SEALS FOR HEAVY DUTY AIRPORT PAVEMENTS

Stephen Emery, Kubu Australia Pty Ltd, Australia

ABSTRACT

In Australia, seals have been used for many years at airports with aircraft of Boeing 737 and up to Boeing 767 in size, even though asphalt is mainly used as the surfacing on heavy duty airport pavements for airline jet aircraft.

The selection and design of seals for heavy duty airport pavements differs from seals for roads in a number of important ways. The suitability of airport pavements for sealing varies, and seals are not a universal substitute for asphalt. There are operational requirements to be met in terms of texture and friction, which affect the selection. The seal design method is adjusted to reflect airport trafficking. The choice of binder and aggregate is somewhat different from highway seals. Construction and maintenance are generally similar to that on roads, with differences in rolling and ongoing maintenance of seals on airports.

INTRODUCTION

The most common choice of surfacing is asphalt (asphaltic concrete) for flexible pavements used by airline jet aircraft in Australia. This can be expensive for airports with low traffic or where there is no ready access to an asphalt plant. In such cases, a seal can be technically and financially viable, and this paper discusses seals for heavy duty airport pavements. In other countries, a seal may be called a surface treatment, surface dressing, or chip and spray.

In Australia and its neighbouring territories, seals have been extensively used on airports for many years. Their use is common on airports used by light (general aviation) aircraft, and over 200 regional airports have sealed runways (White, 2007). They have also been used on heavy duty airport pavements carrying airline jets ranging from Fokker F28 through Boeing 737 up to Boeing 767 aircraft. Operations have been reported in the South Pacific with DC-10 and L-1011 aircraft on seals (McClung, 1992).

The Technical Working Group of the Australian Airports Association undertook a survey of runway surfacings on medium to large Australian airports in 2004. The survey covered 38 of the main civilian and military airports; the types of surfacings in use are shown in Table 1. It can be seen that the seal is widely used as a surfacing for airline aircraft up to medium size.

Table 1: Surfacings on medium-large Australian airports used by airline aircraft

Runway surfacing	Number of runways by largest aircraft type using runway					
	Saab 340	BAe146	Boeing 717	Boeing 737	Boeing 767	Boeing 747
Concrete runway ends and asphalt centre	-	-	-	1	1	5
Asphalt	2	-	1	8	1	8
Asphalt runway ends and sealed centre	1	-	-	1	-	-
Seal	7	1	1	2	1	-

Seals are commonly used in other countries which have similar surfacing philosophies to Australia, and these include southern Africa and New Zealand. Elsewhere, seals have been used on airports as a friction treatment and the Federal Aviation Administration note their use for the temporary improvement of surface friction (FAA, 1997).

SUITABILITY OF AIRPORT PAVEMENTS FOR SEALS

The suitability of airport pavements for seals varies, and are characterised by:

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

Design aircraft

The suitability of seals decreases with increasing size of design aircraft (Table 2). For the smallest airline jets and airline turboprops (40 tonne class F28 all variants, BAe146-200, and the turboprop SAAB 340 and Brasilia aircraft), seals 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 seals become less suitable and should be confined to progressively lower traffic frequencies. Seals are suited for Boeing 737-800 class of aircraft at moderate numbers of movements (and experience has been gained with aircraft weights to 78 tonnes, and 5-10 aircraft per day).

For the Boeing 767 class of aircraft, seals are probably suited only to occasional operations (and experience has been gained with aircraft weight to 145 tonnes, and 1 aircraft per week). For the heavier aircraft such as Boeing 747, seals are not recommended. For pavement structural reasons, the stresses imposed by widebody aircraft in the basecourse usually favours the use of asphalt as a structural layer.

Location

Seals are better suited to locations with lower horizontal stresses. Although much of a runway or taxiway experiences low horizontal stresses from aircraft traffic, the sections with higher horizontal stresses are the runway turning nodes, runway ends (if these are used for 180 degree turning), intersections, and (to a much lesser extent) the touchdown zone. These areas are less suited to seals, and some special treatment may be necessary. It is very rare to see damage due to aircraft braking, and this is therefore not considered a stress problem. Aprons are generally medium stress areas, although the parking bays are a special case. Viscous flow of bitumen in surfacings under the wheels of a parked aircraft in a hot climate can be a problem and asphalt or concrete is often used.

In the low stress areas, the double seal (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 seal 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. Other seals such as 14/10 have reportedly been successfully used at high bitumen application rates (approximately 4 litres/sq.m).

In the high stress areas, the triple seal (double seal with a thin sand seal on top to fill the voids) or a Cape Seal (single seal with a 13mm or a 19mm stone, and a thin slurry on top which almost fills the voids and creates a strong mosaic) can be used. It may be desirable to use asphalt or concrete or concrete block paving in the high and very high stress areas. However the surface macrotexture of triple seals, slurry seals, Cape Seals, and asphalt is usually less than the ICAO requirements for runways, and attention must be given to ensure adequate macrotexture.

Table 2 Suitability of seals for airport pavement surfacings

Aircraft type	Location		
	Runway, taxiway	**Runway ends, intersections**	**Apron parking**
Airline turboprops and 40 tonne jets (Fokker F28)	Good	Good	Fair
Airline jets 60-80 tonnes (Boeing 737-800)	Good	Fair	Fair
Airline jets 120-140 tonnes (Boeing 767-200)	Fair	Poor	Not suited
Airline jets 250+ tonnes (Boeing 747)	Not suited		
General aviation aircraft	Good		
Military jet aircraft	Poor due to FOD and damage from narrow very high pressure tyres		
Helicopters	Fair	Poor	Not suited for parking. Even light skid helicopters cause damage, and wheeled helicopters punch through or pick up stones.

Foreign object damage

The issue of damage to aircraft by stones and/or bitumen must be addressed for seals. The main problem is that loose stone can be ingested into engines or damage propeller blades, although minor problems also occur if bitumen or stone adheres to the wheels and are flung into the wheel wells or along the underside of the aircraft causing a cleaning problem.

Foreign object debris (FOD) is obviously more of a potential problem with seals than with asphalts, and a specific pavement maintenance capability is essential to deal with it. Given that capability, in over 25 years of experience with operations on seals, the author has encountered only 2 problems with FOD on seals due to stone ingestion, and both were where inadequate maintenance had combined with deficient design and construction.

There have been occasional problems with bitumen thrown into aircraft wheel wells and on to 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 safety problems.

DESIGN

The design of seals is increasingly derived from roads practice (in Australia this is Austroads: 2000 and 2006, and in South Africa, this is TRH 3 1998 and 2007). The road design methods reflect advances in design, but have led to some problems with seal design and maintenance when the difference between roads and airports has not been properly addressed. These differences include:

- Risk of stone damage to aircraft which generally limits the maximum stone size of the top seal coat on airports to 7mm (roads often use 14mm stone).
- Traffic levels on most airports are very low by road standards, which means that the binder application rate is higher than on most roads, and there is insufficient traffic to roll the stone into the bitumen after construction.
- The amount of loose stone tolerated on an airport surfacing is close to zero, which is far less than roads.

The design of airport seals aims 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, or can damage tyres on spin-up. From this perspective, a low surface texture would be desirable but this is contrary to the requirement for good macrotexture for wet weather skid resistance. A balance between the two is needed.

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 may lead 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 seals, larger stones were experimented with. At Karratha Airport in the mid-1970s, a 10mm top stone gave very high surface texture from 1.7 to 3.3 mm, 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. Some designers have reportedly used 10mm top stone in seals which are oversprayed or sand sealed.

Given the small range of stone sizes possible for airports, a particular concern is the combination of aggregates such as 10/7 mm where the second aggregate application is greater than half the size of the first. This is not recommended, for the same reason that it is not suited to roads (Austroads, 2006a). In such cases, the second aggregate can bridge over void spaces in the first aggregate. Binder from the second application is lost into the open texture of the first layer, resulting in insufficient binder to hold the second aggregate application in place and a consequent risk of stripping and stone loss. The same problem can arise if the stone for the first application is overspread and there are insufficient voids to accommodate the second layer of stone.

Airport regulatory standards

Airport regulatory standards exist which require certain functional properties of the runway. These are controlled internationally by ICAO Annex 14 (2004) and in Australia by the Civil Aviation Safety Authority Manual of Standards (2004). The surfacing is required to provide adequate wet weather friction and an average surface macrotexture of at least 1.0 mm over the full runway width and length. The same requirements are not applied to taxiways and aprons.

A seal can usually meet the regulatory requirements in terms of wet weather friction and macrotexture depth; it is a friction treatment in itself. Other surfacings such as asphalt may have reasonable wet weather friction, but are inherently smoother and do not provide enough macrotexture which plays an increasingly important role in wet weather skid resistance at speeds above 80 kph (Benedetto, 2002).

Care is needed when using seal types which have low macrotexture, such as triple seals and Cape Seals, or sand seals to lock in the stone seal. It is important not to reduce average macrotexture below 1.0 mm and thus breach the airport regulatory requirements on runways. These seal types are not recommended for use along an entire runway; however they are useful for high stress areas such as runway ends and turning nodes.

Binder

Binder grade and type

The binder in use for seals on airports is either Class 170 bitumen (viscosity graded unmodified bitumen, with viscosity at 60 ^{o}C of 140-200 Pa.s), or the more viscous Class 320 bitumen (viscosity graded unmodified bitumen, with viscosity at 60 ^{o}C of 260-380 Pa.s). Class 320 has been used in hot-dry and semi-tropical climates with success. However Class 320 has given some problems of stone loss when constructed during cold weather without sufficient cutter and rolling being applied; and its use is probably limited to summer construction. Multigrade bitumen has been used on some recent projects in hot climates.

When sealing in cool weather on airports, the viscosity of the binder is temporarily reduced as it is on roads by the addition of cutter (medium curing diluent such as Jet A1 fuel / kerosene / paraffin). Experience has shown that the amount of cutter should be somewhat reduced on airports relative to roads, and flux (or diesel) should not be used due to its prolonged softening effect on the binder. If significant amounts of cutter are required (say > 5%), then either the pavement should be kept closed for a significant period before trafficking, or a specific anti-stripping design used such as a sand seal on top.

It is generally held that the performance of bitumens may be enhanced by the addition of selected polymers or the use of multigrade bitumens (Austroads, 2006b). These performance enhancements are theoretically relevant to airports, and include improved aggregate retention, reduced risk of bleeding, and improved shear resistance.

Despite the theoretical advantages, experience with modified binders on airports in Australia has been mixed. It is the author’s opinion that modified binders produced in Australia have risks associated with their use, which need to be balanced against the benefits. The first risk is that they can be delivered with different properties to those specified and do not perform at the required level (Neaylon and Busittil, 2007). The second risk is that the PMBs could be storage unstable, and the polymer partly separates out from the bitumen. These risks are of particular interest for airports where the PMB might have to be transported considerable distances from the point of manufacture. Polymer modified bitumen is quite sensitive to variations and/or deficiencies in the transport chain, while unmodified bitumen is relatively insensitive to variations and/or deficiencies in the transport chain (Kubu Australia, 2005).

Binder application rate

The binder application rate for airport seals is generally higher than that for roads because of the low traffic on airports. Most road design methods have mechanisms to rationally design suitable seals for very low traffic roads (which is the equivalent to airports), but too often designs for typical road traffic are used on the airport instead. This leads to too little bitumen to hold the stone. The amount of rolling at construction is also often based on road experience where much less is required than at an airport. Since the airport does not have enough traffic to roll the stone into the bitumen, the stone sits up above the bitumen. The phenomenon is loss of stone (stripping), leading to loose stone and sometimes the entire seal is compromised. In the subsequent summer, it might also lead to what seems to be bleeding; this is simply the bitumen, now uncovered by the lost stone, being hot and sticky, and adhering to tyres.

The suitability of road seal design methods for airports varies. The design of a 7mm single seal (single/single in Austroads terminology), and a 10mm/5mm double seal (double/double in Austroads terminology) are presented here using various seal design methods and compared to airport experience. The Austroads 2000 AP-T09 method (Austroads, 2001), and the Austroads 2006 AP-T68/06 update (Austroads, 2006a) were used, and the South African TRH 3 method of 1998 (TRH 3, 1998) and its 2007 revision (TRH 3, 2007) were used.

A number of common assumptions were made. There was no allowance required for texture depth or embedment, the stone was crushed angular, pre-coated and had some absorption. For

Austroads designs, extra binder of 0.1 l/m^2 has been added to each binder application because of the absorptive aggregate. For TRH 3 designs, no special allowance for absorption is made by the method because the stone was precoated. For the 7mm single seal, the ALD was 5.2mm. For the 10/5 double seal, the ALDs were 6.6mm and 4mm respectively. It was assumed that both applications were placed with no delay between applications.

The traffic was 90 light aircraft movements per day and 10 airline jet movements per day. It was assumed that the traffic was spilt in half because due to wind, half the aircraft use one end of the runway for takeoff/landing and half use the other end for takeoff/landing. Because the wander of an aircraft on a runway is much greater than a road (the lane width is effectively 30m wide and not 3.5m wide), the effect is opposite that of channelisation, and the design traffic was halved again. These traffic reductions would not be used for airport seals where wander was less or where trafficking was not dependent on wind direction, such as on aprons or taxiways.

For the Austroads 2000 method, the Basic Voids Factor was chosen as halfway between the Bleeding Limit and the target, based on airport experience. In the Austroads 2006 method, the central target line is required to be used to determine the Basic Voids Factor in all cases. For the TRH 3 method, the texture target was 0.5 mm for double seals and 0.3 mm for single seals, based on airport experience (texture target in the TRH 3 seal design method is not the same as the as-constructed macrotexture on airports).

The designs for the 7mm single seal are shown in Table 3. The actual airport application rate used is shown the last column. In practice, after three years of trafficking, this proved to be correct in the centre of the runway but proved to be slightly too light on the outer edges of the runway which were essentially completely untrafficked. A fogspray (dilute emulsion) was then used to add 0.2 l/m^2 of residual bitumen to the seal outside the central 10m width of the runway. Generally the road seal design methods relate well to airport experience, except the TRH 3 (2007) method gives binder application rates which will be 0.2-0.4 l/m^2 too low for airport seals.

Table 3 Comparison of 7mm single seal designs

Parameter	Austroads		TRH 3		Actual airport application rate
	2000	2006	1998	2007	
Bitumen application rate (l/m^2 @ 15 ^oC)	1.50	1.35	1.30	1.16	1.35

The designs for the 10/5mm double seal are shown in Table 4. The actual airport application rate used is shown the last column. In Australia, historic Department of Civil Aviation airport seal spray rates for a 10/5 double seal were 1.35 l/m^2 cold with the 10mm stone (nominal size, not ALD) and 1.2 l/m^2 cold with the 5mm stone (Department of Transport, 1973). The historic Department of Civil Aviation method did not recognise absorptive stone, and in the light of experience with this particular stone, it would be reasonable to add extra binder of 0.1 l/m^2 per binder application in line with the typical Austroads allowance. This adjusted rate is shown in the second column of Table 4. For the TRH 3 seal designs, the total binder application rate for both layers was calculated, and the binder application rate for each layer was proportioned as 55% of the total binder in the first layer and 45% in the second.

The Austroads 2006 revision and the TRH 3 2007 revision gave binder application rates which were lower than airport experience has found is necessary. Limited experience with airport seals designed using Austroads 2006 has found these lower binder application rates to be unsatisfactory. Even applying the (high) recommended rolling rates for airports at the time of construction, the stone is not sufficiently incorporated into the (too-lightly applied) binder at construction and with the very low trafficking at an airport, significant stone loss has been experienced.

Table 4 Comparison of 10/5mm double seal designs

Layer	Bitumen application rate (l/m^2 @ 15 ^{o}C)					
	Dept. Civil Aviation (adjusted for absorption)	Austroads		TRH 3		Actual airport application rate
		2000	2006	1998	2007	
10mm first layer	1.45	1.44	1.29	1.51	1.38	1.50
5mm second layer	1.30	1.18	1.06	1.24	1.12	1.20
Total binder	2.75	2.62	2.35	2.75	2.50	2.70

For the design of seals on airports, it is suggested that the 2006 Austroads and the 2007 TRH 3 methods not be used for double seals on airport pavements, and the 2007 TRH 3 not be used for single seals on airport pavements, because the calculated binder application rates are lower than airport experience has found is necessary.

For all these methods, the binder application rate on the runway outer edges, outside the central 10m, can either be increased slightly (possibly by a further 0.2 l/m^2) because of the almost complete lack of trafficking on the edges or alternatively and with lower risk, a diluted emulsion can be applied to the outer edges of runways after construction as necessary.

Stone

The treatment of the stone is a key issue in the performance of the surfacing. Experience has been that the testing and pre-treatment of stone (aggregate or chip) for airport seals is a more extensive process compared to roads. The aggregate used in airport seals should conform to the normal quality recommendations of the various road or airport authorities.

The main difference between airports and roads is that closer attention is paid to adhesion for airport seals. It is essential that the stone has good adhesion characteristics, and these should be retained throughout the life of the seal in order to maintain a stable position under the action of aircraft. Moist aggregate does not adhere well to bitumens (except bituminous emulsions) and if aircraft are allowed to use the seal 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 seals. Adhesion agents (generally of the amine type) are mandatory and are either mixed with the bitumen or mixed in with the precoat. Laboratory adhesion tests with the actual aggregate and various precoat 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 in the precoat. When in hot bitumen, adhesion agents degrade in a few hours and the manufacturer's recommendations should be followed.

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 seal.

The shape of the stone affects the interlocking of the compacted stone layer and thus the stability of the seal, 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.

The aggregate must be strong enough not to break excessively during rolling or under traffic, and this parameter is more critical for airport seals 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). Experience has been that a polished stone value requirement is not generally applicable due to the low traffic on an airport. The stone should not weather during the life of the seal; this property 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. Hard aggregate can cause its own problems with tyre cutting, and steel rolling is mandatory to reduce texture in such cases.

Various test limits have been adapted from Australian and South African road and airport specifications to give a partial specification for seals on airports (Table 5).

Table 5 Partial specification for airport sealing aggregates

Test	Function	Suggested limit
10% FACT dry	Aggregate crushing	≥ 210 kN
Ratio soaked/dry 10% FACT Los Angeles and sodium sulphate soundness	Durability	≥ 75% LA ≤ 25% and Na_2SO_4 ≤ 3%
ACV	Aggregate crushing	≤ 21
Stripping test	Adhesion	Low; varies with test type
Flakiness Index (not applicable for 7mm or 5mm stone)	Shape	≤ 30%
Grading	Particle size distribution	Sieve size — % passing 13.2 mm — 100 9.5 — 97-100 6.7 — 0-40 4.75 — 0-5 0.600 — 0-2

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 in high stress areas and ameliorate crushing to an extent.

CONSTRUCTION

Construction of seals at airports is generally similar to that on roads, with the main differences being the amount of rolling and control of texture depth. Rolling is more important on airport pavements than roads, because of their lack of subsequent trafficking. A newly constructed bituminous seal or reseal needs to be rolled to embed the stone into the bitumen, and to ‘work’ the bitumen around the stone. On the highway, 20% of the necessary rolling is done at the time of construction, and the remaining 80% is provided by traffic. On runways and taxiways, the traffic is much less than on highways, and more rolling should be done at construction.

The historic airport 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); and in modern airport specifications this has been adjusted to one roller hour per 500 litres of hot bitumen sprayed.

This is typically four times the rolling applied on road construction. At normal production rates on airport seals, balanced production is achieved with 5 operating rollers and a bitumen sprayer; four rollers or less are just not sufficient to apply the specified rolling. Practical experience is that the supervision of an airport seal 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. This is essential if large hard aggregate has been used.

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

Timely and ongoing maintenance of an airport seal is essential, and in countries which lack an institutional capability for maintenance, seals are not recommended for airports. Experience has shown that most seals 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. Various patch methods are used, such as sweeping the stone back in and then overlay with a thin sand-cement grout (mix of 1:4 cement to sand) and rolling, or rolling in coarse sand, or using bitumen emulsion plus sand. Another 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 seal on a new pavement.

Ongoing maintenance of a seal on an airport comprises maintenance rolling, sweeping, and a possible fogspray (enrichment coat or dilute emulsion).

Maintenance rolling

Maintenance rolling is usually provided by further rolling during the first few years of life of the seal to complement the very small amount of aircraft traffic. This maintenance rolling significantly extends the life of the seal, and for airports, it also reduces the risk of loose stone and FOD. The author’s experience is that omitting maintenance rolling can reduce the seal life by 2-4 years. For sealed runways used by jet-engined aircraft, maintenance rolling post construction is an essential part of runway maintenance and safe operating practice.

The maintenance rolling specification is to apply, post construction, a total of 1 roller hour per 1000 litres of bitumen sprayed. For a double seal with 3 litres/sq.m. bitumen on a runway 2500 x 45m, this is 338 hours of rolling. Rolling is done uniformly over the full runway width. The best rollers are multi-tyre rollers as used in normal seal construction. Typical weights are 12-20 tonnes, and typical tyre pressures are 550-800 kPa (with perhaps a target of 700 kPa). Weight per tyre is typically 1–2 tonnes per tyre. Very heavy multi-tyre rollers have been used with success (35 tonnes class on 9 tyres when fully ballasted and reduced down to 20-25 tonnes for rolling), but these were confined to the stronger runways. Maintenance rolling should be done when the pavement is hot; typically a pavement temperature of 35 ^{o}C or above.

Rolling at Broome Airport, for example, is usually is done on a part-time basis in between the groundstaff's other duties. This works out to roughly 4 hours per day for 50 days for a typical runway. Assuming 3 days per week, the rolling is done over 4 months in summer. Obviously any other combination can be used depending on traffic, staff and plant availability. In cooler regions, rolling can be done down to a minimum 25 ^{o}C pavement temperature. Rolling is effective while the bitumen is lively – typically in warmer parts of Australia, this is for the first 4 years.

In the first summer, pickup may occur on the tyres when turning at the end of each run. Rolling should be halted if the pickup is excessive, and should be limited then to cooler times for the first summer.

Brooming

Periodic brooming (or sweeping) of a seal 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. Proprietary FOD brooms have given excellent results.

Fogspray

A fogspray (enrichment or dilute emulsion) can be used to improve stone retention or to increase the residual binder. A fogspray can be applied either early in the seal life to increase binder (such as on the untrafficked parts of a seal), or late in life as the seal bitumen hardens and there is an increase in the amount of loose stone. If brooming frequency has to be increased to more than once a month on an old seal, this is usually an indication that the binder is overly hardened and a fogspray should be considered if there is sufficient texture.

The fogspray reduces the texture depth, and its use is limited by considerations of macrotexture. The application rate depends on the available texture. A fine texture requires either a light fogspray or, if very fine, no fogspray at all. Only a very coarse, open texture surface can take a heavy fogspray. The application rates are shown in Table 6, which conforms to the practical diluted emulsion spray limits of 0.5 – 1.0 l/m^2. The author has found that a fogspray without blinding reduces macrotexture by the amount of the residual bitumen, so a medium fogspray with a residual binder of 0.27 l/m^2 would reduce the macrotexture by approximately 0.27 mm.

Table 6: Fogspray application rates.

Parameter	Application Rate (residual binder in l/m^2)		
	Light	Medium	Heavy
Target residual binder (l/m^2)	0.12	0.27	0.42
Typical mixture of 60% bitumen emulsion/water	1:2 mix sprayed at 0.6 l/m^2	2:1 mix sprayed at 0.7 l/m^2	4:1 mix sprayed at 0.9 l/m^2

The fogspray is usually applied without cover sand, although some is held ready at construction for blinding if required. Some airport practitioners apply the fogspray with sand; the binder is applied at a medium to heavy application rate and then river sand is applied in excess just as the emulsion is breaking. It is rolled with 6 passes before the excess is broomed off. The sand should be well graded with a high coefficient of uniformity. Sand further reduces macrotexture and this needs to be managed.

CONCLUSIONS

The use of seals for heavy duty airport pavements serving airline jet aircraft can be technically and financially viable. The use is governed by aircraft size, frequency of operation, and location. Seals are suited for frequent operations for aircraft of BAe146 size, moderate operations by aircraft of Boeing 737 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 may be needed.

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

REFERENCES

Austroads (2001) Austroads provisional sprayed seal design method, Revision 2000, AP-T09/01, Sydney.

Austroads (2006a) AP-T68/06 : Update of the Austroads Sprayed Seal Design Method. Sydney.

Austroads (2006b) AP-T42/06 : Guide to the Selection and Use of Polymer Modified Binders and Multigrade Bitumens. Sydney.

Benedetto, A. (2002) A decision support system for the safety of airport runways: the case of heavy rainstorms, Transportation Research Part A: Policy and Practice, 36, 665-682.

CASA (2004) MOS Manual of Standards Part 139 - Aerodromes. Civil Aviation Safety Authority. Canberra

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

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

FAA (1997) Measurement, construction and maintenance of skid resistant airport pavement surfaces. Advisory Circular 150/5320-12C. Washington.

ICAO (2004) Annex 14 Aerodromes. Vol.1. Aerodrome design and operations. 4th ed. International Civil Aviation Organisation, Montreal.

Kubu Australia (2005) AAA Binder Research C - Survey of Production of Bituminous binders for Australia. Australian Airports Association, Melbourne, August 2005.

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

Neaylon, K and Busittil, R (2007) A study of polymer modified binder properties before spraying. AAPA Pavement Industry Conference, Sydney.

TRH 3 (1998) Draft surfacing seals for rural and urban roads. Technical Recommendations for Highways. Committee of Land Transport Officials, Pretoria

TRH 3 (2007) Design and construction of surfacings seals. Technical Recommendations for Highways. South African National Roads Agency, Pretoria

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

White, G (2007) Bituminous surfaced pavement maintenance for remote airfields. AAPA Pavement Industry Conference, Sydney

AUTHOR BIOGRAPHIES

Stephen Emery has worked as a civil engineer in consulting, research, contracting, public sector, and an academic. He is currently a director of both Kubu Australia and Kubu Consultancy South Africa. Stephen graduated from the University of NSW in 1975, and worked in the Department of Civil Aviation in Australia. He did road research at the CSIR in South Africa, while doing his PhD at University of Witwatersrand on pavements. He returned to Australia and worked as a consulting engineer in Western Australia. He has held the Chair in Asphalt Pavement Engineering at Stellenbosch University in South Africa, and is currently teaching at CPEE and University of Witwatersrand. He is involved in research, design and rehabilitation, and forensic investigations of airports and roads. He has published and presented over 70 papers, and is a Fellow/Member of a number of learned Societies.