1 INTRODUCTION

Western Australia has a network of airports servicing towns, mines and oil and gas projects. These are almost totally flexible pavements. Historically they were built with naturally occurring granular materials for the basecourse and subbase courses and, if surfaced, had a bituminous seal. This was adequate for the DC-3 and Fokker F-27/F-28 aircraft in use in earlier days. The airport scene has changed in the last 10 to 15 years with the mining boom and fly-in, fly-out operations (FIFO). FIFO commuting has become common in WA, leading to a surge in air travel and an even greater surge in the number of aircraft. Safety and fatigue rules in the mining industry make it economical to locate jet airports as close as 60 km apart. Mining airports were initially serviced by small jet airliners, but in the last five years there has been an increase in airliner size. Common jet airliner types in use in WA are the BAe 146-200, Fokker F100, Boeing 717-200, Embraer 190, Airbus A320 and Boeing 737-800.

This paper addresses pavements and surfacings on airports in WA. The practices have derived over time and reflect in part the climate and geology of WA and in part the low traffic volumes on most WA airports. Awareness of differences in traffic, climate, geology and specific concerns like shallow water tables and weak clay subgrades is needed when considering these outside WA. The paper also highlights differences between airport and road pavements because the gap between the two widens for larger aircraft. Tyre loads and pressures of aircraft are higher than for regulation highway vehicles, but there are some offsetting factors for airport pavement performance:

- The bituminous surfacing is very wide and in the normal operation aircraft are several metres from the edge zone affected by lateral infiltration of water.
- Load repetitions are very low (commonly less than 10 per day) and fatigue life is much less of a concern for airports compared with roads.
- Sprayed seals on runways, taxiways and aprons have higher binder application rates than highways with the same size aggregate. The airport asphalt design typically uses a different grading and higher binder content when compared with normal road asphalt and is less permeable.
- There are no drive axles on aircraft and tyres in a dual pair can rotate independently.
- Grades on runways and taxiways are in the majority 1.5% or less.

2 AIRCRAFT TYPES

A wide range of aircraft types is in use in WA, with a corresponding range of weights and tyre pressures (Table 1). The loading for smaller aircraft up to the Fokker F50 is not dissimilar to highway loading. The Fokker F100, with 10.9 tonnes per main gear tyre and 980 kPa tyre pressure, is well above highway loading and the differences become larger for the Boeing 737-800 and above. These are classified as dual-wheel undercarriage with two main gear legs, except the Boeing 777-300 which has a dual tridem undercarriage with two main gear legs.

Table 1: Aircraft types in use in WA.

<table>
<thead>
<tr>
<th>Group</th>
<th>Typical aircraft</th>
<th>Maximum take-off weight kg</th>
<th>Load/tyre kg</th>
<th>Tyre pressure kPa</th>
<th>Passengers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large general aviation</td>
<td>Beech King Air 200</td>
<td>5,670</td>
<td>1,347</td>
<td>359</td>
<td>12</td>
</tr>
<tr>
<td>Medium turboprop airliner</td>
<td>Fokker F50</td>
<td>20,820</td>
<td>4,945</td>
<td>590</td>
<td>50</td>
</tr>
<tr>
<td>Small jet airliner</td>
<td>Fokker F100</td>
<td>45,810</td>
<td>10,880</td>
<td>980</td>
<td>107</td>
</tr>
<tr>
<td></td>
<td>Boeing 717-200</td>
<td>54,900</td>
<td>13,039</td>
<td>1,131</td>
<td>125</td>
</tr>
<tr>
<td>Medium jet airliner</td>
<td>Boeing 737-800</td>
<td>79,015</td>
<td>18,766</td>
<td>1,143</td>
<td>168</td>
</tr>
<tr>
<td>Large jet airliner</td>
<td>Boeing 777-300</td>
<td>352,441</td>
<td>27,902</td>
<td>1,524</td>
<td>400</td>
</tr>
</tbody>
</table>

3 AIRPORT PAVEMENT DESIGN METHODS

Several airport pavement design methods are in use in WA. They focus on flexible pavements since airports in WA are almost totally built with flexible pavements. There is limited use of concrete on WA airports. The main examples are the rigid pavements for aprons at Perth Airport, servicing medium and heavy jet airliners.

Chadwick Geotechnics is a leading supplier of Field and Laboratory Testing and Drilling Services to the Geotechnical and Environmental Engineering disciplines and Drilling Services to the Geotechnical supplier of Field and Laboratory Testing.
3.1 COMMONWEALTH GOVERNMENT METHOD
The Commonwealth Government’s construction authority set standards for airport design and construction but was wound up in 1997. There is no longer a similar authority setting pavement thickness standards in Australia. It used the US Army Corps of Engineers’ methods, and their method was last published some 40 years ago. Design charts for aircraft in use at that time were widely used in WA, but there have been significant changes in aircraft types in use since then. This method is little used today.

3.2 CIVIL AVIATION SAFETY AUTHORITY METHOD
The Civil Aviation Safety Authority (CASA) is now the Federal Government body responsible for airport pavement standards. They do not have an airport pavement design method. There is an Advisory Circular on Strength Rating of Aerodrome Pavements (CASA, 2011), which notes that the design of heavy duty aircraft pavements is not the same as that of roads, and road pavement design methods such as Austroads are not applicable to airport pavements. It also requires operators of regulated aerodromes to rate the strength of pavements using the International Civil Aviation Organisation (ICAO) accepted ACN-PCN method. The circular mentions the American Federal Aviation Administration design method discussed in the next sub-section.

3.3 FEDERAL AVIATION ADMINISTRATION METHOD
The American Federal Aviation Administration (FAA) has well-developed flexible and rigid airport pavement design methods (FAA, 2009), which are commonly used in WA for airports. They include the software COMFAA and FAARFIELD. The original basis for these methods was the US Army Corps of Engineers method, S77-1, which catered for high wheel loads, thick pavement structures, a variety of wheel arrangements, and large and variable degrees of vehicle wander (Wardle et al., 2003). Since then, new full-scale testing was undertaken by the FAA to better model multi-wheel undercarriage configurations, and the FAA design procedures in use today incorporate this (Brill & Hayhoe, 2004). COMFAA software (version 2.0 dated 2007 and version 3.0 dated 2010, and updated 2014) is based on the empirical CBR method for flexible pavement thickness and the PCA method for rigid pavements (FAA, 1995). The old LEDFAA and newer FAARFIELD software are based on layered elastic theory for flexible pavements and 3D finite element analysis for rigid pavements; both use the cumulative damage factor concept to model the full traffic spectrum (FAA, 2009). FAARFIELD is the official FAA flexible pavement design method. It has various default parameters with regard to materials and thicknesses, and some caution is needed in using it in Australia. Helped by its ease-of-use, COMFAA is still probably the most widely used airport pavement design software in WA.

3.4 APSDS DESIGN SOFTWARE
The Australian APSDS software (Airport Pavement Structural Design System) is based on elastic layer theory for the design of flexible pavements subjected to the heavy wheel loads associated with large aircraft. It is designed to model each combination of aircraft and take-off weight and to combine the damage using the cumulative damage factor concept (MINCAD, 2007). It is based on the CIRCLY software, and uses transfer functions from the new full-scale FAA testing to convert subgrade strain to life. It is less commonly used in WA.

4 PAVEMENT

4.1 LIMITATIONS OF ROAD DESIGN SYSTEMS
Many aspects of the design methods for highway/road pavements such as those presented in the Austroads Pavement Design Guide are not appropriate for designing airport pavements. On roads, wheel loads are 2-3 tonnes and tyre pressures are about 750 kPa. The wheel layout of all trucks is quite similar and repetitions of the standard axle can be up to $10^5$. On airports, wheel loads up to 28 tonnes and tyre pressures over 1500 kPa can be expected, the wheel layout varies considerably between makes and models of aircraft, and repetitions can be in the range of about 10,000 to 100,000 (Smith, 2010). For traffic, road design systems use 12 generalised traffic classes while airport design systems are aircraft specific.

Experience in WA and elsewhere in Australia is that road design methods can yield unsatisfactory airport pavements. Road design methods which been attempted include the Austroads pavement design method (and CIRCLY software), the South African pavement design method TRH4 and the MePADS design software. The issue is that design methods for airports are necessarily different. Austroads empirical rutting criterion, having been developed for highway loadings, will not be fully applicable at the much higher wheel loads used on airfields (Wardle et al., 2003). It has been argued that the relationship between subgrade vertical strain and permanent deformation of the pavement surface is not independent of wheel load (Rodway, 1998). The road design software can indeed calculate stresses and strains in any layer in the pavement, but for the granular basecourse common in WA airports, the transfer function(s) to convert those stresses/strains to layer life are not available. This leaves the highly stressed basecourse layer essentially un-designed.
when using road design methods. Therefore in WA it is essential to design airport pavements using airport design methods.

4.2 DESIGN TRAFFIC

Airport pavement designs are aircraft specific. Aircraft types and expected numbers are available from airport master plans. Forecasts of annual departures by aircraft type are needed for the FAA design system. For airports in WA, the pavement is usually designed for aircraft at maximum take-off weight (MTOW). Use of MTOW rather than actual take-off weight provides some degree of conservatism in the design and is justified by the fact that changes in operational use can often occur and recognition of the fact that forecast traffic is approximate at best. There can be a small difference in pavement thickness calculated as a result. At Broome, the Boeing 737-800 actual take-off weight is 70 tonnes for flights to Perth compared with the MTOW of 79 tonnes; the difference in pavement thickness design between the two cases is 40 mm.

The FAA design system converts annual departures to coverages over the design life. This process is described by the FAA PCN procedure (2006). Often aircraft arrive at an airport with a smaller amount of fuel than at take-off. As a consequence, the stress loading of the wheels on the runway pavement is less when landing than at take-off due to the lower weight, and therefore the stress applied by the aircraft during arrival is ignored. However at some airports in WA, especially those closer to Perth, aircraft are not refuelled at the airport, and the landing weight is the same as the take-off weight. For those cases, the arrival and departure are both counted. Furthermore since most airports in WA have only a single runway and no parallel taxiway, part of the runway is used during taxiing. If applicable, this taxi pass is also counted, and there are then 3 to 4 passes of the aircraft on the runway pavement per aircraft visit (depending on the airport layout).

The concept of design aircraft is used in COMFAA software, but in FAARFIELD, the various forecast aircraft are combined using the cumulative damage factor (CDF) and Miner’s Law. When CDF = 1, the design life is exhausted. As expected, almost all the contribution in CDF comes from the larger aircraft. At airports served by small/medium jets, the loading by general aviation aircraft usually can be ignored because their CDF contribution is so low.

4.3 SUBGRADE AND PAVEMENT MATERIALS

4.3.1 Proof rolling

The influence of tyre loads of aircraft can extend to a greater depth than experienced on highways. A Fokker F-100 requires a pavement thickness of 925 mm over a poor subgrade CBR 3% (20 years, 1,200 annual departures), compared with a pavement thickness of 380-520 mm for a road over subgrade CBR 3% (10^5-10^6 design traffic ESAs). Proof rolling is commonly used on airports to ensure the foundation is sound to depth. The subgrade is proof rolled with six coverages of a pneumatic tyred roller before any pavement materials are placed on a prepared subgrade. Any soft spots or areas, which become unstable under this rolling are excavated and replaced with compacted stable material. Proof rolling is a visual test that covers the entire subgrade surface. A second series of proof rolling is carried out on the basecourse using a suitable roller prior to surfacing to ensure adequate pavement strength is achieved. Pneumatic tyred rollers should be related to aircraft and thickness of layer to be compacted. For most airport work, tyre pressures of 700 kPa and wheel loads of 2250-4500 kg would be relevant. At major airports, the Marco roller might be used, which gives the basecourse higher densities and strength in the crushed rock basecourse than is possible in normal Australian road practice. The Marco roller can roll up to 50 tonnes on four pneumatic tyres, limited to 1,000 kPa.

4.3.2 Subgrade

The subgrade dominates the airport pavement thickness design. Considerable effort is spent on the assessment of its design CBR. A number of field tests may be used to estimate subgrade CBR: in situ CBR test, dynamic cone penetrometer (DCP) and/or FWD tests. In situ CBR measurements are not common in WA and FWD tests alone are not adequate enough to determine CBR. Sufficient tests need to be done to ensure that the subgrade is properly characterised. Where the water table is deep, equilibrium moisture conditions are often expected in the pavement since the bituminous surfacing is very wide and, in normal operation, aircraft are several metres from the edge zone affected by lateral infiltration of water. However despite much of WA being arid, ground water can be encountered in old creek beds after rains and soaked conditions might occur if the pavement is located within this zone. The soluble salt content of the in situ ground should also be checked.

In testing for subgrade CBR, the DCP is quick and inexpensive to use. A useful approach is to do many DCP tests to measure the subgrade CBR and identify homogenous sections, and then do sufficient test-holes in each section to identify layer depths and extract samples for laboratory testing. Laboratory CBR testing can be used to correlate the in situ DCP results. The FWD also can be used on existing pavements to identify homogeneous segments, but because the
4.3.4 Basecourse

The basecourse is the most important layer; it has the major function of distributing the imposed wheel loadings to the pavement foundation, the subbase and/or subgrade. Its high stresses are usually thin. Basecourse materials used in WA airports include natural gravels, crushed rock, and cement-modified crushed rock (low % cement) with the addition of a low percentage of LH cement, possibly 2%. The target UCS (7 day curing, 4 hour soaking, GP cement, 95% MMDD) would be 1.5 to 2MPa to reduce crushing and minimise surfacing cracks. It is essential to apply a bituminous prime within a day or two of cement modification to reduce carbonation. This is a higher level of cement than recommended for WA roads, but is also necessary because aircraft have higher tyre pressures than trucks. Crushing can occur at the top of lightly cementsed layers and the time to crush initiation is a

4.3.5 Airport fine crushed rock basecourse

The FAA design system limits uncrushed rock [gravel] to pavements serving aircraft up to 27,200 kg MTOW, which are medium turboprop airliners. In WA, many airports serving medium turboprop airliners such as the Fokker F-27 and F-50 have been built with natural gravel basecourses and double seals, providing excellent service for many years.

The FAA design system limits crushed rock to pavements serving aircraft up to 45,350 kg MTOW; above that stabilized basecourse and subbase courses are necessary. The small jet airliners sit just over the 45,350 kg boundary, and the medium jet airliners are well above this. The FAA does allow exceptions to stabilisation on the basis of superior materials being available, such as 100 percent crushed, hard, closely graded stone; these should have a laboratory soaked CBR minimum of 100% for the basecourse and 35% for the subbase. This is above the quality of highway crushed stone and is discussed further in the next section.

In WA, many airport pavements with natural gravel subbases, highway-quality crushed stone basecourses and double surfacing seals have performed well with light aircraft through to medium turboprop aircraft loadings. Under small jet airliner loadings though, the basecourse is becoming overstressed and can become noticeably rougher over time. Instead of needing only periodic resels as is usual under lighter aircraft loadings, the pavement under heavier loading may eventually need asphalt overlay to restore shape and smoothness. This form of construction minimises capital cost, but that must be balanced against the eventual high cost of asphalt overlay.

Under medium jet airliner loads, natural gravel and high-quality crushed stone basecourses and double seals deteriorate more rapidly. The basecourse quality has to be improved, usually the surfacing must be asphalt, and the subbase must provide good support. The basecourse must be a very high-quality crushed rock material with a soaked CBR of 100%+ (experience suggests this should be more like 130%+). Good success has been had with cement modified crushed rock, with the addition of a low percentage of LH cement, possibly 2%. The target UCS (7 day curing, 4 hour soaking, GP cement, 95% MMDD) would be 1.5 to 2MPa to reduce crushing but minimise surfacing cracks. It is essential to apply a bituminous prime within a day or two of cement modification to reduce carbonation.
function of the ratio of tyre pressure to UCS (Theyse et al., 1996). Note that care must be taken if stabilising runway base materials with cement; cracking may occur and ingestion of loose material is more serious for jet engines than for road vehicles.

The FAA design system requires a minimum aggregate basecourse thickness so as to protect their nominal CBR 20% subbase. This minimum is 150 mm for aircraft up to 45,350 kg MTOW on dual wheels, and 200 mm for dual wheel aircraft heavier than that such as the Boeing 737-800. The Boeing 777-300 requires a minimum of 250 mm thick basecourse (FAA, 2009). The FAA system has scope for using equivalency factors to reduce the minimum thickness of basecourse if it is strongly cement stabilised, but reductions are not appropriate for lightly cemented layers.

### 4.3.5 Airport fine crushed rock basecourse

Some use has been made in the past of a special airport fine crushed rock for the basecourse layer. This is a premium quality quarry product that is specifically engineered for aircraft pavements. The material is unusual as it is a coarse graded product and non-plastic. It does not resemble typical granular materials used for road pavements. The material requires a special run during manufacture and possibly changes to the crusher plant setup including screening and/or blending processes. This material is not normally available in WA and so it is not normally used.

Some designs have used it with thin asphalt surface (50-70 mm thick), 200 mm unstabilised airport fine crushed rock basecourse, over a cement-treated subbase (3-4% cement - UCS 2000-3000 MPa). The pavement is rolled at final basecourse level using an ultra-heavy Marco roller achieving extremely high densities (and resilient moduli). This is similar in philosophy to the South African G1 basecourse over cemented subbase design. Performance is dependent on the quality of the fine crushed rock and the construction; it uses specifications and techniques that are rarely used in WA road construction.

### 4.4 AIRPORT PAVEMENT STRUCTURAL DESIGN

#### 4.4.1 Design principle

In principle, airport pavements are similar to road pavements except they are generally thicker. They consist of a bituminous wearing surface placed upon a basecourse and, usually, one or more subbase layers. The entire flexible pavement structure is ultimately supported by the subgrade. The pavement thickness for a Boeing 737-800 commonly ranges between 350 and 900 mm in WA. The pavement can be much thicker for heavier aircraft on weak subgrades. The main controlling parameter in most airport pavement design is vertical compressive strain at the top of the subgrade, although horizontal strain at the bottom of the asphalt surfacing layer is also considered if provided.

When designing the structure, the high loading and thick pavements mean it is important to ensure that the pavement has structural balance and layering. Essentially, there should be a steady increase in material quality from the in situ subgrade to the base or surfacing layers. A minimum thickness of basecourse is required to protect the subbase. One of the possible mistakes that a pavement designer may make is to design an unbalanced, shallow pavement system by having a cemented or asphalt base layer on a subbase or subgrade of much lower stiffness. Such a pavement will be more sensitive to heavy loads than a well-balanced, deep pavement structure.

#### 4.4.2 Design examples

Two examples were modelled. The first was an airport pavement serving a mine, with design parameters requiring a thin pavement. The second was serving a town with design parameters requiring a thicker pavement. For three common aircraft in WA, the pavement analysis was done broadly following the earlier FAA design method (FAA, 1995) and COMFAAA software, but incorporating Australia’s good experience with thin surfacings. The resultant pavement structures are shown in Table 2 and Table 3. The same pavement would be used for the runway, taxiway and apron.

The use of seals and thin asphalt surfacings in both examples is commonly done across all of Australia, but is contrary to the FAA design method assumptions of asphalt surfacing, and has been justified in Australia by the good experiences with them. Fully compliant FAA designs require 100 mm AC surfacing (75 mm in non-critical areas) for dual wheel gear aircraft. For the thinner Australian surfacing designs, the basecourse must be of good quality as discussed above, and the pavement needs a well-balanced, deep structure.
Table 2: Light airport pavement structure.

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Fokker F100</th>
<th>Boeing 717-200</th>
<th>Boeing 737-800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pavement thickness</td>
<td>305 mm</td>
<td>342 mm</td>
<td>371 mm</td>
</tr>
<tr>
<td>Surfacing</td>
<td>Double seal</td>
<td>Double seal (a)</td>
<td>60mm AC (c)</td>
</tr>
<tr>
<td>Basecourse</td>
<td>150 mm</td>
<td>200 mm (b)</td>
<td>200 mm (b)</td>
</tr>
<tr>
<td>Subbase (d)</td>
<td>150 mm</td>
<td>150 mm</td>
<td>150 mm</td>
</tr>
</tbody>
</table>

Table 3: Medium airport pavement structure.

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Fokker F100</th>
<th>Boeing 717-200</th>
<th>Boeing 737-800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pavement thickness</td>
<td>510 mm</td>
<td>564 mm</td>
<td>660 mm</td>
</tr>
<tr>
<td>Surfacing</td>
<td>Double seal</td>
<td>Double seal (a)</td>
<td>60mm AC (c)</td>
</tr>
<tr>
<td>Basecourse</td>
<td>150 mm</td>
<td>200 mm (b)</td>
<td>200 mm (b)</td>
</tr>
<tr>
<td>Subbase 1 (d)</td>
<td>150 mm</td>
<td>160 mm</td>
<td>200 mm</td>
</tr>
<tr>
<td>Subbase 2 (e)</td>
<td>200 mm</td>
<td>200 mm</td>
<td>200 mm</td>
</tr>
</tbody>
</table>

Notes to Table 2 and Table 3
a: Triple seal, using sand seal on top of double seal for the apron, intersection and runway ends.
b: Minimum aggregate basecourse thickness of 200 mm.
c: This is the typical minimum asphalt thickness for a Boeing 737.
d: CBR > 45%  e: CBR > 25%

5 SURFACINGS ON AIRPORTS

5.1 CHOICE OF SURFACING

In WA, most airports have sealed runways, and bituminous seals are almost universally used on runway, taxiway and apron pavements carrying aircraft up to and including small jet airliners (Fokker F100 size). Asphalt is used on pavements for large aircraft. The division between seal and asphalt sits about the small jet airliner level, with seals common for the F100 and asphalt sometimes used for Boeing 717-200. At the Boeing 737-800 level, asphalt is more common, although Broome Airport had 737 operations for many years on seals and, even after the runway was asphalted in 2013, its RPT apron is still sealed. There is a trade-off between cost and maintenance requirements in the decision to use seal or asphalt. Economics, maintenance capability available to the airport, and service life often influence the decision.

5.1.1 Runway

Seals are generally limited to locations with lower horizontal stresses, which are most of the runway. The sections with higher horizontal stresses are runway turning nodes, runway ends (if these are used for 180-degree turning) and intersections. Seals are still usually used in these areas but a special treatment such as a sand seal is sometimes applied on top to lock in the stone. Sand seals reduce the macrotexture of the seal and should not be used along the whole runway, but treating just the ends and the intersection does not usually reduce the average macrotexture below the MOS Part 139 requirement of 1.0 mm (CASA, 2013). Any sand seal should be delayed by at least 12 weeks after double seal construction to allow volatiles to evaporate; experience has shown that severe bleeding can occur otherwise.

It is rare to see damage on seals due to aircraft braking; therefore this is not considered a stress problem. Slight damage from wheel spin-up occurs in the touchdown zone for a few weeks after a new seal, and this requires attention with sweeping and minor rolling. Ongoing sweeping and maintenance of the seal such as rolling will be needed.

5.1.2 Apron

Aprons are generally medium stress areas, although the parking bays are a special case. Seals are still used, but 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 might also be used. Protective coatings to seals and asphalt or concrete pads may be required on apron bays where jet engines may drip fuel and oils when parked or during refuelling. However seals are still found on some aprons at less busy airports where the Boeing 737-800 is used.

5.1.3 Interlocking concrete blocks

Interlocking concrete block pavements are sometimes used on airports; they are also used for helicopter stands because concrete is more resistant to damage from helicopter skids and/or high pressure tyres. It is recommended that pavers...
should normally only be used to surface the following categories of aircraft pavements: aprons, low speed taxiways not subject to significant jet blast or propeller wash, aircraft maintenance areas not subject to significant jet or propeller blast, and helicopter pads. Block pavers should normally not be used to surface runways, areas where aircraft engines are run at high thrust values (such as engine run-ups), or high speed taxiways.

5.1.4 Helicopters
Helicopters are a particular problem for the surfacing. Small helicopters with skids commonly damage seals and even asphalt when parked in hot weather; the skids tend to move slightly apart over time as the bituminous surfacing yields in creep. Large helicopters with wheels are less damaging but create significant downwash over large areas and minimisation of foreign object debris requires large areas to be bituminous surfaced. It is common to use asphalt, concrete or block paving for helicopter aprons, although triple seals (14/7/sand) have been used with some success.

5.2 CHOICE OF BITUMEN/BINDER

5.2.1 Binders available in WA
The binder most commonly used in WA is Class 320 unmodified bitumen. The range of binders available in WA is slightly more limited than in other parts of Australia. Unmodified bitumen Class 170 and 320 have been available for many years. In 2014, Class 600 became available and the technology used to manufacture Class 600 means that Class 240 and 450 also would be available although they have not yet been produced commercially in WA.

Multigrade binder is not available locally, and would have to be shipped into WA. Such shipping is technically feasible; for Darwin Airport runway resurfacing in 2007, multigrade was manufactured in Brisbane, loaded into bitutainers, cooled and transported to Darwin by train, then reheated onsite. As a parallel, Broome Airport used B380 modified binder in 2013 for asphalt. It was manufactured in Fremantle, loaded into bitutainers, cooled, and transported by road to Broome by triple road trains, each carrying three bitutainers totalling of 50 tonnes of binder.

All Austroads grades of modified binders are available in WA. The often considerable distances between modified binder manufacturer and the airport/asphalt plant means significant concern over their storage stability and/or degradation by handling. The use of modified binders at airports in WA has been limited because of these risks.

5.2.2 Seal binders
The seal binders used on WA airports are Class 320 in the warmer regions and Class 170 in the cooler areas. Care should be exercised to cutback C320 if sealing in cooler seasons, using normal cutback practices.

5.2.3 Asphalt binders
Class 320 bitumen has given good service in asphalt at many airports across Australia for aircraft up to small jet airliners, but heavier aircraft loads in hot climates are particularly damaging to asphalt. Asphalt binders for medium jet airliners usually require modification, especially in the north of WA. For large jet airliners, modification is almost always required, especially in areas subject to turning stresses and/or slow moving aircraft. Modification in this context is either polymer modification or the use of multigrade bitumen. Plastomer modifiers such as EVA (grade A35P) have been used at Perth Airport and some regional airports such as Barrow Island and Onslow; these give improved rut resistance.

There has not been widespread use of elastomeric modifiers (such as SBS) but when it has been used it is usually either grade A10E and A15E. More recently A15E has been preferred because it has a slightly lower modification level; elastomers are preferred where the pavement is very flexible and many load repetitions are expected. The elastomeric-plastomer modified bitumen offers both improved rut resistance and more flexibility compared to unmodified bitumen, and has been used at several airports in Australia; this is not a standard Austroads grade. SAMI B380 is one such bitumen and was developed in response to the Australian Airports Association’s search for an asphalt binder best suited to airports. This airport asphalt binder had to have resistance against deformation characteristics such as wheel rutting, and excellent storage stability so it can be transported and stored for lengthy periods without risk to the binder properties. B380 is available in WA and was used at Broome Airport in 2013 in asphalt. There has been some use of PBD modifiers in proprietary BP binders elsewhere in Australia on airports.

5.2.4 Site blending of modified bitumen
The blending of some EVA polymers is simple and the asphalt plant operator can do it at the asphalt plant or it can be pre-blended in a tank on site. At Onslow, A35P grade modified binder was manufactured on site by blending EVA with bitumen in a simple blending plant. Direct addition of EVA (and notably the Polybilt 101 grade) in the asphalt plant pugmill is also easy and has been done in Perth. The addition of EVA into the pugmill of the plant is usually done by
volume. In the pugmill, the aggregates must first be covered by a layer of bitumen; therefore the addition of EVA should not be started before at least 50% of the bitumen is injected. This step is critical because if the polymer is added first to the aggregates the polymer will melt and stick on the aggregates and only part of it will be dissolved when the bitumen is added later. If possible, the process computer of the asphalt plant should control the different steps and in order to reach a good mixing result of polymer and bitumen, the "wet-mixing time" should be extended 5 to 10 seconds (Delmé, 1999).

5.3 DESIGN OF SEALS

In low-stress areas, the double seal (10-14 mm stone on the lower layer and 5-7 mm 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 <5700 kg, but it is not suitable for airline aircraft. In high-stress areas, either the double seal or a triple seal (double seal with a thin sand seal on top to fill the voids) has been used. However, the surface macrotexture of triple seals (and sand seals) can easily be less than the requirements for runways, and attention must be given to ensure adequate macrotexture.

Experience has shown that the stone on the upper layer of a double seal should have a maximum nominal size of 7 mm (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, a 10 mm top stone gave high surface texture but caused unacceptable tyre wear in just four movements of a 30 tonne jet aircraft. The runway had to be re-rolled with a steel wheel roller and the touchdown area resealed with a smaller size aggregate. More airport seal design details are in Emery (2008).

5.4 DESIGN OF ASPHALT

5.4.1 Marshall design

Airport asphalt mix design in WA is the same as in the rest of Australia, and is done in accordance with the Marshall design method using 75 blows per face. The design is based on maximising the bitumen content consistent with achieving specified design air voids content and minimum Marshall stability. The philosophy is for good compactability, long durability given the low trafficking, and low permeability. Stripping evaluation of the design mix is done by using Austroads Stripping Potential of Asphalt test, AG:PT/T232, and the optional freeze-thaw cycle has proved valuable in detecting stripping. The Tensile Strength Ratio should not be less than 80%. A typical specification for airport asphalt is given in Emery (2005).

5.4.2 Difference between airport and road asphalt

Specifications used for asphalt for airports differ from roads because they have been written by only a handful of individuals, and have been essentially unchanged for decades, apart from necessary updating.

If the airport mix specification is assessed for roads usage, it may raise concerns over rutting. The airport mix has a high binder content, the grading is close to the maximum density line, and the voids filled with binder are high. A void structure overfilled with binder will tend to lubricate aggregates (or even force them apart), thereby reducing frictional resistance with a resulting increase in rutting potential. From fundamental principles, the mix aspects related to rutting resistance are the viscosity of the mastic, packing characteristics of the mix, volumetric aspects, and aggregate characteristics. The airport mix design is relying more than usual on the viscosity of the mastic for its rut resistance. For this reason, airport asphalt in the warmer parts of WA needs polymer-modified bitumen or multigrade to improve rut resistance.

Some airports in WA have used the standard 14mm intersection asphalt mix to Main Roads Western Australia (MRWA) specification with mixed results. This mix is quite permeable and has a relatively low binder content; however, there is too little traffic on airports to give it the compaction it still needs after construction and the asphalt ages rapidly. It is not really considered an appropriate choice.

5.4.3 Airport asphalt performance testing

Airport performance testing is now common for pavements servicing medium to large jet airliners. Rut resistance and stripping resistance are the parameters usually tested. The various methods used include refusal density, wheeltracking and MMLS. Refusal density using 300 or 600 blow Marshall compaction does not provide adequate compaction energy to reach true material refusal, and so the British Standard Kango hammer test is used for refusal density (British Standard, 2003).
Wheeltrack testing has been done using the Austroads (2006) method and the more complex Model Mobile Load Simulator (MMLS). MMLS is a scale tester for evaluating the rut propensity performance of asphalt mixes in the laboratory or field which has been used with some success on airfield pavements (Emery & Mihaljevic, 2008). The test bed for trafficking by the MMLS in the laboratory allows nine 150 mm cores to be placed adjacent to each other, each fitted snugly into a restraining mould that provides circumferential support to the test specimens. Standardisation of test protocol is important; therefore, it is suggested to use the updated Baton Rouge Protocol (RPF, 2008). MMLS testing for asphalt used recently at Broome was undertaken during design and construction. Mix was made in Australia and sent as either bulk or cores to South Africa where there are several laboratories with the MMLS equipment.

6 OTHER DIFFERENCES BETWEEN AIRPORT AND ROAD WORKS

The paper has already discussed differences in design methods and materials between airport and road works. The other differences are safety and wet weather operations. Operating speeds of up to 225 kph and engine vulnerability to damage are the main risks facing airports. The consequences are potentially more severe on airports than roads due to the high number of passengers/occupants in an aircraft and the high aircraft fuel capacity (up to 13,000 litres).

Wet weather is a particular issue on runways because of the high speeds. It is mandatory on airports that the surface of a paved runway shall be so constructed as to provide good friction characteristics when the runway is wet. There are CASA (2013) requirements for minimum macrotexture, minimum limits for runway slopes and crossfall to ensure drainage, and limits on irregularities and ruts to reduce ponding of water. For airports, this requires close attention to gradient and surface finish for the basecourse and surfacing.

Good macrotexture is provided by using a bituminous seal or grooving the asphalt surfacing. There are no other options used in WA. Overseas, porous asphalt and ultra-thin friction courses (UTFC) have been used with success as friction treatments on top of asphalt. However ungrooved asphalt is not acceptable on the runway alone because it is simply not possible to meet the CASA macrotexture standard without grooving. It is of course quite suitable for taxiways and aprons.

Macrotexture should be considered when runway rejuvenation treatments using bitumen emulsion or coal tar based products are used. This technology has been used in the roads sector; however, rejuvenation can lead to slippery runways when wet. It reduces microtexture and macrotexture, and does not readily reduce wheel ruts or correct drainage problems. Even grooved runways can become slippery when wet after rejuvenation as recent accident and incident investigations have shown (Emery et al., 2011). Rejuvenation using fogsprays has been done on sealed runways with success, provided there is adequate macrotexture for the new bitumen. Rejuvenation is suitable for taxiways, aprons and shoulders.

7 REFERENCES

FAA (2009) Airport pavement design and evaluation. AC No: 150/5320-6E. Washington, DC.