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The Use of Stone Mastic Asphalt on Aircraft Pavements

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Abstract

Traditionally in Australia, flexible aircraft pavements on runways and taxiways have been surfaced with a thin layer (50 mm) of conventional dense graded asphalt. In recent years, with airport owners and operators demanding increased performance from asphalt to resist the applied loads, polymer modified and multigrade bitumen binders have been used in asphalt.

The benefits of these binders are to not only delay the onset of environmental deterioration, but to produce an asphalt capable of withstanding the ever increasing volume of aircraft traffic without showing permanent deformation, plastic flow or fatigue.

Stone mastic asphalt (SMA) has been in use overseas on aircraft pavements for a number of years, mainly in Europe. Overseas experience suggests SMA has been very successful and its use on aircraft pavements has spread from Norway and Sweden to Germany, Austria, Belgium and the United Kingdom (England and Ireland).

Although initial costs are higher than conventional dense graded asphalt, these costs are more than offset in the longer term through longer life. The longer life is as a result of increased rut resistance, increased fatigue resistance, increased durability and increased resistance to crack propagation.

Cairns International Airport in far north Queensland first introduced SMA to aircraft pavements in Australia in late 1998. Sydney International Airport conducted a trial of SMA on a heavily loaded taxiway in the domestic sector of the airport in May 1999. The trial was not entirely satisfactory however and a further trial is to be undertaken.

As with the Cairns trial, SMA was trialled at Sydney International Airport evaluate its performance and ability in overcome specific asphalt problems related to climate and aircraft load. These trials are in their infancy and conclusive results on performance are probably two to three years away.

Based on overseas experience, SMA has the potential to provide a high performance wearing surface for aircraft pavements, capable of withstanding both the Australian environment and the ever increasing volume of aircraft traffic.

The use of stone mastic asphalt on aircraft pavements in Australia would seem to be inhibited at this stage only by a lack of experience and performance of this material on an aircraft pavement in Australia and airport operator inertia. The trials at Cairns and Sydney International Airports are seen as the stepping stones to gain valuable experience in the use of this material on aircraft pavements and breakdown the apprehension of airport operators about the use of a new material.

Acknowledgments

The research associated with this report included some 400 requests for information. These were issued to airports, contractors, asphalt producers and suppliers of stone mastic asphalt (SMA) around the world. The technology and processes used by contractors and other organisations involved in the design, manufacture, supply and laying of SMA is kept as a closely guarded commercial secret, both in Australia and around the world. Hence apart from the language barrier, information on actual experience with SMA on aircraft pavements was extremely difficult to obtain.

Therefore I would like to acknowledge all those who took the time to respond to my requests for information, provide technical information, or point me in the direction where information could be sought.

Special thanks are extended to the following individuals and organisations who provided significant assistance and feedback to assist in the compilation of this report.:

(a) Mr Gier Lange, Senior Engineer, Norwegian Civil Aviation Administration, who provided a significant contribution on the experiences and use of SMA on Norwegian Airports,

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List of Symbols and Abbreviations

Following is a list of abbreviations used throughout the report.

Abbreviation	**Meaning**
AADT	Average Annual Daily Traffic
AAPA	Australian Asphalt Pavement Association
AC	Asphaltic Concrete
APRG	Austroads Pavement Research Group
BAA	British Airports Authority
BCA	New Zealand Bitumen Contractors Association
CPA	Cairns Port Authority
DGA	Dense Graded Asphalt
EAPA	European Asphalt Pavement Association
FAA	Federal Aviation Administration
FOD	Foreign Object Damage
LDPE	Low Density Polyethylene
NACO	Netherlands Airport Consultants
NCAA	Norwegian Civil Aviation Administration
PE	Polyethylene
PMB	Polymer Modified Binder
SABITA	South African Bitumen Association
SACL	Sydney Airports Corporation Ltd

Abbreviation	Meaning
SBS	Styrene Butadiene Styrene
SMA	Stone Mastic Asphalt

1. Introduction

Traditionally in Australia, flexible aircraft pavements on runways and taxiways have been surfaced with a thin layer (50 mm) of conventional dense graded asphalt. In recent years, with airport owners and operators demanding increased performance from asphalt to resist the applied loads, polymer modified and multigrade bitumen binders have been used in asphalt.

The benefits of these binders are to not only delay the onset of environmental deterioration, but to produce an asphalt capable of withstanding the ever increasing volume of aircraft traffic without showing permanent deformation, plastic flow or fatigue.

In some severe loading situations on aircraft pavements, mainly on taxiways and at the rear of apron stands where asphalt is used, even polymer modified and multigrade bitumen binder asphalts are failing to meet the increased performance requirements.

It is clear that the potential exists for a new technology to be embraced by Australian airport owners and operators to achieve or even surpass performance expectations. It is considered that this new technology will come in the form of stone mastic asphalt (SMA).

Cairns International Airport in far north Queensland first introduced SMA to aircraft pavements in Australia in late 1998. Sydney International Airport conducted a trial of SMA on a heavily loaded taxiway in the domestic sector of the airport in May 1999.

As with the Cairns trial, SMA was trialled at Sydney International Airport evaluate its performance and ability in overcome specific asphalt problems related to climate and aircraft load. These trials are in their infancy and conclusive results on performance are probably two to three years away.

This report will consider the use of SMA on aircraft pavements and more specifically will address the following:

(a) a detailed description of SMA is and how it differs from dense graded asphalt,

(b) the materials and composition requirements for SMA,

(c) the features and benefits of SMA compared to dense graded asphalt,

(d) a brief consideration of the life cycle costing of SMA compared to dense graded asphalt,

(e) the use of SMA overseas, and in particular its use on aircraft pavements,

(f) the performance of SMA compared to dense grade asphalt,

(g) a detailed look at the Cairns and Sydney International Airport trials in relation to mix design, performance characteristics and comparison with overseas SMA mix designs, and

(h) the suitability or otherwise of SMA for use on aircraft pavements.

2. Literature Review

2.1 Description of Stone Mastic Asphalt

Stone mastic asphalt had its origins in Germany in the late 1960's as an asphalt resistant to damage by studded tyres. Stone mastic asphalt is a popular asphalt in Europe for the surfacing of heavily trafficked roads, airfields and harbour areas.

It is also called splittmastixasphalt in German speaking countries and elsewhere may be called split mastic asphalt, gritmastic asphalt or stone matrix asphalt. In Australia it is normally called stone mastic asphalt or SMA for short.

There are many definitions of SMA. APRG Technical Note 2 (1993) defines SMA as

"*a gap graded wearing course mix with a high proportion of coarse aggregate content which interlocks to form a stone-on-stone skeleton to resist permanent deformation. The mix is filled with a mastic of bitumen and filler to which fibres are added in order to provide adequate stability of the bitumen and to prevent drainage of the binder during transport and placement.*"

The European definition of SMA (Michaut, 1995) is

"*a gap-graded asphalt concrete composed of a skeleton of crushed aggregates bound with a mastic mortar.*"

An explanatory note is added indicating that the binder content is generally increased because of segregation problems.

"These materials are not pourable. It is common practice to use additives and/or modified binders in the manufacture of these materials especially to allow the binder content to be raised and to reduce segregation between the coarse fraction and the mortar."

Australian Standard AS2150 (1995) defines SMA as

"*a gap graded wearing course mix with a high proportion of coarse aggregate providing a coarse stone matrix filled with a mastic of fine aggregate, filler and binder.*"

The BCA (1998) defines SMA as

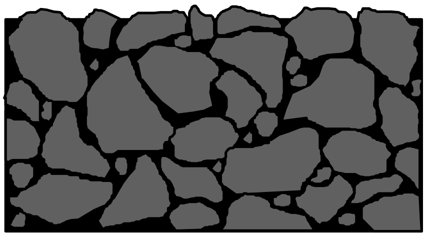
"a gap graded bituminous mixture containing a high proportion of coarse aggregate and filler, with relatively little sand sized particles. It has low air voids with high levels of macrotexture when laid resulting in waterproofing with good surface drainage."

Technically, SMA consists of discrete single sized aggregates glued together to support themselves by a binder rich mastic. The mastic is comprised of bitumen, fines, mineral filler and a stabilising agent. The stabilising agent is required in order to provide adequate stability of the bitumen and to prevent drainage of the bitumen during transport and placement.

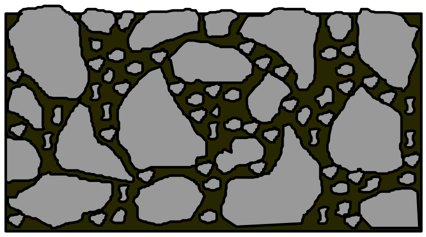
At the bottom, and in the bulk of the layer, the voids in the aggregate structure are almost entirely filled by the mastic, whilst, at the surface the voids are only partially filled. This results in a rough and open surface texture. This provides good skidding resistance at all speeds and facilitates the drainage of surface water (Nunn, 1994).

The structure of SMA is fundamentally different from dense graded asphalt. This is clear if a mix is considered as merely consisting of stones and mastic (bitumen, fines, filler and stabilising agent). The SMA has a stone skeleton which is bound by a rich (overfilled) mastic. In comparison, conventional dense graded asphalt consists of an underfilled (lean) mastic in which, by volume, only few stones are found.

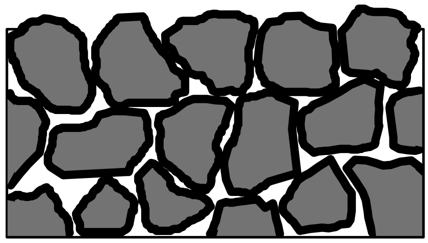
Figure 2.1 provides a comparison of the structures of SMA, dense graded asphalt and open graded asphalt.



Stone Mastic Asphalt



Dense Graded Asphalt



Open Graded Asphalt

Figure 2.1 ***Comparison of Common Asphalt Mix Types***

Since its “discovery” in Europe in the early 1960s, and the completion of many trials in America, Australia and several other countries, SMA has risen in status to such a level that it is now regarded as the premium pavement surfacing course for heavy duty pavements, high speed motorways and highways, and other roads having high volumes of truck traffic.

2.2 Stone Mastic Asphalt Properties

The concept behind the development of SMA is fairly straight forward. The SMA mixture consists of two major components:

(a) a “skeleton” of large sized aggregate, and

(b) a “mortar”, or mastic, consisting of the remaining aggregate, the asphalt binder, and a stabilising additive (Haddock, et al, 1993).

APRG (1998) indicates that the essence of SMA is a high coarse aggregate content with a high binder and filler content. This binder/filler mixture forms a "mastic". A stabilising agent is normally used to avoid binder drainage during transport and placement.

Due to the voids between the coarse aggregate being filled with the rich mastic, the resulting air voids are lower than would otherwise be the case with a conventional dense graded asphalt.

Stone mastic asphalt has excellent deformation and durability characteristics, along with good fatigue resistance. Stone mastic asphalt has a rough surface texture which offers good skid resistance and lower noise characteristics than dense graded asphalt.

The enhanced deformation resistance, or resistance to rutting, compared to dense graded asphalt is achieved through mechanical interlock from the high coarse aggregate content forming a strong stone skeleton. In dense graded asphalt, the lean mastic provides the stability.

The improved durability of SMA comes from its slow rate of deterioration obtained from the low permeability of the binder rich mastic cementing the aggregate together.

The increased fatigue resistance is a result of higher bitumen content, a thicker bitumen film and lower air voids content. The higher binder content should also contribute to flexibility and resistance to reflection cracking from underlying cracked pavements. This is supported from the experience from trials undertaken in the United States, where cracking (thermal and reflective) has not been a significant problem. Fat spots appear to be the biggest problem. These are caused by segregation, draindown, high asphalt content or improper amount of stabiliser (Brown, et al, 1997).

The rich mastic provides good workability and fret resistance (aggregate retention). The high binder and filler content provides a durable, fatigue resistant, long life asphalt surfacing for heavily trafficked areas.

The difficult task in designing an SMA mix is to ensure a strong stone skeleton and that it contains the correct amount of binder. Too much binder assists in pushing the coarse aggregate particles apart, while too little results in a mix that is difficult to compact, contains high air voids and has too thin a binder coating - and hence is less desirable (Wonson, 1998).

An SMA, properly designed and produced, has excellent properties:

(a) the stone skeleton, with its high internal friction, will give excellent shear resistance,

(b) the binder rich, voidless mastic will give it good durability and good resistance to cracking,

(c) the very high concentration of large stones - three to four times higher than in a conventional dense graded asphalt - will give it superior resistance to wear, and

(d) the surface texture is rougher than that of dense graded asphalt and will assure good skid resistance and proper light reflection.

In Germany, surface courses of SMA have proven themselves to be exceptionally resistant to permanent deformation and durable surfaces subject to heavy traffic loads and severe climatic conditions (DAV, 1992).

There is little detailed, recorded SMA performance data. It has a very good reputation in Europe and performance has been reported as exceptional in almost every case – perhaps this is a recommendation of its own. Stone mastic asphalt surface courses are reported to show excellent results in terms of being particularly stable and durable in traffic areas with maximum loads and under a variety of weather conditions (Wonson, 1996).

2.3 Stone Mastic Asphalt Composition

Stone mastic asphalt is a delicate balance between the mastic and the aggregate fraction requiring good quality aggregates, consistent gradings and careful dosage of mineral fibres to avoid an unstable mix. Variations in production can alter the mix dramatically, hence the use of additives and/or modified binders.

The design philosophy revolves around developing a strong stone skeleton with a high stone content, high bitumen and mortar content and a binder carrier.

Typical parameters are that the coarse aggregate (> 2.36 mm sieve) makes up 70-80% of the aggregate weight, the fine aggregate 12-17% and the filler fraction is in the range 8-13%. In America’s view of SMA, its percentage of passing sieves, 0.075 mm, 2.36 mm and 4.75 mm are 10%, 20% and 30% respectively and the gap gradation comes into being. Crushed stone over 5 mm occupies 70%, mineral filler and asphalt content are high, and some stabilisers (fibres or polymers) are employed (Shen, et al, undated).

Binder contents are typically in the range of 6.5 - 7.5% by mass of mix for 14 mm and 10 mm mixes. Typically, Europeans use slightly lower binder contents.

Cellulose fibres (acting as binder carriers) have been found to be excellent stabilising agents, and are typically used at a rate of 0.3% by mass of the mix (Wonson 1996, 1997).

The mix is filled with a mastic of bitumen and filler to which fibres are added in order to provide adequate stability of bitumen and to prevent drainage of the binder during transport and placement. The addition of small quantity of cellulose or mineral fibres renders adequate stability of the bitumen by creating a lattice network of fibres in the binder. The addition of fibres also prevents drainage of the bitumen during transport and placement.

In summary, the high stone content forms a skeleton type mineral structure which offers high resistance to deformation due to stone to stone contact, which is independent of temperature. The fibres added to the binder stiffen the resulting mastic and prevent draining off during storage, transportation and laying of SMA. The mastic fills the voids, retaining the chips in position and has an additional stabilising effect as well as providing low air voids and thus highly durable asphalt (AAPA, 1993).

2.4 Stone Mastic Asphalt Materials

Selection of materials is important in SMA design. The coarse aggregate should be a durable, fully crushed rock with a cubicle shape (maximum of 20% elongated or flat aggregate). Fine aggregate should be at least 50% crushed. Filler can be ground limestone rock, hydrated lime or flyash.

In general, materials of similar quality to those used in dense graded asphalt wearing courses are required for the same conditions. Figure 2.2 shows the individual components of SMA.

Figure 2.2 ***Stone Mastic Asphalt Components***

2.4.1 Aggregates

The strength, toughness and rut resistance of SMA depends mostly on the aggregate in the mix being 100% crushed aggregate with good shape (cubicle) and stringent limits for abrasion resistance, flakiness index, crushing strength and where appropriate, polishing resistance.

Fine aggregate requirements vary from 50% crushed/50% natural sand but trending to 75%/25% to even higher proportions of crushed material. The sand used must be crushed sand as the internal friction of the sand fraction largely contributes to the overall stability of SMA.

2.4.2 Binder

Stone mastic asphalt contains more binder than conventional dense graded mixes, with percentages ranging from about 6.0% up to 7.5%. Heavy duty performance is usually enhanced with polymers and fibres. These help to provide a thick aggregate coating to the aggregate, and the prevention of drain down during transportation and placement.

Class 320 bitumen is commonly used for most applications. Multigrade binders and polymer modified binders (PMB) can be used to give even greater deformation resistance. The type of PMB most commonly used with SMA is styrene butadiene styrene (SBS) which is an elastomeric polymer type. Brown et al (1997a) reported that SMA incorporating an SBS PMB produced more rut resistant mixes than SMA with unmodified binder. Superior fatigue lives are also reported as a consequence of using an SMA/SBS system.

Modified binders are used for several reasons, including:

(a) to increase the resistance to permanent deformation,

(b) to increase the life span of the pavement surface,

(c) to reduce application and damage risks especially in cases of very thin layers, and

(d) to reduce the need for a drainage inhibitor (though this can still be necessary with some PMBs).

2.4.3 Mineral Filler

Mineral filler is that portion passing the 0.075 mm sieve. It will usually consist of finely divided mineral matter such as rock dust, Portland cement, hydrated lime, ground limestone dust, cement plant or fly ash.

Experience in Australia has shown that hydrated lime will greatly assist in resisting stripping under adverse moisture conditions and is strongly recommended for inclusion in SMA mixes.

2.4.4 Fibres

The inclusion of cellulose or mineral fibres during the mixing process as a stabilising agent has several advantages including:

(a) increased binder content,

(b) increased film thickness on the aggregate by 30-40%,

(c) increased mix stability,

(d) some interlocking between the fibres and the aggregates which improves strength, and

(e) reduction in the possibility of drain down during transport and paving.

There are many binder carriers on the market including cellulose, mineral rock, wool fibres, glass fibres, silaceous acid (artificial silica), rubber powder and rubber granules and polymers (less often). When both technical aspects and costs are considered, cellulose fibres have turned out to be the best carriers in practice (Wonson, 1996).

2.5 Advantages and Disadvantages of Stone Mastic Asphalt

Stone mastic asphalt has a number of advantages over conventional dense graded asphalt. These include the following:

(a) resistance to permanent deformation or rutting (30-40% less permanent deformation than dense graded asphalt). Van de Ven, et al (undated) also suggests that the stone to stone contact of an aggregate skeleton should prevent the mix from becoming temperature sensitive and thus susceptible to permanent deformation at high temperatures.

(b) the mechanical properties of SMA rely on the stone to stone contact so they are less sensitive to binder variations than the conventional mixes (Brown, et al, 1997a).

(c) good durability due to high binder content (slow ageing), resulting in longer service life (up to 20%) over conventional mixes

(d) good flexibility and resistance to fatigue (3-5 times increased fatigue life),

(e) good low temperature performance,

(f) good wear resistance,

(g) good surface texture,

(h) wide range of applications,

(i) SMA can be produced and compacted with the same plant and equipment available for dense grade asphalt, and

(j) more economical in the long term.

Perceived disadvantages of SMA include:

(a) increased cost associated with higher binder and filler contents, and fibre additive,

(b) high filler content in SMA may result in reduced productivity. This may be overcome by suitable plant modifications,

(c) possible delays in opening to traffic as SMA mix should be cooled to 40°C to prevent flushing of the binder surface, and

(d) initial skid resistance may be low until the thick binder film is worn off the top of the surface by traffic.

Apart from good stability and durability that ensures a long service life, other advantages are claimed for SMA including:

(a) it can be laid over a rutted or uneven surface because it compresses very little during compaction. This also helps to produce good longitudinal and transverse eveness (Nunn, 1994). There is no harm to the final evenness of the surface even when applied in different mat thicknesses.

(b) if the pavement lacks stiffness, such that a dense graded asphalt with conventional binder may suffer premature fatigue induced cracking, then it may be beneficial to place SMA because of its improved fatigue resistance properties (Austroads, 1998).

(c) an anticipated secondary benefit of SMA is the retardation of reflection cracks from the underlying pavement (Austroads, 1998).

An indication of the relative performance of SMA in comparison to conventional dense graded asphalt (DGA) has been provided by Nordic asphalt technologists (Carrick et al, 1991) and is summarised in Table 2.1.

Table 2.1 ***Relative Performance of Stone Mastic Asphalt***

Property or Feature	Ranking of SMA Compared to DGA
shear resistance	much better
abrasion resistance	much better
durability	much better
load distribution	somewhat less
crack resistance	better/much better
skid resistance	Better
water spray	equal/better
light reflection	Better
noise reduction	equal/better
public recognition	much better

2.6 Life Cycle Costing

Costs are always difficult to obtain and compare. Evidence to date in both the United States and Australia shows that the initial costs of SMA are 20-40% higher than conventional dense graded asphalt in place in road applications.

To determine whether SMA is more cost effective than a conventional dense graded asphalt surfacing, whole of life or annualised cash flow techniques are used. These techniques take into account the higher initial cost of SMA (20-40% higher than conventional dense graded asphalt in place in road applications) and the longer life expectancy of SMA.

APRG (1998) found that if a conventional dense graded asphalt was designed to achieve a 20 year design life based on a certain layer thickness required, say 50 mm asphalt overlay to resist deformation and/or fatigue, then it would not be unreasonable to allow an additional five years life if an SMA was substituted.

The increased initial costs of SMA compared to conventional dense graded asphalt result from the use of premium quality materials (this may not be as much of a factor in airport related work as aircraft pavements demand the use of premium quality materials already), higher bitumen content, use of fibres, increased quality control requirements and lower production rates due to increased mixing times. However, costs vary considerably with the size of the project, and also on haul distances.

Collins (1996) reported that the State of Georgia had produced a set of life cycle costs based on the State's experience and reasonable mix designs. The analysis showed there were savings in the order of 5% using SMA over dense graded asphalt for overlay work. The analysis used the assumptions of rehabilitation intervals of 7-10 years for dense graded mixes and 10-15 years for SMA. The costings were based on an overlay of an existing Portland cement concrete (PCC) pavement, and a 3% differential discount rate over a 30 year analysis period and assumed:

(a) the costs of SMA are on average 25% higher than dense graded asphalt,

(b) the period between resheeting is on average 10 years for dense graded and 15 years for SMA,

(c) continued inflation rates at 4%, and

(d) a 30 year analysis period.

However, even considering the potential for increased costs, the Georgia Department of Transport (DOT) have found the use of SMA to be quite cost effective based on improved performance and the potential for increased service life.

The Alaska DOT (NAPA, 1998), has found that the approximately 15% increase in SMA cost compared to conventional mixtures is more than offset by a 40% additional life from a reduction in rutting.

Justification for the use of SMA is in whole of life or annualised costing. It appears that SMA could be cost effective for major routes with high performance, durability and frictional requirements.

Given that a life span increase of five to ten years can be obtained, and that additional advantages covered earlier are gained, it is clear that the choice of SMA can be a good investment.

3. Use of Stone Mastic Asphalt on Road Pavements

3.1 Australia

State Road Authorities, pavement engineers and Australian asphalt producers have known about SMA since the late 1980s/early 1990s. Although the benefits of SMA for the road industry and road users were recognised, the rate at which trials and then general use has been developed has been much slower than in the United States.

Stone mastic asphalt trials have been undertaken in Victoria, New South Wales, Queensland and South Australia. Rebecchi (1996) reported that the first trial section of SMA in Australia was placed by VicRoads in early 1990. For various reasons this trial was only partially successful.

The next attempt in Victoria was in early 1993. Trials were placed on the South Eastern Arterial and Hume Highway. These trials were judged successful and subsequently over 150,000 tonnes has been placed around Melbourne.

Shardlow (1998) reports that six individual trail sections have been placed on heavily trafficked roads in Victoria between 1990 and 1993. These trials have been constantly monitored and are performing very well

Only a small number of trials have been undertaken in other states.

In Queensland, the Brisbane City Council has placed SMA on a number of sites around Brisbane, including a 100 metre long trial section over jointed concrete slabs in Frodsham Street at Albion (Shardlow, 1998). The oldest of these trials is four to five years old.

Trials have also been undertaken on the Pacific Highway north of Bundaberg, at Gympie, on the Browns Plain Overpass and even on residential streets in the last couple of years.

In New South Wales, only limited trials have been undertaken. Some of these are believed to be successful but at least one is showing significant rutting (Rebecchi, 1996)

In November 1998, Boral undertook a trial of SMA on Rookwood Road from the Hume Highway to George Street, Yagoona (Bankstown) in South West Sydney. This section experiences extremely heavy traffic with AADT in excess of 30,000 vehicles. The proportion of heavy vehicles is estimated to be around 10%.

The existing pavement was in poor condition and required significant structural improvement by a large proportion of heavy patching.

In general the rehabilitation consisted of a 100 mm mill and resheet with heavy patching of structurally weak areas. The wearing course was 50 mm of 14 mm SMA which was underlain by 50 mm of dense graded 20 mm heavy duty asphalt.

The grading of the mix for the Rookwood Road trial is shown in Table 3.1. The target binder content was 6.2% of SBS (AB6) binder. The fibre content was 0.2%.

Sand patch tests were carried out on the completed SMA trial in the wheel paths and between wheel paths to determine the surface texture depth. Average surface texture depths were in the range of 1.0 to 1.7 mm (Boral, 1998).

This trial was the precursor to the SMA trial undertaken at Sydney International Airport.

Table 3.1 ***Rookwood Road SMA Grading***

Sieve Size	Percentage Passing by Mass
19.0	100
13.2	94
9.5	61
6.7	38
4.75	26
2.36	21
1.18	18
0.600	15
0.300	13
0.150	11
0.075	10

3.2 Overseas

3.2.1 Europe

Stone mastic asphalt is used to some extent in most European countries on roads and highways. The use of SMA spread initially from Germany to Sweden and Denmark and then to Norway, The Netherlands, Finland, Austria, France, Switzerland and now Belgium. It has now been used throughout Europe over the last 15 years. Figure 3.1 shows the wide spread use of SMA across Europe.

In many European countries (Germany, Belgium, The Netherlands, Norway and Sweden) it has become one of the surfacing solutions for resistance to permanent deformation at higher pavement temperatures with increasing traffic loading, tyre pressures, number of heavy vehicles and the introduction of "super singles" (Van de Ven, et al, undated).

Recognition of its good performance led to its standardisation in the German Technical Specifications in 1984. Today it is widely used on the road network in Germany and variants of SMA have been used in many other countries.

Figure 3.1 ***Extent of SMA Use on Roads in Europe***

EAPA (1998) indicates that all countries report very positive experience with SMA, especially its surface characteristics, durability and riding comfort. Its performance on heavy duty pavements is excellent.

The following is table provides a summary of the use of SMA on roads in Europe.

Table 3.2 ***Summary of SMA Use on Roads in Europe***

Country	**Description**
Belgium	Most high traffic roads which need resurfacing are being resurfaced with SMA.
Czech Republic	SMA has been in use since 1991. Current experience with SMA indicates an increasing use of this technology in the Czech Republic.
Denmark	SMA has been used in Denmark since 1982. SMA is typically used as a wearing courseon high volume roads, carrying a high proportion of heavy vehicles, industrial areas, airfields and other areas with heavy loading.
Faeroe Islands	Started using SMA on roads in 1992.
Finland	SMA is especially used on the roads with heavy traffic. SMA is considered to be the best pavement for roads with good resistance to deformation, wear (studded tyres the biggest problem) and low temperatures.
France	France knows two types of bituminous mixtures comparable to SMA, these being "Béton Bitumineux Ultra-Mince" (BBUM) and "Béton Bitumineux Très Mince" (BBTM). These mixes are used as thin surfacings.
Hungary	SMA has been in use since 1983.
Iceland	Limited use on roads.
Italy	SMA has been used on Italian roads since 1991.
Norway	SMA has been used in Norway since 1985. SMA is used in Norway as a wearing course on high volume roads, industrial areas, airfields and other areas with heavy loading.

Table 3.2 cont. ***Summary of SMA Use on Roads in Europe***

Country	Description
Portugal	SMA has been used since 1994. Two types of bituminous mixtures comparable to SMA can be distinguished in Portugal, Bet©o Betuminoso Rugoso and Microbet©o Rugoso.
Sweden	Trials have been undertaken in Sweden since 1974. SMA is now the standard wearing surface on motorways and main roads and has been since 1988.
The Netherlands	SMA has been in use since approximately 1987. The yearly amount produced is in the order of 15% of total production with 35% of all surface course material consisting of SMA.

3.2.2 United States

Stone mastic asphalt is a relatively new paving mixture in the United States. The use of this mixture came as a result of the European Asphalt Study Tour that took place in 1990. The first test section was constructed in the State of Georgia in 1991.

In the United States, SMA has been used in much the same manner as Australia, mainly in trials in various states. More extensive use of SMA on roads and highways is progressively occurring as the trials prove to be successful. Brown et al (1997) indicates that SMA has been used in Alaska, Arkansas, California, Colorado, Georgia, Illinois, Kansas, Maryland, Michigan, Missouri, Nebraska, New Jersey, North Carolina, Ohio, Texas, Virginia, Wisconsin and Wyoming.

Stone mastic asphalt is now the standard surfacing material of the States of Georgia and Maryland.

3.2.3 Canada

A stone mastic asphalt (SMA) surface course implementation trial was completed in 1994 by the Municipality of Metropolitan Toronto Transportation Department (Metro Transportation) on a heavily trafficked urban pavement.

Stone mastic asphalt implementation trials undertaken by the Ontario Ministry of Transport (MTO) in 1990 and 1991 (Carrick, 1991 and Woodman, 1995) and Metro Transportation in 1994 have been most favourable.

3.2.4 United Kingdom

Interest in SMA in the United Kingdom was stimulated by exposure to the alternative technology through the involvement in the exercise to harmonise European Standards for asphalt mixtures. Laboratory studies and in-house full-scale trials were conducted by Tarmac during 1992 and 1993 resulting in their "Tarmac Masterpave" variant of stone mastic asphalt. The first “public” trial demonstration of stone mastic asphalt in the United Kingdom was, ironically, carried out by Tarmac on an airfield taxiway at RAF Lakenheath in July 1993 for the benefit of the United States Air Force as part of their research project to evaluate European pavement practices (Loveday, et al, 1998)

Since 1994 there have been a number of trials on major trunk roads and whilst these are being evaluated, the use of SMA on non-trunk roads has increased substantially.

3.2.5 South Africa

Stone mastic asphalt has been in use in South Africa for only two years on roads. There have been a number of reported failures as can be expected with any new product. The South African Bitumen Association (SABITA) indicates that some exciting results are being achieved on pretty large surfacing projects in the country.

3.2.6 China

Shen et al (undated) reports that the Airport Expressway (Capital International Airport Expressway) in Beijing indicates good performance of the SMA at either high or low temperatures.

3.2.7 New Zealand

Stone mastic asphalt is still a relatively new product in New Zealand with the first SMA project on roads being undertaken in 1998. Experience with SMA is limited to a handful of sites. No results of the performance of these trials are available at this time.

4. Use of Stone Mastic Asphalt on Aircraft Pavements

4.1 General

When considering the sheer number of airports worldwide, the use of stone mastic asphalt on aircraft pavements is confined to less than a handful of airports, with most being in Europe. Outside of Australia, research has indicated that the use of SMA on aircraft pavements in confined to Europe, the United Kingdom and China.

Whilst SMA is used on roads in some 25 countries around the world (the majority being in Europe), airport usage is limited to 15 countries, again the majority being in Europe. Of these, Norway is the single biggest user with some 15 airports using the material on aircraft pavements.

Figure 4.1 shows the extent of the use of SMA over Europe on aircraft pavements.

Figure 4.1 ***Extent of SMA Use on Aircraft Pavements in Europe***

This section looks at where SMA has been used on aircraft pavements around the world and is based on the responses to the questionnaire forwarded to airport authorities, technical organisations and manufacturers. Full details of the distribution of the questionnaire are contained in Appendix E.

This section also considers why SMA has not been used in some countries to date even though it has been used on roads, again based on responses to the questionnaire.

The research associated with this report included some 400 requests for information. These were issued to airports, contractors, asphalt producers and suppliers of stone mastic asphalt (SMA) around the world. The technology and processes used by contractors and other organisations involved in the design, manufacture, supply and laying of SMA is kept as a closely guarded commercial secret, both in Australia and around the world. Hence apart from the language barrier, information on actual experience with SMA on aircraft pavements was extremely difficult to obtain.

4.2 Europe

4.2.1 Norway

General

Norway is by far the largest user of SMA on aircraft pavements. In Norway there are more than 50 runways with regular traffic. There are 19 domestic/international airfields with runways over 1,600 metres and 32 municipal airfields with 800 metre long runways.

The Norwegian Civil Aviation Administration (NCAA) is responsible for the maintenance of al these airfields. This means the NCAA have over 8 million square metres of asphalt pavement which needs regular maintenance.

In the early 1970's nearly all the runways in Norway had to be repaved because of development of newer, larger aircraft. Until 1988 the average age of Norwegian runways was over 15 years, and the condition of the nearly 3.5 million square metres of asphalt pavements was not satisfactory. The "standard choice" of asphalt mix for Norwegian airfield pavements in this period was 11 mm nominal size dense graded asphalt, with unmodified bitumen and a binder content of 5.4 %.

Due to requirements set by NATO, the asphalt mix was designed with a high Marshall stability so that the pavement was able to resist deformations from military aircraft with high tyre pressures. To increase the Marshall stability (above 9,000 N), low bitumen contents (<5.5 %) and stiff initial binders were used.

Norway also has a widely varied climate. Considerable temperature differences are recorded from South to North and between coastal and inland locations. Air temperatures can range from -40^{o}C to +35^{o}C for selected airfields.

Stone mastic asphalt has been used on road pavements in Norway since the mid 1980's with great success. This success has mainly been due to the very good skid resistance against wear from studded tyres. Since SMA also has interesting properties such as friction and stability, the NCAA tested SMA on an airport some years ago. One main advantage according to NCAA was that grooving was not necessary with SMA.

Stone mastic asphalt was chosen at the Gardermoen Airport in order to alleviate the grooving associated with dense graded asphalt. Dense graded asphalt is usually grooved in order to provide positive surface drainage and increase friction during wet conditions. The requirement to groove dense graded asphalt in Norway is also a request from the pilot association. To avoid the need for grooving, NCAA repaved one runway in 1991 with SMA.

All tests carried out concerning wet friction characteristics show that SMA has sufficient wet friction. SMA 11 has a texture depth of 1.2-1.8 mm depending on maximum aggregate size, and temperature and homogeneity of the mix during compaction. By comparison, dense graded asphalt with a texture depth of 1.0 mm provides the best wet friction.

Research Program

In 1990, NCAA initiated a pavement research and development program, where the main objective was to develop more lasting pavements with sufficient friction characteristics to solve the problems associated with ageing, deterioration, different climate and friction. Results showed that SMA mixes are slightly less resistant to ageing than dense graded asphalt. This means that regularly preventive maintenance is very important when these mixes are used.

Experiences since the mid 1980’s with dense graded grooved asphalt indicated that the combination of severe climatic conditions and grooved pavements lead to a high cracking and ravelling rate resulting in shortened pavement life.

Friction Characteristics

To prevent aquaplaning and minimize friction problems on Norwegian runways, dense graded asphalt mixes have normally been grooved. According to the International Civil Aviation Organisation (ICAO) Annex 14, the basic characteristics for a runway surface are:

(a) the surface of a paved runway shall be constructed so as to provide good friction characteristics when the runway is wet, and

(b) the average surface texture depth of a new surface should be not less than 1.0 mm.

As mentioned earlier, nearly all Norwegian runways have been grooved. The texture depth of Norwegian 11 mm dense graded asphalt is less than 1.0 mm, but due to the grooving there has been no questioning of the texture depth.

An SMA mix has a very coarse macro-texture, which leads to higher degree of ageing in the top 10 mm of the pavement. However the higher binder content in the SMA mix can reduce this negative effect. More substantial hardening can be observed in the SMA mix compared with the standard dense graded asphalt mix. However, as the binder film on the SMA is much thicker, the long-term characteristics may be at the same level for these two mixes.

Stone Mastic Asphalt on Norwegian Runways

Since 1992 a total of 15 runways have ben resurfaced with SMA. Different binders and type/amount of additives have been used, depending on the climatic conditions at the actual airport. These are indicted in Table 4.1.

Table 4.1 ***Airports with Stone Mastic Asphalt in Norway***

Airport	Year Surfaced	Mix Type
Ålesund Airport, Vigra	1996	SMA 11
Banak Airport, Lakselv	1992	SMA 11
Bardufoss Airport	1995	SMA 11
Hammerfest Airport	1994	SMA 11
Harstad/Narvik Airport, Evenes	1994	SMA 16
Haugesund Airport, Karmøy	1995	SMA 11
Kristiansand Airport, Kjevik	1997	SMA 16
Molde Airport, Årø	1993	SMA 16
Ørsta/Volda Airport, Hovden	1993	SMA 11
Oslo Airport Gardermoen	1998	SMA 11
Oslo Airport, Gardermoen	1995	SMA 16
Røros Airport	1995	SMA 11
Sørkjosen Airport	1994	SMA 11
Tromsø Airport, Langnes	1994	SMA 16
Vadsø Airport	1994	SMA 11

Conclusions from Norway

Lange, et al (1999) draws the following conclusions from the use of SMA on Norwegian airports.

(a) Based on results from the test track at Gardermoen, the dense graded asphalt mix with a texture depth of 1.0 mm provides the highest wet friction values. The SMA 11 surfaces also have sufficient friction characteristics.

(b) In practice, a texture depth of 1.0 mm is hard to obtain when the air void content has to be <4.5%.

(c) Friction measurements on different runways with SMA pavements show that an SMA 11 surface has about the same properties as a grooved dense graded 11 mm mix.

(d) In Norway, the cost of SMA and dense graded asphalt is about the same depending on the site, distance to nearest mixing plant, etc. As such, price is not considered a factor.

(e) A faster surface ageing may be observed in SMA mixes compared with the dense graded asphalt mixes. However, the binder content is higher in the SMA mix.

(f) SMA needs preventive maintenance more regularly the first 10 years than a dense graded asphalt.

(g) Marshall stability of a SMA mix is lower than a dense graded asphalt mix. Wheel track tests show that SMA is more resistant to rutting than a dense graded asphalt, thus, Marshall stability can not be used as the only requirement for SMA mixes.

(h) Stone mastic asphalt is a good alternative to a grooved dense graded asphalt mixes and is more resistant to rutting.

(i) An SMA stays longer in a "wet condition" after rainfall. This may lead to more de-icing application on the runway during the winter season.

4.2.2 Sweden

The National Fortifications Administration, the owner of military airfields in Sweden, has reported some adverse experiences with SMA on aircraft pavements. The reported problems are:

(a) sensitivity to fuel spillage and de-icing chemicals due to high air voids (permeable) of a special type (concentrated like a straw),

(b) low skid resistance due to the thick binder films on the aggregates,

(c) some problems with separation (segregation), and

(d) low shear strength in curves and places where aircraft turn around.

At this stage, SMA is no longer used in Sweden because of recent problems caused by acetate and formate de-icing chemicals. However, the material has otherwise performed well, even north of the Arctic Circle.

4.2.3 Belgium

Stone mastic asphalt has been used in Belgium at the regional airports of Antwerp and Ostend. Both airports are run by the Flemish Airports Authority. Prior to this, SMA was used by the Belgium Air Force on some of their airfields.

Ostend Airport

Ostend Airport has a single runway, 3,200 metres long, and is mainly used by freight aircraft up to B747 and AN124. Ostend Airport has a pavement area of 84,500 m^2.

The first 1,400 metres of runway 26 was overlaid in 1992/93 with a conventional dense graded asphalt. This overlay was constructed prior to the use of SMA on the highways in Belgium. The remaining 1,800 metres of the runway overlaid in 1996 with the use of SMA 0/14.

Antwerp Airport

Antwerp Airport has one runway with a length of 1500 metres and a pavement area of 67,500 m^2. Antwerp is used by aircraft up to BAe146. The runway was overlaid in 1996 with SMA.

At both airports, good experience on the friction characteristics of the SMA has been reported by the Flemish Airports Authority. In the first period of use of the SMA however, the friction is lower than after some months use. The behaviour in the rain and dry situations is very good at both airports.

The Belgium Air Force continues to use SMA for runway overlays.

4.2.4 Denmark

Obtaining information from Denmark was extremely difficult. The major contractor responsible for SMA design, production and laying, keeps the details of SMA, particularly that which has been used at Copenhagen Airport a closely guarded commercial secret.

SMA has been used in Copenhagen Airport on Runway 04R-22L (length 3,600 metres and width 42 m) and on a Deicerplatform. Only limited results have been able to be obtained for Copenhagen Airport and these relate to a de-icer platform. The mix proportions of the SMA used on the de-icer platform are indicated in Figure A-6 in Appendix A.

On the SMA from the Runway 04R-22L, the surface texture depth, measured using the sand patch method were between 0.64 and 0.70 mm.

General specifications of SMA for use on Copenhagen Airport are indicated in Table 4.2.

Table 4.2 ***Copenhagen Airport SMA Properties***

Property	Requirement
Bitumen	Penetration grade 60 (Class 320)
VMA:	16 %
Air Voids:	Min. 1.5 %; max. 4.0 %
VFB:	78 – 93 %

The SMA pavements at Copenhagen Airport are typically on top of a bituminous base course and a binder course.

With regard to maintenance there are problems in recycling SMA pavements due to the amount of fibres. There has been no recycling of SMA at Copenhagen Airport.

On runway 04R-22L, the surface was sealed using a tar-based surface dressing after 10 to 15 years of service. Analysis of the SMA beneath the surface dressing shows that the bitumen has not aged very much even after 20 years. This indicates that the high amount of bitumen is good for durability.

4.2.5 Czech Republic

Stone mastic asphalt is yet to be used in the Czech Republic on aircraft pavements and there are no plans to do so in the near future. The probable reason given by airport authorities for not using SMA on aircraft pavements is a lack of sufficient experience with the material.

Current experience with SMA on roads indicates an increasing use of this technology in the Czech Republic.

4.2.6 Germany

Despite SMA being used in Germany on roads since the late 1960s, very few airport have embraced this technology. The reasons for this were not able to be identified due to the very limited responses to requests for information being received. Responses which were received are summarised below.

Cologne

At Cologne Airport, SMA has been used on ground services areas. No data in terms of performance, mix design, etc was available from the airport authority however.

Frankfurt

Stone mastic asphalt has been used at Frankfurt Airport on the apron taxilanes between the Terminal 1 aircraft stands. SMA was chosen for application in this situation due to its resistance to deformation by undercarriage of parked aircraft.

SMA has also been used on ground services areas.

No data in terms of performance, mix design, etc were available from the airport authority for either of these applications.

Muenster/Osanbrueck

SMA has been used at Muenster/Osanbrueck, however only in small areas. No data in terms of performance, mix design, etc were available from the airport authority.

4.2.7 Italy

Despite SMA being used on roads in Italy since 1991, there is no reported use of the materials on aircraft pavements.

4.2.8 Romania

Romania has some 16 civil airports although SMA is yet to be used at any of them.

Airport authorities in Romania have advised that due to a lack of traffic and poor financial resources, they are forced to give up a lot of development plans. This includes the use of SMA in on aircraft pavements.

4.2.9 Slovakia

In Slovakia, only three of the country's six civil airports have runways with an asphalt surface, however, SMA has not been used to date. There are no known plans to use SMA on aircraft pavements.

4.2.10 Hungary

Despite being used on roads, SMA is yet to be used on aircraft pavements in Hungary. There are no known plans to use SMA on aircraft pavements.

4.2.11 Finland

In Finland, there is only one test section on a runway. This test section is 500 metres long and was constructed in about 1986.

All experiences with SMA on airfield pavements have been reported as good by the Civil Aviation Authority. However, no data in terms of performance, mix design, etc were available from the Civil Aviation Authority.

4.2.12 The Netherlands

The Teuge Airport Authority has indicated that stone mastic asphalt has been used at Teuge Airport with good results. No data in terms of performance, mix design, etc, were available from the airport authority.

Netherlands Airport Consulting (NACO) have never specified SMA for use on airfield pavements. It is claimed by NACO that the main problem with SMA is to define its engineering properties in specifications. Stone mastic asphalt maybe used by NACO on a project towards the end of the 1999.

4.2.13 Iceland

Stone mastic asphalt has not been used on aircraft pavements in Iceland. The main reason is that SMA is a fairly new product in Iceland and not widely used. There are no known plans to use SMA on aircraft pavements.

4.2.14 Faeroe Islands

There is only one airfield on the Faeroe Islands. The runway was resurfaced in 1992 with conventional dense graded asphalt, despite also starting to use SMA on roads at the same time.

The reason for not using SMA on the airfield was a lack of experience in the use and performance of SMA at the time. The Office of Public Works has indicated that the potential exists in the future to place SMA when the airfield is next resurfaced.

4.2.15 Austria

Stone mastic asphalt SMA has been used at Innsbruck for overlaying the runway. According to the airport operator, the material was chosen because work has to be done during night time (low temperature) and the layer thickness is approximately 40 mm. The airport operator was unable to offer any practical experience concerning maintenance aspects and performance.

4.3 United Kingdom

The British Airports Authority (BAA) who are responsible for eight (8) airports, has only used SMA as either a patch repair to porous friction course, a reinstatement over a runway joint repair, or in a small runway holding area. The mixes used were proprietary products. The British Airports Authority do not plan to use SMA on runways until the de-icer problem being experienced, particularly in Sweden, has been solved.

The costs for SMA compared with conventional dense graded asphalt are similar although the benefits of a good texture and durability mean it is more cost effective in the long term.

The main downside for SMA in the United Kingdom on aircraft pavements has been client inertia according to BAA.

4.3.1 Norwich Airport

Stone mastic asphalt has been used on the subsidiary runway 04-22. The existing asphalt surface of runway 04-22 had deteriorated badly and needed to be resurfaced at minimum cost while ensuring it would last at least until 2001 without major maintenance. An SMA solution was recommended as this provided benefits in terms of surface characteristics, flexibility of laying conditions and potential resistance to reflective cracking.

The works undertaken on runway 04-22 were part of an overall rehabilitation program. They were required to improve the standard of the subsidiary runway so that it could be used while rehabilitation works were undertaken on runway 09-27.

Works started in November 1996. The wearing course surface of the 1,100 metre subsidiary runway was planed to remove irregularities and years of maintenance repairs. Any defective underlying material disturbed by the planing was removed and replaced with hot rolled asphalt before 30 mm of SMA was laid over the runway. This was the first use on a UK runway of Tarmac Masterpave from Tarmac Heavy Building Materials, a proprietary form of SMA.

An inspection of runway 04-22 after one year revealed negligible deterioration of the surface despite increased use during the resurfacing of a 530 metre section of runway 09-27 and a 180 metre section of taxiway.

Following the success of the SMA on runway 04-22, the specification for the overlay on runway 09-27 was changed to SMA during the tender period.

The works were undertaken by Tarmac Professional Services. Despite traffic volumes being low, the experience with SMA at Norwich is claimed to be good.

4.3.2 Prestwick Airport

Stone mastic asphalt has been used at Prestwick Airport as a wearing surface on its second runway runway 03-21. This runway (which is 1,830 metres in length with an additional 150 metres of stopway) was recently surfaced with 14 mm size SMA. The runway is currently used to park C5 Galaxy military aircraft and when in full handling mode, will accept MD11 aircraft.

Current friction measurements on the runway are good and are expected to further increase over time. The airport company advised that there have been no reports of operational problems associated with the SMA to date.

4.2.3 Gatwick Airport

The British Airports Authority have used SMA at Gatwick Airport on a limited basis as thin overlays and as the surface layer on full depth flexible reconstruction.

The reasons given by BAA for trying the material were:

(a) it can accommodate minor movement better than Marshall asphalt,

(b) as it is a proprietary material, it is readily available from local suppliers, and

(c) it is an easy material for local asphalt contractors to lay and make a good job of.

Advice from BAA is that there have been no adverse comments from Operations to date. This may be because in the past Gatwick Airport had a porous friction course on the runway which had the same basic look.

4.3.4 Heathrow Airport

The SMA used at Heathrow Airport was a proprietary form of SMA and was used in patch repair situations to porous friction course and a reinstatement over a runway joint repair. No performance data on this application of SMA has been made available.

4.3.5 St Angelo's Airport - Enniskillen

The runway at St Angelo's Airport in Enniskillen, Northern Ireland was surfaced with 40,000 m^2 of SMA in early 1999. No data in terms of performance, mix design, etc were available from either the airport or the contractor responsible for laying the SMA.

4.3.6 Belfast Airport

Stone mastic asphalt has never been used at Belfast Airport, however the airport operator has indicated that its use would be considered in the future. Prior to this use however, evidence that its frictional properties are acceptable to runway use and that de-icing chemicals have no adverse effects would be required.

4.4 China

The east-west runway of Beijing Capital International Airport has a length of 3,800 metres and a width of 60 metres. It was originally constructed in 1954. Cracks and differential settlement were affecting the normal use of the runway.

The area of the overlay pavement was 259,000 $m^{2.}$ A total of 120,000 tons of asphalt was produced and paved. The project was designed by China Civil Airport Construction General Company and was mainly constructed by Beijing Municipal General Company. The project was continuously constructed from April to June 1996.

Before paving the base course, the old concrete pavement was repaired and coiled material installed at the slab joints to delay the expansion joint reflection cracking.

As part of the overall rehabilitation of the runway, both the surface and intermediate course adopted modified asphalt with admixing PE and SBS to improve the use characteristic. The surface structure (60 mm thick) adopted stone mastic (SMA, 16 mm). The intermediate course (70 mm thick) and base course (30-80 mm thick) structures adopted dense graded asphalt.

The binder used in the SMA was a C170 binder with 3.5% PE and 3% SBS. Low Density Polyethylene (LDPE) was used to improve the high-temperature performance. In order to improve the asphalt's resistance to low-temperature cracking, an SBS polymer was also used. German wood fibre at a proportion of 0.3% by mass of the mix was added to the SMA wearing course mix. The east runway asphalt mixture technical details are shown in Figure A-9 in Appendix A.

No details of the performance of the SMA are available at this time.

4.5 United States

Stone mastic asphalt has not been used on airport projects in the United States to date. The reason for this is uncertain, but it is probably due to the relative newness of the application of this technology to aircraft pavements. States such as Georgia and Maryland use SMA extensively on roads, but other states have only constructed test sections.

One probable reason SMA has not been used for airports is current dense graded asphalt mixes used for airports are very resistant to rutting. Resistance to rutting is one of the major advantages of SMA. The improved durability of SMA mixes will have to be demonstrated before they are commonly used for airports.

The Federal Aviation Administration (FAA) currently has no specification for SMA. All materials on commercial airports must be approved by the FAA. The FAA has not given any indication of approval of this new mix which translates into no federal fund participation.

The normal reaction to new materials is a hesitancy to use it at the airport without the benefit of seeing the performance of the material in place. States such as Hawaii will wait for positive reports on the feasibility of using this material and approval of the FAA prior to using on aircraft pavements.

4.6 Canada

Stone mastic asphalt has never used on Canadian Airports. The main reasons for this are cited as being, lack of promotion of the material by industry and conservatism on the part of the airport authority. Another reason is that current dense graded asphalt does not experience stability problems. Consequently rutting is not a major problem at Canadian airports.

Up until the early 1990's, Canadian airports were always under the influence of Transport Canada and Public Works Government Services Canada for design standards. Since the airports have been transferred or are in the process of being transferred to the local airport authorities, greater freedom in trying new materials now exists.

4.7 Middle East

SMA has never been used in the Middle East. Runways in this region are typically constructed of concrete due to the extremes of temperature.

4.8 Japan

Stone mastic asphalt is not a popular surfacing in Japan according to the operators of the major airports at Kansai and Narita. Stone mastic asphalt is not used on aircraft pavements as they do not think it is needed due to dense graded asphalt performing satisfactorily.

5. Cairns International Airport Trials

Cairns International Airport in far north Queensland began trialling SMA in 1998. The use of SMA on an airport, even the trial at Cairns International Airport, was the first use of this technology in Australia. Cairns International Airport has a history of implementing innovative pavement surfacing materials and the use of SMA is no exception.

Cairns International Airport is the 6th busiest airport in Australia, predominately catering for both domestic and international tourist traffic. Last year, more than 2.6 million passengers and more than 40,000 aircraft passed through Cairns International Airport.

Cairns International Airport comprises a single main runway, predominantly north-south and 3,197 metres long The total pavement area at Cairns International Airport is in excess of 600,000 m^2 of which in the order of 75 percent are asphalt surfaced flexible pavements, including all runways.

The hot and humid tropical environment, and heavily loaded international aircraft combine to provide a rigorous test for the asphalt to withstand and provide adequate performance to avoid plastic flow and rutting. From cores extracted from the pavement, there is no evidence of rutting of the base course.

Cairns International Airport has suffered continual asphalt problems in terms of rutting and general performance of the asphalt since the late 1980’s. Conventional asphalt and PMB asphalt have both been used at the rear of the international apron stands over the past few years. The SMA trials have been conducted on both the domestic apron and two trials on the international apron to evaluate its performance in overcoming these problems. Figure 5.1 indicates the location of the SMA trials at Cairns International Airport.

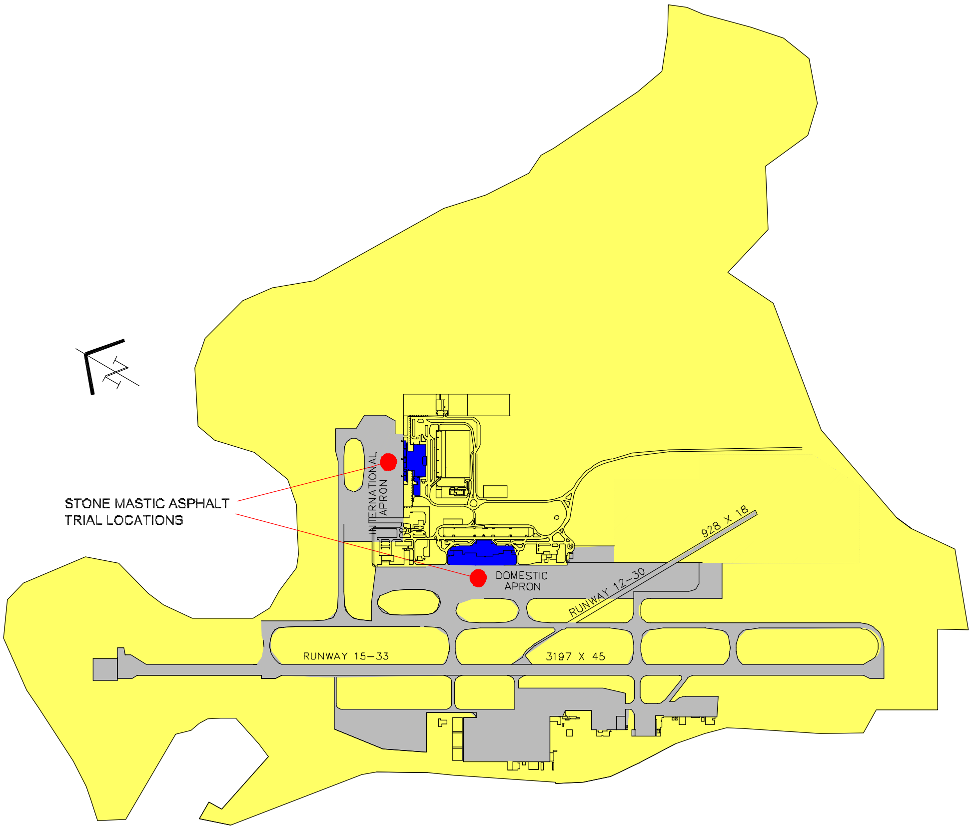


Figure 5.1 ***Location of Stone Mastic Asphalt Trials***

The first trial was placed by Boral Asphalt on International Apron Bay 2 and the domestic apron in August 1998. In this trial, both 10 mm and 14 mm SMA mixes were used. The SMA was laid over a 30 mm layer of CPA Type 14A asphalt. The trial areas are as are indicated in Table 5.1.

Table 5.1 ***1998 Stone Mastic Asphalt Trial Areas***

Area	**Mix Type**	**Area of Trial**
International Apron Bay 2	SMA10	165 m^2
International Apron Bay 2	SMA14	165 m^2
Domestic Apron Bay 19	SMA10	1,800 m^2

The SMA was based on Queensland Main Roads specification. Typical mix design details for the Queensland Main Roads SMA are indicated in Figure A-1 in Appendix A.

In May 1999, a further SMA trial was undertaken by Pioneer North Queensland on International Apron Bay 3. International Apron Bay 3 is the most heavily loaded bay on the international apron in terms of aircraft. This trial used SMA 14 and comprised an area in the order of 250 m^2. Again, the mix designs were based on Queensland Main Roads Department Mix design for SMA.

The Cairns Port Authority (CPA) who own and operate Cairns Internatioanl Airport have advised that there have been no reported operational problems with the SMA. The initial perception on seeing the coarse open texture by Airport personnel was that aggregate would be lost from the surface and become a foreign object damage (FOD) problem. This has in fact not happened.

The costs of SMA in the instance of the trials at Cairns were in the order of 20% higher than those of dense graded asphalt trials, at

(a) Stone mastic asphalt $157/tonne in place

(b) Dense graded asphalt $134/tonne in place

The above rates were based on a tender for 3,000 tonnes of dense graded asphalt and 200 tonnes of stone mastic asphalt (and includes additional costs of jet sealing – a material applied to the surface to protect it from damage from fuel spills). The application rate of the jet seal on the SMA was almost double the rate compared to dense grade asphalt. This is due to open texture of the SMA.

It is surmised that the SMA costs may have been lower if more SMA mix was produced, thereby reducing the cost differential.

Given the environment and the severe traffic loadings experienced on the pavements in Cairns, it is likely that the trials will have to be in place for a minimum of two to three years before any meaningful data is obtained in relation to the performance of the SMA.

Unfortunately no formal monitoring system is in place for the trial areas other than visual inspections, hence no real performance data is available.

It is also unfortunate that neither Boral or Pioneer were able to make production results from the trails available for this research for comparative purposes with international practice.

6. Sydney International Airport Trial

Sydney International Airport was first declared an airport in 1920. By 1930, the first gravel runway was completed. In 1935, the then Mascot Aerodrome became an international airport. Since these humble beginnings, Sydney International Airport has grown to become Australia's major aviation hub and premier international airport. Sydney International Airport is one of the world's oldest continuously operating airports.

Sydney International Airport is rated as the 8th busiest airport in the Asia/Pacific Region and the 40th busiest in the world. More than 21 million passengers and 280,000 aircraft passed through Sydney last year. Sydney International Airport comprises three runways. The main north-south runway is 3,962 metres long while the parallel north-south runway is 2,438 metres long. The east-west runway is 2,529 metres long.

The total pavement area at Sydney International Airport is in excess of two million square metres of which in the order of two thirds is asphalt surfaced flexible pavements, including all runways.

Figure 6.1 provides an aerial view of Sydney International Airport.

Figure 6.1 ***Sydney International Airport***

Totally surrounded by water and only three metres above sea level, Sydney International Airport experiences its own unique problems associated with pavements close to sea level and with a high water table.

Asphalt stripping has been a major concern for a number of years as has deterioration of the crushed rock through secondary mineralisation. Despite the use of multigrade and PMB binders, the long term performance of the asphalt has not been anticipated. The stripped asphalt is now in the order of 175 mm below the surface in places and would require long term closure of the pavement area to remove the affected layer and reinstate the pavements to operational condition.

In the past, various trials have been undertaken with PMB and multigrade binder asphalt. Recent runway overlays and construction works on the heavily load taxiways in the international sector have used PMB asphalt. Despite this, the asphalt continues to rut under the heavy aircraft, particularly on the taxiways.

Sydney International Airport is revising its approach to maintenance of asphalt pavements in an effort to enhance pavement performance. A number of different asphalt mixes have been used for patching to obtain some empirical data on relative performance. The trialling of SMA is part of this process.

The SMA trial was undertaken to assess SMA and it ability to perform where other asphalt's had not performed up to expectation. The aim of the trail was to produce and lay SMA with similar properties as that developed by Boral Asphalt technology's laboratory for use in the Rookwood Road trial.

This trial, is the first of two to be carried out. A second trial is programmed for a more demanding location on the international sector of the airport subject to the outcome of the first trial. Figure 6.2 indicates the location of the SMA trial.

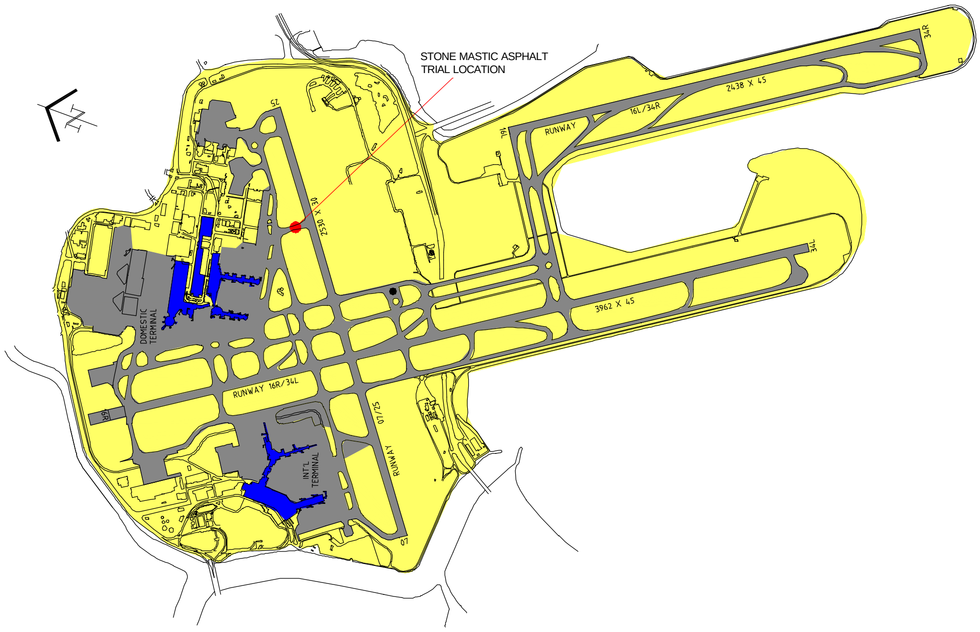


Figure 6.2 ***Location of Stone Mastic Asphalt Trial***

The location of the trial was on Taxiway D situated in front of the Ansett Australia terminal. The trial area was constructed on 26 and 27 May 1999. The trial is in the order of 105 metres long, 18 metres wide with a depth of 50 mm. The estimated quantity of asphalt placed was 220 tonnes.

Appendix B contains photographs of the trial area while Appendix C contains test reports and production results relevant to the trial. The mix design for the trial is shown in Table 6.1. The mix design for the Sydney trial is also compared with other SMA mixes from Australian authorities and from around the world in Appendix A.

The main problem with the trial was significant areas where there was a coarse, uneven surface finish. Beside looking poor, these areas are of concern due to ravelling of the coarse aggregate. It is estimated that between 20 and 30% of the area paved is affected by poor surface finish. A number of factors contributed to the poor surface finish including haul distance, plant difficulties, use of smaller paver than has constructed previous SMA work and low mix temperatures.

Table 6.1 ***Trial SMA Grading***

Sieve Size	Percentage Passing by Mass
19.0	100
13.2	90-100
9.5	50-65
6.7	30-44
4.75	21-32
2.36	16-26
1.18	
0.600	11-18
0.300	
0.150	
0.075	8-12
Binder Content	5.7-6.7
Fibre Content	0.2-0.3
Air Voids	3-6
Draindown	0.3 max
VMA	16 min

Unfortunately the aims of the trial have not been satisfied due to the area of poor surface finish. The poor surface finish areas will be treated with a sand emulsion sealing to prevent further loss of aggregate form the surface.

Monitoring to date has consisted of visual inspections only for loss of aggregate from the surface. No other measurements (rut depth, friction, permeability, etc) have been undertaken and will not be not be on the trial. It is hoped that a more formal monitoring program will be implemented on the new trial.

At the time of submission of this report, SACL had still not decided on a new date for the new trial.

7. Discussion

Research into the use of stone mastic asphalt (SMA) on aircraft pavements was undertaken through consultation with in the order of 400 airports, contractors, asphalt producers and suppliers of stone mastic asphalt (SMA) around the world. The list of those contacted during the course of this research is contained in Appendix E. The response to the questionnaire was limited to in the order of 20%.

This thesis involved research into technology and processes which contractors and other organisations involved in the design, manufacture, supply and laying of SMA keep as a closely guarded commercial secret, both in Australia and around the world. Hence apart from the language barrier, information on actual experience with SMA on aircraft pavements was extremely difficult to obtain.

Whilst SMA is used on roads in some 25 countries around the world (the majority being in Europe), airport usage is limited to 15 countries, again the majority being in Europe. Of these, Norway is the single biggest user with some 15 airports using the material on aircraft pavements.

The airport industry as a whole is very cautious regarding new surfacings. The risk of foreign object damage (FOD) to aircraft jet engines cannot be over emphasised and loose aggregate must be avoided at all times. Hence there is a resistance to use new materials, particularly on runways, which depart from normal practice.

The major obstacles facing the use of SMA on aircraft pavements would seem to be client inertia or conservatism. This is the normal reaction to the use of new materials at an airport without the benefit of seeing the performance of the material in place.

The research indicated that where SMA is being used, it is generally performing very well. The biggest single operational problem associated with the material is that it is prone to degradation with de-icing chemicals commonly used in Europe. The chemicals are not used in Australia and hence this type of problem will not be experienced on Australian airports.

The common response from respondents to the questionnaire was that the use of SMA would be considered in the future after sufficient performance history was available to confirm its applicability to aircraft pavement use. The British Airports Authority (BAA) have advised that they will not consider its use on runways until the de-icing problem currently being experienced in Europe is overcome. American states such as Hawaii will wait for positive reports on the feasibility of using this material and approval of the FAA prior to using on aircraft pavements.

In the United States, the Federal Aviation Administration (FAA) currently has no specification for stone mastic asphalt for aircraft pavements. All pavement materials used on commercial airports must be approved by the FAA. No indication of approval of this new mix has been given by FAA which translates into no federal fund participation if an airport elects to use SMA.

Up until the early 1990’s, Canadian airports were always under the influence of Transport Canada and Public Works Government Services Canada for design standards. Since the airports have been transferred or are in the process of being transferred to the local airport authorities, greater freedom in trying new materials now exists.

Australia’s first experience with SMA on an aircraft pavement was in late 1998 when a trial was constructed at Cairns International Airport in far north Queensland. A further trial was constructed in early 1999. By all reports from the Cairns Port Authority, these trials are performing well in the hot tropical environment, however no formal monitoring data is available. It is also unfortunate that actual mix design and production results were not available from these trials for comparison with other airport experiences.

During May 1999, a SMA trial was undertaken at Sydney International Airport. This trial is part of an overall review process to maintenance of asphalt pavements in an effort to enhance pavement performance.

Unfortunately the aims of the trial have not been satisfied due to the area of poor surface finish. The main problem with the trial was significant areas where there was coarse uneven surface finish. Beside looking poor, these areas are of concern due to ravelling of the coarse aggregate. The deficiencies in the trial were not attributed to the materials as such, but rather to the construction techniques adopted. These areas are indicated on the photographs in Appendix B.

Monitoring of the trial to data has consisted of visual inspections only for loss of aggregate from the surface. No other measurements (rut depth, friction, permeability, etc) have been undertaken and will not be on the trial. It is hoped that a more formal monitoring program will be implemented on the new trial.

Both of these Cairns and Sydney trials are in their infancy in terms of performance, however, the mere fact that SMA has been used at all indicates a willingness on the part of the airport operators to trial new materials in an attempt to gain improved pavement performance. Meaningful data is in the order of two to three years away, subject to continual monitoring.

In terms of cost, the cost differential between SMA and dense graded asphalt on an aircraft pavement is not considered to be as great as for road pavements for the following reasons:

(a) current asphalt specifications for aircraft pavements in Australia require the use of premium quality aggregates,

(b) the magnitude of the increase in bitumen content for aircraft pavements from a dense graded asphalt to a stone mastic asphalt is not as great as that for roads, and

(c) asphalt overlay works on aircraft pavements already attract an increase in quality assurance for obvious safety reasons.

Based on the above, it is considered that the cost differential between dense graded asphalt and stone mastic asphalt for aircraft pavements may be in the order of 5-10% (based on an equivalent quantity of dense graded asphalt), the increase being mainly due to:

(a) the addition of fibres,

(b) slower production rates due to the increased mixing times to incorporate the fibres into the mix, and

(c) limited knowledge of SMA and laying procedures.

It could be reasonably expected that as experience with SMA increases through trials and research, the costs of SMA will reduce even further, minimising the cost differential and making SMA even more economical in the longer term.

The use of stone mastic asphalt in Australia on aircraft pavements would seem to be inhibited at this stage only by a lack of experience and performance of this material on an aircraft pavement and airport operator inertia. The trials at Cairns and Sydney International Airports are seen as the stepping stones to gain valuable experience in the use of this material on aircraft pavements and breakdown the apprehension of airport operators about the use of a new material.

8. Conclusion

The use of stone mastic asphalt dates back to the late 1960's when it was first used on road pavements in Germany. Since then, its popularity has grown due to its numerous benefits over dense graded asphalt.

Stone mastic asphalt with or without polymer modified binder is one of the new and innovative materials being used by road authorities in their challenge to provide cost effective solutions for roads carrying a continuingly increasing volume of commercial vehicles with increasing axle loads.

Whilst SMA is used on roads in more than 25 countries around the world (the majority being in Europe), airport usage is limited to less than 15 countries, again the majority of which are in Europe. Of these, Norway is the single biggest user with some 15 airports using the material on aircraft pavements.

Australia's first experience with SMA on an aircraft pavement was in late in 1998 when a trial was constructed at Cairns International Airport in far north Queensland. A further trial was constructed in early 1999. By all reports, these trial are performing well in the hot tropical environment, however no formal monitoring data is available.

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Both of these trials are in their infancy in terms of performance, however, the mere fact that SMA has been used at all indicates a willingness on the part of the airport operators to trial new materials in an attempt to gain improved pavement performance. Meaningful data is in the order of two to three years away, subject to continual monitoring.

Whilst aircraft pavements constructed with SMA overseas are reported to be performing well, many of their fundamental material and performance criteria remain to be quantified. For SMA to be specified and used with confidence, comprehensive material performance data is required to explain and predict the performance under a range of operating conditions.

Whilst initial costs of SMA are typically higher than dense graded asphalt, the cost difference for aircraft pavements is likely to be in the order of 5-10% rather than the 20-40% higher quoted for road pavements. Even though initial costs for SMA may be higher than dense graded asphalt, there have been sufficient experiences and research to date to clearly demonstrate that the long term benefits, both economically and technically, far outweigh those initial costs.

Further research and experimentation is continuing in the United States, other countries and Australia with SMA. With incremental improvements being made both in design and production, costs are likely to reduce as production rates increase, volumes increase, and as authorities and producers realise the advantages both technically and economically.

Based on research associated with this report, there do not appear to be any technical, logistical or life-cycle cost reasons to the wider use of stone mastic asphalt on aircraft pavements.

The use of stone mastic asphalt in Australia on aircraft pavements would seem to be inhibited at this stage only by a lack of experience and performance of this material on an aircraft pavement in Australia and airport operator inertia. The trials at Cairns and Sydney International Airports are seen as the stepping stones to gain valuable experience in the use of this material on aircraft pavements and breakdown the apprehension of airport operators about the use of a new material.

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Appendixes

Appendix A

This appendix contains comparative stone mastic asphalt mixes and associated grading curves.

Appendix B

This appendix contains photographs from the stone mastic asphalt trial undertaken at Sydney International Airport in May 1999.

Photo 1 *Laying of stone mastic asphalt trial*

Photo 2 *Compaction of stone mastic asphalt trial*

Photo 3 *Typical surface texture of trial area*

Photo 4 *Typical surface texture of trial area*

Photo 5 *Typical joint between paving lanes*

Photo 6 *View of aircraft wheel marking on trial surface*

Photo 7 *View of trial looking north – note open textured areas*

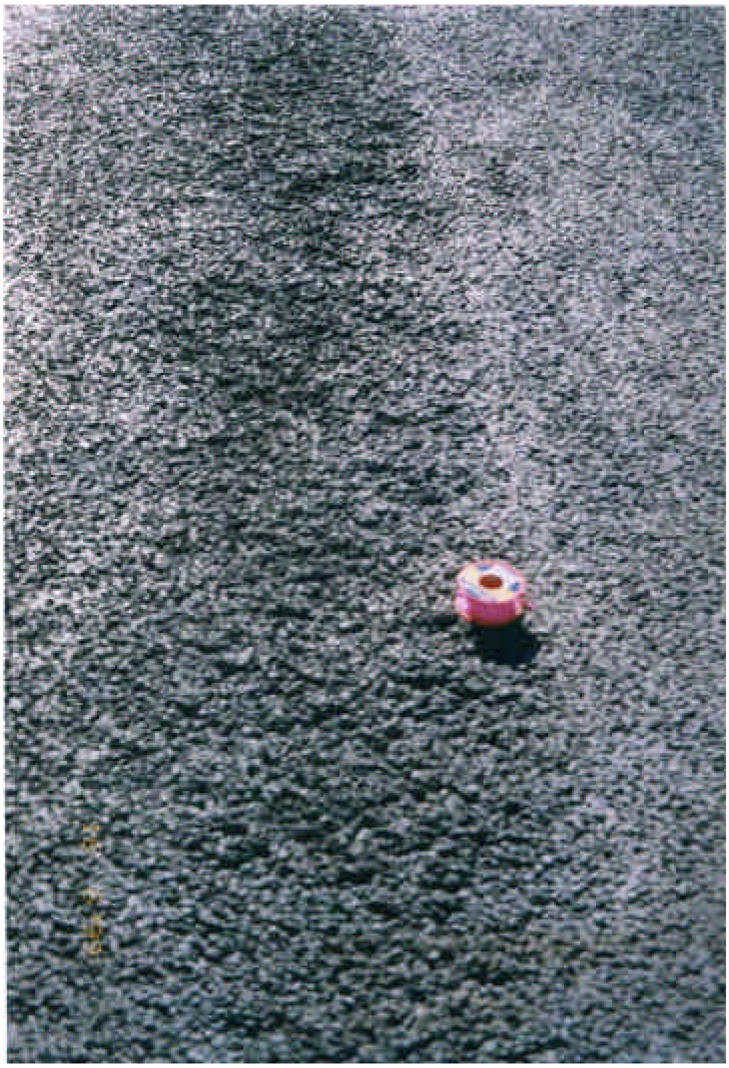

Photo 8 *Typical open textured area caused by dragging of mix*

Photo 9 *Typical open textured area*

Photo 10 *Overall view of trial area looking south*

Appendix C

This appendix contains the following production results from the stone mastic asphalt trial undertaken at Sydney International Airport in May 1999.

(a) Asphalt result summary report for production including gradings, binder content, voids and VMA

(b) In-situ voids

(c) Summary of wheel tracking and fatigue testing.

(d) Moisture sensitivity test reports

These test results have been sourced from Boral Asphalt Technology (1999), *Stone Mastic Asphalt Trial, May 1999, Field Report 16/A.*

Appendix D

This appendix contains a typical life cycle costing analysis prepared by the Norwegian Civil Aviation Administration (NCAA) comparing dense graded asphalt and stone mastic asphalt.

The following is an example of a typical life cycle costing analysis prepared by the Norwegian Civil Aviation Administration (NCAA) comparing dense graded asphalt and stone mastic asphalt (Lange, 1998).

The Norwegian Civil Aviation Administration (NCAA) has undertaken life cycle cost analyses for different maintenance programs for asphalt wearing surfaces on aircraft pavements.

As an example, a runway on the Norwegian West Coast was repaved in 1995. Three alternative actions are possible over a period of 30 years.

Alternative 1 Repave with dense graded asphalt and groove the runway after 15 and 30 years (previous method for repaving runways)

Alternative 2 Repave with SMA after 15 and 30 years

Alternative 3 Preventive maintenance with fog seal every fifth year and repave after 30 years

Table D-1 ***Rehabilitation Alternatives and Costs***

Action	**NOK / m^2**
Repave with a new overlay of 100 kg AC	60
Mill off existing pavement and repave 75 kg SMA	50
Fogseal	6
Grooving (only on AC pavement)	Included in AC

The following net present values can be calculated for each alternative with an interest rate of 7 %

Table D-2 ***Net Present Values***

Year	Alternative 1		Alternative 2		Alternative 3	
	NOK/m^2	NPV	NOK/m	NPV	NOK/m^2	NPV
5		0.00		0.00	6	4.28
10		0.00		0.00	6	3.05
15	60	21.75	50	18.12	6	2.17
20		0.00		0.00	6	1.55
25		0.00		0.00	6	1.11
30	60	7.88	50	6.57	50	6.57
SUM		30		25		19

Appendix E

This appendix contains details of organisations and individuals consulted during the research for this project.