thin asphalt surfacing layer with a lower quality base material was used as seen the pavement structure below:

- 50 mm continuously graded BTB using 40/50 Pen Grade binder
- 150 mm G3 quality crushed stone base
- 250 mm C3 quality cement stabilised subbase.
- 300 mm of selected subgrade (150 mm G9 lower, 150 mm G7 upper).
- Up to 3 meters of fill obtained from on site sources
- Building rubble as a replacement for expensive rock fill was used due to wet swamp conditions.

Very minor defects were reported while this short-term pavement was subjected to code E traffic (e.g. 747 and other code E cargo planes). All the material was immediately re-used in the adjacent Papa taxiway project.

7 CASE STUDY: SUCCESSFUL TRAIL SECTIONS

Based on a number of development studies and full scale field trails the following innovated asphalt designs have been found to have potential and are likely to be implemented in future airport projects.

7.1 Long life BRASO runway friction layers

Traditionally, conventional continuous graded asphalt surfacing mixes are used on South African airport runways. Recent maintenance history shows that costly surface grooving and rubber removals are frequently required to restore non-compliant and/or borderline friction measurements on runways. 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 deeper base layer) damage and cracking or interlayer shear failures which necessitate costly premature resurfacing.

In the case of the previous surfacing layer of RW 01/19 at Cape Town International Airport, it only provided an 8 to 9 year safe surfacing life at an estimated R2.0 million maintenance cost per annum (mostly rubber removal, grooving and patching costs).

A number of trials utilizing high friction mixes were placed in the runway touch-down zone of at Cape Town International Airport and the study concluded that the Bitumen Rubber Asphalt, Semi Open-graded friction system is the most cost-effective at a comparative life cycle cost (30 years average) of approximately R20/m²/year versus the Ultra thin friction course and Conventional AC layers at approximately R30/m²/year and R33.3/m²/year respectively.

Overall it was found that the selection of optimal runway friction systems, together with a long life pavement technology application (such as Hi Modulus Asphalt discussed below) could reduce the life cycle costs of ACSA's major 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.

7.2 Hi Modulus Asphalt (HiMA) (also refer to as EME (Enrobé à Module Élevé))

Hi-Modulus Asphalt is currently widely promoted and the technology as been widely published. Airport application in full scale projects was been limited to date, but it has been used in a few airport applications in Europe, e.g.:

- Copenhagen Airport (Denmark) - used on Aprons
- Toulouse Airport (France) – current trial sections
- Charles De Gaulle Airport (France) – heaviest traffic in Europe

A trail section on one of the busiest intersections at ORTIA (Bravo and Lime taxiways) is currently being monitored and initial performance appears promising.

Initial findings of the investigation into use of HiMA asphalt on taxiway and runway applications are:

- Due to higher stiffness and increase in fatigue life (2 to 3 times more than normal asphalt) a decrease in asphalt thickness of up to 30% is possible
- Due to higher binder content in HiMA mixes, an initial increase in capital expenditure of about 6% is expected.
- Based on a saving of 45mm of asphalt and milling and heavy rehabilitation projects, the overall the cost savings compared to normal asphalt is R120/m² (R302/m² vs R405/m²)

7.3 Warm mixes

A number of technologies are being evaluated currently (e.g. Foamed bitumen, FT Waxes and Surfactants) but most products that make use of chemical additives have a 5% cost premium.

Of the various technologies, Foamed Asphalt holds the most significant environmental benefits as well as cost benefits, in particular when used in combination with RA.

8 ENVIRONMENTAL BENEFITS

Based on the success of these initial projects these strategic and innovative technologies will enable ORTIA to meet the following sustainability/environmentally beneficial targets on their next 10 year's intended projects:

- 33% reduction in aggregates for asphalt layers ($\pm 500\,000$ ton reduction);
- 22% reduction in bitumen binder for asphalt layers ($\pm 16\,500$ tons reduction);
- 22% lower fuel consumption and CO₂ emissions or a reduction of $\pm 8\,000$ trees equivalent (to obtain carbon neutrality).

9 CONCLUSION

Significant cost savings and environmental benefits can be achieved by utilizing innovative materials and associated pavement and mix design methodologies in combination with the use of recycled materials and the implementation on new product developments.

Similar to a cost comparison of various design options, the impact on the environment should also be assessed by calculating the embodied energy and carbon emissions resulting from a specific design option.

A number of case studies have been presented to illustrate the benefits of innovative and optimized designs in reducing the need for expensive modifiers to meet performance criteria, the environmental and cost benefits of RA and effective use of new modifiers (i.e. carbon black) to enhance durability. Examples of innovated designs for short design life applications have also been discussed (temporary works and haul roads)

Promising new long-term cost saving applications (e.g. BRASO friction systems for runways and HiMA mixes for runway, apron and taxiway base layers) have been successfully evaluated in trial sections and will shortly be implemented in airport projects.

10 REFERENCE

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