USE OF SURFACE TREATMENTS ON PAVEMENTS FOR PASSENGER JET AIRCRAFT

By S. J. Emery[1] and M. W. Caplehorn[2]

ABSTRACT

Asphalt is generally used as the surfacing for flexible airport pavements with airline passenger jet aircraft. In Australia and its neighbouring territories, surface treatments (seals) have been used for many years in remote areas, and for aircraft up to Boeing 767 in size. The suitability of surface treatments; their design, construction and maintenance; and their cost effectiveness are discussed within a framework of practical application.

TERMINOLOGY

Bitumen terminology used in this paper	Terminology used in other countries
Asphalt	Bitumen concrete, premix, hotmix
Cape Seal	A single seal overlain with a thin (5mm) slurry to form a relatively smooth surface texture
Cutter	Jet A1 or AVTUR or kerosine or paraffin
Double seal	Two engineered layers of stone and of bitumen
Fogspray	Enrichment coat
Flux	Diesel, flux oil
Modified bitumen	Bitumen with the addition of rubber or polymers
Surface treatment	Seal
Slurry	Cold microsurfacing, without polymer modification of the bitumen, and with a setting time of 10-24 hours
Stone	Aggregate, chip
Triple seal	Two engineered layers of stone and of bitumen, overlain with a third engineered layer of sand and of bitumen

---

[1] Prof., Asphalt Pavement Engrg., Dept of Civ. Engrg., Univ. of Stellenbosch., Stellenbosch, South Africa

[2] M. W. Caplehorn, Director, Wallace, Emery & Assoc., 4/10 Fremantle Road, Gosnells, Perth, Australia

INTRODUCTION

For flexible pavements carrying airline passenger jet aircraft, the choice of surfacing is generally restricted to asphalt (for example: ICAO Aerodrome Design Manual, 1983). This type of treatment can be expensive to construct in areas which do not have ready access to an asphalt plant. In these areas, the alternative of a surface treatment (bitumen seal) can be technically and financially viable.

In Australia and its neighbouring territories, surface treatments have been used on flexible airport pavements for many years. The aircraft types using these pavements range from Fokker F28 to Boeing 767. Operations have also been reported in the South Pacific with DC10 and L1011 aircraft on surface treatments (McClung, 1992). The experiences built up have led to an understanding of the limitations and practicalities of surface treatments on these pavements.

In particular, this paper draws on experiences at 8 airports with surface treated pavements and served by airline passenger jet aircraft (Table 1). At these airports, the authors' have been variously involved with new surface treatments, reseals, pavement inspections and full-scale pavement investigations. This experience is combined with the results of recent research into bituminous surfacings for low volume roads in southern Africa by the Council for Scientific and Industrial Research (CSIR) and Southern African Bitumen and Tar Association (SABITA) (Emery et al., 1991).

The main advantage of surface treatments over asphalt is construction cost. Many areas do not have access to an asphalt plant, and the infrastructure to support a mobile asphalt plant in terms of materials sources is poor. If materials have to be transported significant distances, the volume of materials required for surface treatments is less than for a thin asphalt. Under these circumstances, a surface treatment can cost as little as half that of an asphalt.

Surface treatments should not be automatically substituted for asphalt, and the limitations to their use are discussed here. Experience in the use of surface treatments on airport pavements and roads has shown important differences between the two applications. These differences are discussed in terms of design, construction and maintenance. The cost effectiveness of surface treatments is compared to asphalt, and their increased maintenance costs and reduced lives are balanced against construction cost savings.

TABLE 1 Airports with surface treatment pavements

Airport (1)	Main runway (2)	Largest aircraft (3)	Movements[a] (4)
Broome, WA	2026m x 45m	F28/BAe146 Boeing 767	8 per day 1 per month
Carnarvon, WA	1679m x 30m	F28	4 per day
Christmas Island, Indian Ocean	2103m x 45m	Boeing 737	4 per week
Derby, WA	1736m x 45m	F28/BAe146	4 per day[c]
Geraldton, WA	1981m x 45m	F28/BAe146 DC9	4 per day 1 per month[b]
Kalgoorlie, WA	1828m x 45m	F28/BAe146 Boeing 727	4 per day 1 per month[b]
Meekatharra, WA	2181m x 45m	Boeing 727	1 per month[c]
Newman, WA	2072m x 30m	F28/BAe146	6 per day

Notes: a: varies with schedule; b: used or was used as an alternate and aircraft type may vary with fleet changes; c: no longer in use

SUITABILITY OF FLEXIBLE AIRPORT PAVEMENTS FOR SURFACE TREATMENT

The suitability of flexible airport pavements for surface treatments varies, and surface treatments should not be considered to be a universal substitute for thin asphalt surfacings. Suitable applications are characterised by:

- Location : areas of lower shear stress,
- Traffic : occasional or infrequent trafficking,
- Design aircraft: lower tyre pressures, lighter aircraft.
- Foreign object damage (FOD) control.

<u>Location</u>
Surface treatments are better suited to the low stress locations. Although most of the runway and taxiway has low shear stress from aircraft traffic, the sections with higher shear stress on the surfacing are the runway turning nodes, runway ends (if these are used for 180^{o} turning), intersections, and (to a much lesser extent) the touchdown zone. These areas are less suited to surface treatments,

and some special treatment may be necessary. It is very rare to see damage due to aircraft braking, and this is therefore not defined here as a high stress area. Aprons are generally medium stress areas, and parking bays are considered to be very high stress areas.

In the low stress areas, the double surface treatment (10-14mm stone on the lower layer and 5-7mm stone on the upper layer; plus a prime) has proved very successful for new construction. The single surface treatment has been used occasionally for general aviation aircraft <5700kg (such as Laverton, Western Australia), but extrapolating research into its performance on roads (Emery et al., 1991) confirms that it is not suitable for airline passenger jet aircraft.

In the high stress areas, the triple surface treatment (double surface treatment with a thin sand seal on top to fill the voids) or a Cape Seal (single surface treatment with a 13mm or a 19mm stone, and a thin slurry on top which almost fills the voids and creates a strong mosaic; TRH3, 1986) can be used. It may be desirable to use asphalt or concrete or concrete block paving in the high and very high stress areas; this has been done at Broome, for example, where the runway, taxiway and apron have a surface treatment and the parking area for 767 aircraft is concrete.

Traffic

The experience to date has been with airports with infrequent or occasional trafficking, and the suitability of surface treatments for intensive trafficking by airline passenger jet aircraft is not known. Surface treatments have been used on roads at traffic volumes more than 100,000 vehicles per day (Colwill, 1991). The materials requirements are more stringent at higher traffic volumes involving stone polishing/abrasion, and possibly modified bitumens. However with these requirements met, it should be possible to accept some increase in traffic volumes on airport pavements with surface treatments, although the contribution of asphalt to the pavement structural capacity would need to be balanced.

Design aircraft

The suitability of surface treatments decreases with increasing size of design aircraft. For the smallest airline jets (40 tonne class: F28 all variants, BAe146-200), surface treatments are generally suited to all pavements, and good success has been had with these at varying levels of traffic over many years. As the design aircraft size increases (and typically the tyre pressure increases), then surface treatments become less suitable and should be confined to progressively lower traffic frequencies. For the Boeing 767, they are suited only to occasional operations. For the Boeing 747, surface treatments are not recommended.

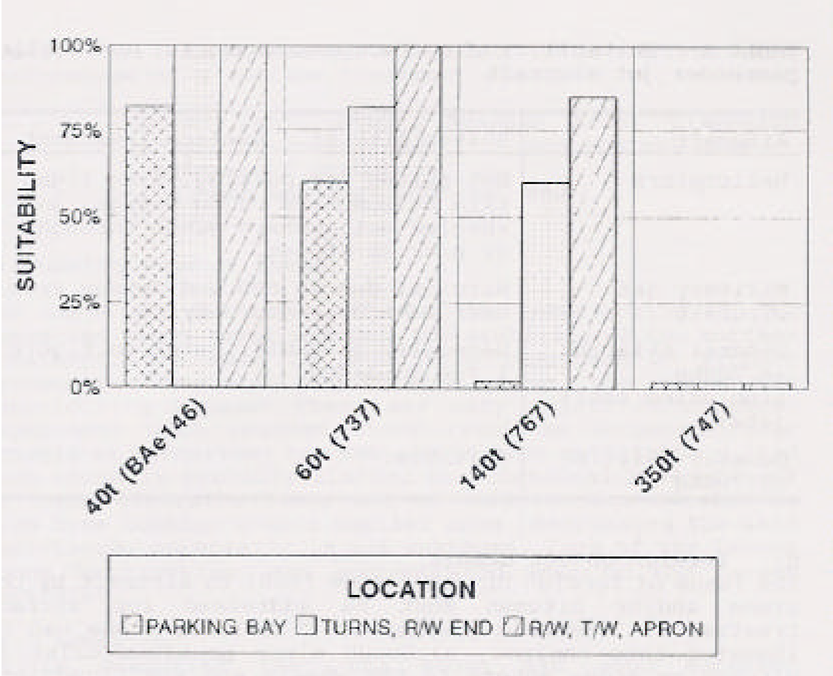

Figure 1. Suitability of surface treatments by aircraft type

The suggested suitability, based on the authors' experience, is shown in Figure 1. The range of design aircraft is 40 tonne, 60 tonne (Boeing 737-400, DC-9, Airbus 320), 140 tonne (Boeing 767-200, Airbus A300), and 350 tonne (Boeing 747). Although this paper addresses airline passenger jet aircraft, the suitability of surface treatments for other aircraft is noted briefly in Table 2.

TABLE 2 Suitability of surface treatments for non-airline passenger jet aircraft

Aircraft	Suitability of a surface treatment
Helicopters	Not suited for parking. Even light skid helicopters cause damage, and wheeled helicopters punch through or pick up stones.
Military jet aircraft	Marginal due to FOD and damage from narrow high pressure tyres.
General aviation >5,700kg (including small jets)	Generally suitable; refer to Figure 1 for guidance.
General aviation <5,700kg	Suitable.

Foreign object damage

The issue of foreign object damage (FOD) to aircraft by the stone and/or bitumen must be addressed for surface treatments. The main problem is that loose stone can be ingested into engines, although minor problems exist if bitumen or stone adhere to the wheels and are flung into the wheel wells or along the underside of the aircraft causing a cleaning problem.

FOD is obviously more of a potential problem with surface treatments than with asphalts, and a specific pavement maintenance programme is essential to deal with it, as discussed later under maintenance. However in over 15 years of airline jet operations on surface treatments, with suitable maintenance, the authors' have encountered no problems with FOD due to stone ingestion.

There have been occasional problems with bitumen in the wheel wells and on the aircraft in the first week after a new seal or reseal, usually when the work has been done in hot weather and the airport is opened to traffic within an hour of completing each stage. These have not caused operational or safety problems.

DESIGN

The design of a surface treatment for an airport pavement is similar to that for a road. The performance of the pavement depends on the:

- characteristics of the stone and bitumen,
- rate of application of the stone and the bitumen,
- texture depth, development of good adhesion, and initial compaction at the construction stage to obtain a dense interlocking mosaic of stone,

and a number of other factors including the strength and flexural properties of pavement, climate, etc. which are common to roads and well documented (NAASRA, 1975). Only the design differences for airport pavements will be discussed here.

Stone

The suitability of the stone is a key issue in the performance of the surfacing. Experience has been that the testing and validation of stone supplies for airport surface treatments is a more extensive process compared to roads. The stone-related factors that affect the performance of a surface treatment are the:

- spread rate, shape, Average Least Dimension (ALD), Flakiness Index (FI) and nominal size,
- single-sized gradation,
- cleanness and dust content,
- strength, and
- adhesion.

All aggregates used in surface treatments, whether stone, crusher dust or natural sand, should conform to the specific quality recommendations on these factors from the various road or airport authorities.

The shape of the stone affects the interlocking of the compacted stone layer and thus the stability of the surface treatment, and this is especially important on airport pavements. The more angular the stone, the better the interlocking because there are many points of contact. Experience with rounded stone (such as screened river gravels at Carnarvon) has not always been satisfactory, and such stone is probably limited to occasional movements of 40 tonne aircraft. Stone not of uniform size results in firm tyre contact over a smaller area (decreasing the skid resistance, especially in wet weather), loss of the larger stone by plucking, and concentrated wear on the larger particles.

It is essential that the stone has good adhesion characteristics, and these should be retained throughout the life of the surface treatment in order to maintain a stable position under the action of aircraft. The presence of one per cent dust on the stone can result in a substantial loss of stone (TRH 3, 1986). Moist aggregate does not adhere well to bitumens (except bituminous emulsions) and if aircraft are allowed to use the surface treatment coat before adequate bonding has occurred, excessive whip-off can occur.

Precoating improves adhesion and obviates the problems associated with stone that is not free of dust and moisture. Generally speaking, it should be mandatory for airport surface treatments. Adhesion agents (generally of the amine type) are either mixed with the bitumen or applied in a dilutant to the aggregate. Laboratory precoating tests with the actual aggregate and various agents are essential to determine the correct agent and application rate. On occasions it has been necessary to use adhesion agents in both the bitumen and applied to the stone in the precoat (such as Broome with a high percentage of quartz).

Caution should be exercised with the application of diesel to the aggregate as part of a precoat. This acts as a fluxing agent, softening the bitumen for several months leading to a possible loss of stone. Precoating at 6-9 litres/m^3 with diesel is equivalent to a flux of 2-4% in the bitumen in the surface treatment.

The aggregate must be strong enough not to break excessively during rolling or under traffic, and this parameter is more critical for airport surface treatments than for roads because of the higher tyre pressures and wheel loads on airports. Recommended tests include the 10 per cent Fines Aggregate Crushing Test (FACT) or the Aggregate Crushing Value (ACV). The Los Angeles abrasion test is not especially applicable to airports since it is a wear test rather than a crushing test. Experience has been that a polished stone value requirement is not generally applicable due to the low traffic on an airport.

The stone must not weather during the life of the surface treatment. This property is more difficult to assess, but is generally specified by a minimum percentage ratio of soaked/dry 10 per cent FACT. In addition to this the stone should be inspected visually for the presence of inferior material, quartz (poor adhesion), and harmful minerals such as pyrite; a hand microscope is recommended.

Various test limits have been adapted from Australian and South African road and airport specifications to give a partial specification for stones for surface treatments on airports (Table 3). Other specifications such as grading can be taken directly from the road specifications.

TABLE 3 Partial specification for airport sealing aggregates

TEST	FUNCTION	SUGGESTED LIMIT
10% FACT dry	Aggregate crushing	≥ 210 kN
Ratio soaked/dry 10% FACT	Weathering	≥ 75%
ACV[a]	Aggregate crushing	≤ 21
Fines	Cleanliness	≤ 0,5% passing 0,425mm sieve
Stripping test	Adhesion	Varies with test type
Flakiness Index	Shape	≤ 30%

However in some areas, stone which meets this specification is just not available economically, and a marginal stone must be used. In such cases, the use of a triple seal or Cape Seal will give additional support to the stone and ameliorate crushing to an extent.

Bitumen

Retention of the stone, the degree of stone whip-off, and durability are all related to the adhesive forces developed by the bitumen, and in turn depend on the type, grade and amount of bitumen applied. The bitumen must develop early adhesion and cohesive strength, and must be able to withstand "softening-up" under the normal temperature range encountered in service and to retain the stone under the action of moving wheel loads. Bitumen properties that affect the performance of a surface treatment are the:

- grade and type,
- spray rate, and
- durability.

Bitumen grade and type

The climatic conditions in the region where the surface treatment is to be laid affect the correct grade and type of bitumen to cater for. Extremely hot weather will reduce cohesion, and cold weather will result in a brittle, hard binder. Penetration grade bitumens, cut-back bitumens (i.e. bitumen with added cutter), and bitumen emulsions are used as binders for the construction of surface treatments on roads. However on airports penetration grade bitumens are preferable because of their rapid improvement in cohesive properties after spraying. The amount of cutter and flux depends on the climatic conditions. Experience has shown that the amount of cutter should be somewhat reduced on airports relative to roads, and the flux should be substantially reduced. If significant amounts of cutter are required (say > 8%), then the pavement should be kept closed for as long as possible before trafficking, or a specific anti-stripping design used such as a sand seal on top.

Good experience has been found in the warm to hot climate of Western Australia with medium class bitumens (such as Australian Class 160. Typically penetration at 25^{o}C/100g/5s,1/10mm of 80-100; viscosity at 60^{o}C, Pa.s of 60-130 ASTM D4402). Some work has been done with harder bitumens in warm climates (such as Australian Class 320. Typically penetration at 25^{o}C/100g/5s,1/10mm of 60-70; viscosity at 60^{o}C, Pa.s of 140-240 ASTM D4402), but no practical benefit could be identified despite the theoretical advantages. There may be a cost penalty with the harder bitumens, and at Broome in 1992 the tendered price was an extra $US0.20/l for the harder bitumen which is approximately $US60,000 for the entire runway.

The use of modified bitumens on roads has indicated properties which may be of benefit to airport surface treatments and where available are worth considering. Compared to penetration grade bitumens, they typically have improved toughness-tenacity properties and improved temperature sensitivity (Van Zyl, 1991). A higher application rate can be used resulting in a thicker bitumen film thickness and reduced voids, and bitumen rubber modified bitumens retain flexibility for longer than unmodified bitumen (Bergh and Thompson, 1991).

Spray rate

The bitumen spray rate (application rate) for airport surface treatments is higher than that for roads, partly because the lower traffic requires a higher design percentage voids filled and partly because bleeding is rarely an issue so the spray rate can go closer to the limit. A minimum spray rate is required to hold the stone firmly in place and bind it to the underlying surface. There is also a maximum spray rate, which, if exceeded, will overfill the voids in the compacted layer and result in low skid resistance, particularly in wet weather.

In Australia, typical spray rates are 1.35 l/m^2 cold with a 10mm stone (nominal size, not ALD) and 1.2 l/m^2 cold with a 5mm stone (Department of Transport, 1973). At Broome, for example, on a new double seal, the rates used were 1.45 l/m^2 cold with a 14mm stone and 1.2 l/m^2 cold with a small 7mm stone. It is possible to increase the spray rate on the runway outside the central 10 metres by 0.1-0.2 l/m^2 to improve the stone retention in untrafficked areas.

A "split application" of binder (defined below) for double surface treatments can be used to improve early stone retention and avoid any problems of fluxing from a diesel precoat on the top layer of stone, although it is less common now since it is preferred to precoat the top layer of stone instead. Split application and precoated top stone are not combined. The aim of the split application is to provide a fog spray with a hot application rate of 0,8 - 1,0 l/m^2 . This fogspray is subtracted from the total (both layers) calculated binder application rate. The remaining binder application rate is divided between the first and second layers in the ratio 60% for the first and 40% for the second (TRH 3, 1986). A disadvantage of the split application is that it closes the voids and a later fogspray (say at 80% life) is usually not possible.

Durability

The main cause of long term deterioration of surface treatments is the hardening of the bitumen. In Australia, this is primarily through a slow thermal reaction which causes oxidation hardening at high pavement temperatures (Dickenson, 1982). There is an Australian Road Research Board Durability Test for bitumen which has been adopted by most authorities in Australia and its use is recommended to ensure that the bitumen has good durability characteristics.

Texture depth, adhesion and compaction

The design of airport surface treatments should provide for mechanical interlock and support between the stones, and only slight protrusion of the stone above the bitumen. Stones which protrude far above the bitumen are likely to be plucked out by aircraft tyres, especially in turns. A low surface texture is therefore desirable. Experience has also shown that the stone on the upper layer should have a maximum nominal size of 7mm (maximum size - not average least dimension which is smaller). The use of larger stone leads to tyre shredding or excessive tyre wear on wheel spin-up in the touchdown zone.

In the early stages of introducing airline jets to runways with surface treatments, larger stones were experimented with. At Karratha Airport in the mid-1970s, a 10mm top stone gave a very high surface texture of 1.7-3.3mm, but caused unacceptable tyre wear in just four movements of a Gulfstream II (Tuisk, 1977). The runway was urgently rolled with a steel wheel roller and the touchdown area resealed with a smaller size aggregate. No data are available on the grading and ALD of the original stone, but from the unusually high rate of tyre wear, it is suspected that this was a particularly 'large and angular' 10mm stone.

Some texture depth is required to alleviate reverted rubber and viscous skidding problems. A limit of a minimum of 0.5mm and desirably 1mm has been used in Australia (Tuisk, 1977). There is no maximum value yet specified. Measurements at a number of airports across Australia gave general values in the range 1-2mm for surface treatments (isolated examples in the range 0.5-1.0mm), in the range of 0.25-1.00mm for ungrooved asphalts, and in the range 1.0-2.0mm for grooved asphalts; all using the grease patch method. The texture depth of a Cape Seal is usually low (it presents the appearance of an asphalt), and it is not recommended for use along an entire runway; however it is useful for runway ends and turning nodes.

The final control of texture depth on a new surface treatment or a reseal is best done at construction, and this is discussed below.

CONSTRUCTION

Construction of surface treatments at airports is similar to that on roads. The main differences are rolling and control of texture depth. Rolling is more important on airport pavements than roads, because of their lack of subsequent trafficking. An Australian specification is 1 roller hour per 450 litres of bitumen sprayed for the first seal and again for the second seal (Department of Transport, 1973). This is at least twice the rolling applied on road construction, and close supervision of the contractor is needed to achieve it. Indeed practical experience is that the supervision of an airport surface treatment is very important, and it is somewhat unsatisfactory to leave the project to a supervisor experienced only in road construction.

The final control of texture depth is best done at construction. For runways where operations of medium to large airline jets are envisaged, a prudent construction method is to adjust the average texture of the pavement by applying steel rolling using static three point steel rollers.

At Broome on a new double seal for Boeing 767 aircraft, the high strength of the aggregate meant that static steel rolling did not significantly reduce the texture, and there was concern about stones being stripped during turns. Therefore at the runway ends, a large vibrating steel roller was used to crush the stone. It was observed during 767 operations that some minor stripping occurred while the aircraft was travelling in a straight line on the area just prior to the vibrating steel rolled area. This stripping ceased completely once the aircraft, still travelling in a straight line, reached the area where the surface texture had been reduced. Stripping still occurred where the aircraft was forced to do a minimum radius turn, though clearly the reduction of the surface texture in this area prevented major stripping.

MAINTENANCE

Maintenance of a surface treatment on an airport comprises mainly patching, rolling, sweeping, fogsprays and reseals. Early and ongoing maintenance of an airport surface treatment is essential, and in countries which lack an institutional capability for maintenance, surface treatments are not recommended. Experience has shown that most surface treatments will be damaged by airline jet aircraft during the initial period of their life, particularly at turning areas and to a lesser extent at touchdown areas. It is common in Australia to issue a NOTAM during this initial period requesting "maximum radius turns at minimum speed". Even then, at the very least, there is rollover and stripping of stone at the inside wheels on turns and this has to be patched. The preferred patch method is to sweep the stone back in and then overlay with a thin sand-cement grout (mix of 1:4 cement to sand) and roll in.

One solution is to leave new work closed to aircraft for a month and only traffic it with a maintenance roller. This is not as impractical as it seems, particularly in the case of a surface treatment on a new pavement. Another solution is to use a triple seal or Cape Seal for the high stress areas.

Rolling

Rolling can be an important component of maintenance in the first year or two after sealing or resealing, to compensate for the lack of trafficking. The pavement is rolled during warm weather (surface warm to touch) to knead the stones and bitumen and to push in loose stone. A suitable roller type is the pneumatic tyred roller, with 11 wheels, and an unballasted weight of 6 tonnes which can be ballasted to 12 tonnes. Tyre pressures should be about 600 kPa.

This type of maintenance rolling is negligible in structural terms. With a 12 tonne roller on a pavement designed for 40 tonne aircraft, and taking load equivalencies into account at an exponent of 4 (TRH 4, 1985), six months of maintenance rolling at 3 hours/day on a 2,000m x 45m pavement is structurally equivalent to one aircraft movement. However the effect of the roller on the surface treatment is much greater. It can be assumed that in terms of the trafficking effect on the surface treatment, 1 roller is equivalent to 15 light vehicles (TRH 3, 1986), and so the same six months maintenance rolling is equivalent to 1200 vehicles trafficking.

Practical experience with maintenance rolling has been good, although difficult to quantify. The need varies with each surface treatment. At Broome (new work, double seal), rolling was performed for 3 hours daily for a month after sealing. At Christmas Island (reseal), rolling was performed for 3 hours daily for the first few months. The positive effect in re-embedding loose aggregate can easily be observed. At Newman (reseal with a fogspray shortly afterwards to reduce the stripping), no rolling was needed after the fogspray, although the number of aircraft coverages at Newman is in the order of ten times higher than Christmas Island.

An example of contrary maintenance was observed at Christmas Island (Thomas, 1992), with excessive stripping, which was noted as a combination of failure to continue maintenance rolling, along with excess sweeping with mechanical brooms during warm weather (daily air temperature range 22-28^{o}C) on a surface treatment which was only a year old.

Brooming

Periodic brooming (or sweeping) of a surface treatment is required every month or two to remove loose stone, although it is noted that brooming of any surfacing type is needed periodically to maintain a clean runway from the FOD viewpoint. Brooming should be reserved for the cooler times of the day (surface cool to touch). The broom pressure should be adjusted so that it is not actually picking out stone.

Brooming is a low cost maintenance option. It is possible to reduce the frequency by applying a fogspray (provided there is adequate texture). However the cost of a fogspray is equivalent to five years of daily brooming in the cooler seasons, even before the need to broom for FOD containment, is considered.

Fogspray
A fogspray can be used to improve stone retention, particularly if the bitumen is oxidised and brittle. The application of a fogspray (usually of emulsion diluted 50% with water, and sprayed at 1 l/m^2) is usually triggered by an increase in the amount of loose stone. If the brooming frequency has to be increased to more than once a month, this is usually an indication of problems and a fogspray should be considered. The fogspray reduces the texture depth, and its use is therefore limited by considerations of skid resistance.

Sand seal
If stripping of stone from a surface treatment is noted in its early life, a sand seal may be useful on top to reduce texture depth, and improve stone retention in high stress areas.

Resealing
It is important for good performance that resealing of surface treatments be done before the integrity and impermeability of the surface treatment is lost. Reseal intervals range from 7 to 10 years, depending on climate (oxidation) and seal performance (stone loss). The two are inter-related, and experience is that a reseal is generally indicated by an increase in stone loss after several years of stable conditions. A fogspray can be used to extend the period before resealing. Interestingly, the higher binder application possible on an airport surface treatment with the subsequent increase in binder film thickness and increase in life seems to be countered by a reduction in life due to the low levels of trafficking on an airport.

COSTS

The primary advantage of a surface treatment over asphalt is construction cost, and this is particularly important in outlying areas without a local asphalt plant, which is the case over large parts of Australia and Africa.

Experience has shown that in these outlying areas, the main cost variable is the supply of stone (the authors' experience includes stone hauls of 700 km by road at Meekatharra and 800 km by rail at Forrest). The cost to haul and spray bitumen in remote areas is in the same order of magnitude as non-remote areas.

To quantify the cost differential, a lifecycle cost analysis was performed for a new flexible pavement surfacing in a remote area for the range of surfacings shown in Table 4. The analysis was performed over a 30 year period, and lifecycle cost was calculated from construction and major maintenance costs, and expressed as present worth of costs, discounted at 8% real rate.

The construction cost included bitumen and stone buy, haul and apply, job establishment costs (also known as mobilisation, P&Gs, or set-up), camp and accommodation, site engineer's fee, profit, contingency, and basecourse sweeping. The cost of a prime was considered to be common to all new surfacings and was omitted. The construction costs were taken from a study which considered 27 combinations of size, location and cost in South Africa (Wright et. al., 1990), and were adjusted to 1993 costs and converted to $US. The costs used here were for a typical 90,000 m^2 project with a bitumen haul of 300km and a stone haul of 100km. These were then checked against recent tender prices at Australian airports and good agreement was found.

The cost of grooving was not included for asphalt, since its use is partially climate and traffic dependent. It would however add significantly to the cost of the asphalt and would increase the differential between asphalt and surface treatment. The routine maintenance cost of brooming, crack sealing and patching was assumed to be the same for all surfacings and not included. Even for brooming, this is considered reasonable because asphalt pavements need to be broomed at similar frequencies as pavements with surface treatments to remove foreign objects. The additional routine maintenance cost of rolling was added to the cost of surface treatments. Major maintenance costs such as overlays and reseals were included as noted in Table 4.

The lifecycle costs are shown in Figure 2. The lifecycle cost of surface treatments is less than that of the thinnest asphalt pavement, even though the lives are shorter. The "double seal and repairs" option was included to show the cost implications of problems with the surface treatment; this example required two fogsprays over the entire runway and a sand seal on the high stress areas. Even with the cost of the repairs, the lifecycle cost of the 25mm asphalt was 40.8% higher than this.

The cost analysis suggests that it is probably justified to vary the surface treatment for the low and the high stress areas from the start. The cost of the 'double/triple seal' option was only 7.7% higher than the 'double seal' alone; but the 'double seal & repairs' was 29.0% higher than the 'double seal' alone.

TABLE 4 Surfacings analyzed by lifecycle cost in Figure 2

Surfacing	Construction cost	Pavement history

(1)	$US/sq.m. (2)	(3)
Asphalt 25mm	$4.20	Initial surfacing of 25mm asphalt; overlay every 16 years with 25mm asphalt
Asphalt 50mm	$6.35	Initial surfacing of 50mm asphalt; overlay every 16 years with 25mm asphalt
Double seal	$2.23	Initial surfacing of double seal; resealed every 10 years with single seal
Double/triple	varies	Initial surfacing of double seal in low stress areas and triple seal in high stress areas; resealed every 10 years with single seal
Triple seal	$3.04	Initial surfacing of triple seal; resealed every 10 years with single seal
Double seal & repairs	varies	Initial surfacing of double seal which is unsuccessful; fogspray at years 1 and 8, sand seal in high stress areas at year 1; resealed every 10 years with single seal

<u>Sensitivity analysis</u>
In the sensitivity analysis, a 25mm asphalt was compared with a double/triple seal. The four alternatives were:

- asphalt cost reduced by two-thirds,
- surface treatment cost increased by one-third,
- surface treatment life reduced to 7 years,
- asphalt life increased to 20 years.

The results are shown in Figure 3 and confirm that lifecycle cost differential between asphalt and surface treatments is robust.

<u>Rapid assessment</u>
To enable the lifecycle cost differential between a surface treatment and a 25mm asphalt to be rapidly assessed, Figure 4 was developed. This is used by entering the construction cost of each (the Figure is dimensionless so any currency can be used), and the surfacing choice can be quickly seen.

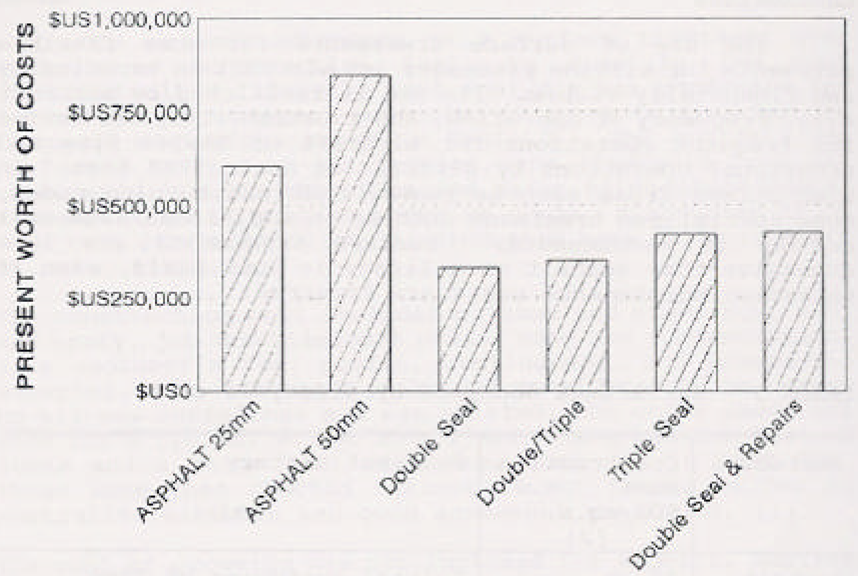

Figure 2. Lifecycle costs of various surfacings

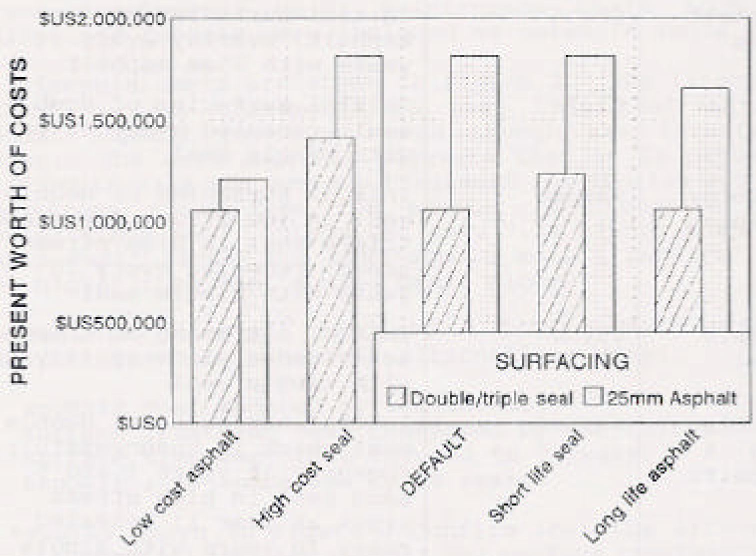

Figure 3. Sensitivity of lifecycle costs

CONCLUSIONS

The use of surface treatments for some flexible pavements for airline passenger jet aircraft is technically and financially viable. Its use is restricted by aircraft size, frequency of operation, and location. They are suited for frequent operations for aircraft of BAe146 size and occasional operations by aircraft of

Boeing 767 size. In high stress areas such as runway ends and turning nodes, some specialised treatment such as an additional sand seal on top is recommended.

There are a number of differences between surface treatments on airports and on roads. In design for airports, they are characterised by small stone sizes, angular stone, mandatory precoating of stone, and higher bitumen application rates. In construction they are characterised by increased rolling and careful control of texture depth. In maintenance they are characterised by maintenance rolling, patching and brooming.

The lifecycle cost of various surface treatments and asphalts has been calculated on a present worth of costs basis over a 30 year analysis period. The surface treatments are less expensive than asphalt, even if excessive maintenance costs are incurred. A sensitivity analysis of construction cost and surfacing life confirm this.

REFERENCES

Aerodrome Design Manual. (1983) Int. Civil Aviation Org., Montreal

Airport Construction Requirements - Local Ownership Aerodromes. (1973) Department of Transport, Melbourne, Australia.

Bergh, A.O. and Thompson, H.C. (1991) "A simple design method for bitumen rubber low volume road applications." Modified Bitumens Seminar, SABITA, Cape Town, .

Colwill D.M. (1991) "Synthesis of "State of the Art Reviews" by Member countries on surface dressing" SPRINT RA 183 Congress, Lisbon

Dickenson, E.J. (1982) "The performance of thin bituminous pavement surfacings in Australia." 11th Proc. Austr. Road Res. Bd., Vol. 11(3), pp35-51, Melbourne.

Emery, S.J., Van Huyssteen, S., and Van Zyl, G. (1991) "Appropriate Standards for Effective Bituminous Seals: Final Report" RDT Report 17/91 for SABITA, DRTT, CSIR, Pretoria.

McClung, L. (1992) "Personal communication." Manager, Airport Technology, Boeing, Seattle.

Principles and Practice of Bituminous Surfacing; volume 1 - sprayed work. (1975) National Association of Australian State Road Authorities, Sydney.

TRH 3 Surfacing seals for rural and urban roads. (1986) National Instit. Road Res., CSIR, Pretoria

TRH 4 Structural design of interurban and rural road pavements. (1985) National Instit. Road Res., CSIR, Pretoria.

Thomas, K. (1992) "Report on airport inspection, Christmas Island, Indian Ocean." Wallace, Emery and Assoc., Perth.

Tuisk, U.U. (1977) "Grooving and texturing of pavement surfaces." Pavement Surface Drainage Symposium, Department of Transport, Sydney.

Van Zyl, R. (1991) "The characteristics of SBR modified emulsions." Modified Binders Seminar, SABITA, Cape Town.

Wright, B., Emery, S., Wessels, M., Wolff, H. (1990). "Appropriate standards for effective bituminous seals: cost comparisons of paved and unpaved roads." Contract report 89/1 for SABITA, DRTT, CSIR, Pretoria.

KEYWORDS
AIRPORTS, ASPHALTS, BENEFIT COST ANALYSIS, BITUMEN, PAVEMENTS