Developing a Performance-Based Specification for Stone Mastic Asphalt as an Ungrooved Runway Surface

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ABSTRACT

Flexible airport pavements in Australia have traditionally been surfaced with Marshall-designed dense graded asphalt (DGA). Grooving is undertaken to avoid aircraft skidding incidents during wet weather conditions, as well as satisfying regulatory surface texture requirements. Groove closure is a common distress experienced at airports surfaced with DGA in Australia and has led to the investigation of stone mastic asphalt (SMA) as an alternate runway surfacing. Due to the gap-graded nature of SMA, and therefore coarse surface texture, grooving can be avoided. To facilitate the use of SMA on Australian runways, a performance-based specification was developed in line with the latest advances of airport technology. This paper describes the development of a performance-based specification for Australian airport SMA, focusing on constituent materials and mixture design.

INTRODUCTION

Flexible runways in Australia are typically surfaced with grooved Marshall-designed dense graded asphalt (DGA). DGA for airports has been traditionally specified using a prescriptive or recipe-based approach, where an asphalt producer must ensure compliance with constituent materials, target grading, Marshall properties and volumetrics. In recent times, a number of airport hot mix asphalts (HMAs) that were compliant with the prescriptive requirements have failed to perform as expected in the field (White 2018). Consequently, a performance-based specification for airport DGA was developed and released in February 2018 (AAPA 2018) which included performance testing to determine if an asphalt mixture achieved the minimum requirements for deformation resistance, fatigue resistance and durability; therefore, reducing the risk of asphalt distress in the field.

Airport DGA is typically grooved to enable the runway to shed water during wet weather events, as well as satisfying regulatory requirements set by the Civil Aviation Safety Authority (CASA) for surface texture (CASA 2017). Groove closure is a common distress at Australian airport runways and inhibits the drainage ability of the runway surface (White 2018), increasing the likelihood of hydroplaning – a serious phenomenon that has caused multiple aircraft safety incidents (ASTB 2008). In addition, when groove closure does occur, the cost of repair is substantial, as is the impact to the operational capability of the runway. Consequently, Australia airports seek an alternate asphalt mixture that meets regulatory surface texture requirements without the need to groove.

Stone mastic asphalt (SMA) is a surface material that has high rut resistance and coarse texture, potentially negating the need to groove. It has been used successfully in Europe and China as an ungrooved runway material (Campbell 1999; Prowell et al. 2009) and is used as a heavy-duty road material in Australia (Rebbechi et al. 2003). Trials of SMA have also been

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undertaken on non-runway surfaces at Australian airports, with most performing well. However, for SMA to be used as an ungrooved runway surface, a specification must be developed and validated in the Australian airport context, and keeping in line with the current advances of airport technology, the specification should be performance-based.

This paper details the development of a performance-based specification for Australian airport SMA (ASMA). The scope of this paper focuses on constituent materials and mixture design. Although asphalt production and construction are key fundamentals of any specification, these elements are only briefly mentioned, as reliable SMA construction practices have developed over two decades of Australian road experience.

BACKGROUND

Airport Asphalt

Flexible airport pavements in Australia have traditionally been surfaced with grooved Marshall-designed DGA. Although the fundamental design, construction and maintenance of airport HMA is similar in nature to roads, the design traffic of aircraft presents increased performance requirements. Aircraft are heavier, have higher tyre pressures, are more susceptible to undulations in pavement surface, are less stable on the ground and can suffer catastrophic damage to fragile aircraft engines by loose stones (AAA 2017). In Australia, an airport DGA surface is typically designed from a nominal 14mm maximum aggregate particle size with voids in the mineral aggregate (VMA) in the range of 13 – 17%, total air voids in the mix of 3.5 – 4.5%, and binder content of 5.4 – 5.8% (AAPA 2018).

Prescriptive versus Performance

Traditionally airfield HMA has been specified using a prescriptive or recipe-based approach (White 2017c). The prescriptive requirements focus on gradation limits, Marshall properties and volumetric properties based on the Marshall method - a method that was developed to design and control asphalt mixtures by the United States Department of Defense from World War II to the late 1950s (White 1985). For a prescriptive approach, the asphalt producer is responsible for ensuring the mixture design is compliant with a provided specification. That is, constituent material properties, Marshall Stability, Marshall Flow, volumetrics, and aggregate grading are all verified during the mixture design stage. If the asphalt producer designs and constructs a surface that is compliant with all specified requirements, the intention is that they are not responsible for the performance of the asphalt mixture (White 2017a).

Marshall properties provide an empirical link to historical pavements that have performed well under aircraft traffic (Rushing et al. 2012); however, since the Marshall method's development, aircraft have evolved to become heavier with significantly higher tyre pressures (AAA, 2017). Coupled with anecdotal evidence that bituminous binder reliability has reduced in Australia (White 2016), several airport HMAs that were compliant with the prescriptive requirements have failed to perform as expected in the field (White 2018). Consequently, there is an appetite in industry to transition to a performance-based specification for Australian airport HMA.

For a purely performance-based approach, a client would provide an asphalt producer with the expected aircraft traffic, underlying base layer composition and condition, any local environmental conditions and expected life of the pavement. The asphalt producer would be able to select the constituent materials, mixture type and design method to satisfy the client's

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functional requirement. The asphalt producer would also accept liability for any surface defects during the design life of the surface, and would inspect, maintain and replace when required. Losses associated with operational disruptions will be substantial compared to the costs of repair works; therefore, an increased trust between airport owner and asphalt producer would be essential. Additionally, significant development of surface performance measurement tools is still required, and consequently, a purely performance-based approach is too large of a change to implement suddenly (White 2017c). Therefore, more appropriate for the current Australian airport industry is the adoption of a performance-compliance specification.

A performance-compliance specification contains a combination of performance-indicative and prescriptive properties that are required to achieve surface performance expectations (White 2017c). It provides the asphalt producer the flexibility to select the binder used in the design, as binder type is not specified. Performance-indicative laboratory testing is also included to give confidence in the mixture's deformation resistance, fatigue resistance and durability. Where performance requirements are not measurable in the laboratory, for example, raw aggregate durability, the current prescriptive requirements are maintained. The first iteration of the Australian airport DGA performance specification was based on a performance-compliance approach (White 2017a).

Performance requirements

Performance requirements for airport HMA relate directly to asphalt distress modes that minimise the life of a HMA surface and increase the risk to safe aircraft operation. Deformation resistance, fracture resistance, durability, and surface friction and texture are key performance requirements for the life of an airfield HMA as in Table 1. For the development of a performance-based specification, these four physical requirements must be tested and validated during the mixture design.

Table 1. Airport HMA performance requirements (White 2018).

Physical requirement	Protects against	Level of importance
Deformation resistance	Groove closure Rutting Shearing / shoving	High
Fracture Resistance	Top down cracking Fatigue cracking	Moderate
Surface friction and texture	Skid resistance Compliance requirement	High
Durability	Pavement generated FOD Resistance to moisture damage	Moderate

Australian airport DGA performance-based specification

In February of 2018 the first iteration of the Australian airport runway DGA performance-based specification was released. The performance specification was developed based on four general principles (White 2017a):

- Constituent materials.
- Mixture design.
- Asphalt production.

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- Asphalt construction.

In addition to these principles, guidance for several commercial issues were included in the preamble to the specification, including tendering, superintendence and contractual provisions. Of high relevance to this paper, however, are the constituent material and mixture design requirements.

With the exclusion of binder type, the specification retained the traditional prescriptive requirements for constituent materials. The quality of the constituent ingredients affects HMA durability and cannot always be measured by current asphalt mixture performance tests. For example, HMA performance tests may not indicate an individual aggregate's ability to withstand weathering, and therefore tests such as sodium sulphate soundness are better indicators for potential aggregate durability. Binder type is not defined in the specification, giving the asphalt producers flexibility to either use a common Australian modified binder or a proprietary airport binder that has been modified for improved performance under aircraft traffic.

Although traditional volumetrics and target aggregate grading was retained in the performance specification, Marshall properties were removed from mixture design (though still included for quality control during the asphalt construction phases). Rather, the mixture design focused on performance-indicative asphalt tests as detailed in Table 2. A notable absence from the performance-indicative tests is that of surface friction and texture. Surface friction can only be tested post construction using continuous friction measuring equipment (CFME), such as a Griptester, and is therefore not included in the mixture design. Texture was not included as DGA for Australian airport runways is typically grooved, as discussed below.

Table 2. Australian airport asphalt performance requirements (AAPA 2018).

Physical requirement	Test Property	Standard	Requirement
Deformation resistance	Wheel Tracking Test (10,000 cycles at 65°C)	AG:PT/T231	Not more than 2.0 mm
	Air voids at refusal density	AS/NZS 2891.2.2	Not less than 2.0%
Fracture resistance	Fatigue life(at 20°C and 200 µm)	AG:PT/T274	Not less than 500,000 cycles to 50% of initial flexural stiffness
Surface friction and texture	-	-	-
Durability	Indirect Tensile Strength Ratio (TSR)	AG:PT/T232	Not less than 80%

Skid resistance and grooving

As detailed in Table 1, skid resistance is a key functional requirement of airport runways. Landing speed of aircraft are typically in the range of 260 - 280km/h in all conditions (AAA 2017). Aircraft operators cannot reduce their landing speed to account for differences in surface conditions. They instead rely on adequate pavement surface to tyre interaction to provide the required friction for stopping within the available distance. Skid resistance is influenced by two key factors: micro-texture and macro-texture. At speeds greater than 50km/h macro-texture plays

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a greater part (Austroads 2014) and is therefore a higher consideration for airport owners. Macro-texture affects the friction component of hysteresis, by creating a deformation of the tire rubber through interaction with the pavement surface (Prowell et al. 2009). Additionally, macro-texture determines the reduction in friction available to an aircraft tyre as a consequence of the film of water on the pavement surface during wet weather events (AAA 2017).

The International Civil Aviation Organisation (ICAO) recommends a minimum 1mm surface texture for airport runways (ICAO 2016). To account for ICAO's skid resistance recommendation, Australia's CASA requires airports to (CASA 2017):

- maintain at least 1mm surface texture, or
- provide adequate wet friction levels when measured with CFME, or
- have its surface grooved.

New DGA will not achieve the 1mm requirement and will typically have a surface texture of 0.4 – 0.6mm (White 2017b). Therefore, to fulfil the regulatory texture requirement, and to ensure surface water can escape, airport DGA is typically grooved in Australia.

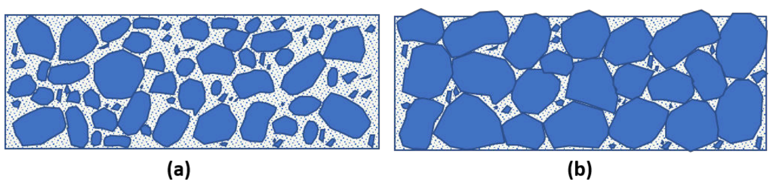

Figure 1. Representative mixture drawing of (a) DGA and (b) SMA.

The introduction of grooving to an airfield pavement is costly and introduces the risk of groove related distresses. Groove closure is one the most commonly reported airport DGA surface distresses in hot climates, and effects the ability of the pavement to remove surface water due to the reduction in volume of the grooves (White 2018). Groove closure is commonly observed in locations where aircraft traffic slowly and parallel to the grooves, and after very hot weather periods. Repairing of grooves by re-sawing is not possible, and the only solution is to plane off the closed grooves, overlay with new DGA, and then regroove the surface (White and Rodway 2014). Not only is this process costly, but also effects the operational capability of an airport for the period of repair works. Consequently, some Australian airports seek an alternate asphalt mixture that meets surface texture requirements without the need to groove. Of the alternates available, SMA is the most suitable as detailed below.

Stone mastic asphalt as an alternate surface

The original SMA was developed in Germany in an attempt to reduce the distresses in wearing courses caused by the use of studded snow tyres (Blazejowski 2011). Conceptually, SMA consists of three parts: a coarse aggregate skeleton, a mastic, and air voids. The coarse aggregate skeleton, which is composed of aggregate larger than the break point sieve (4.75mm for 11 - 14mm size mixtures), (Brown et al. 1997) provides high deformation resistance to rutting due to stone-to-stone interaction. The mastic consists of fine aggregates, filler and a high volume of binder (approximately 6-7% by mass). The higher binder content leads to a very durable asphalt mixture. The large binder content also introduces the risk of binder drain-off during production, transport and laydown. To account for this, SMA mixtures include stabilisers, or drainage inhibitors, commonly in the form of cellulose fibres.

Of significance in SMA mixtures is its surface texture depth. Due to its gap graded nature,

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mixtures larger than 10mm maximum aggregate size usually exhibit texture depths greater than 1mm (EAPA 1998; Joubert et al. 2004; Prowell et al. 2009), potentially satisfying CASA regulatory surface texture requirements. Figure 1 details a representation of an SMA mixture compared to a traditional airport DGA mixture.

Internationally, SMA has been used as a runway surface in Europe and China, with surface trials also being undertaken in South Africa and the United States (Campbell 1999; Prowell et al. 2009). Norway has used SMA as a runway surface with over 15 runways resurfaced with the material since 1992 (Campbell 1999). Recently, Norway's Oslo international airport had its western runway overlaid with size 11mm SMA in 2015 (Jacobsen 2015). Germany also uses a size 11mm SMA for runways; both the Hamburg Airport and Spangdahlem United States Air Force Base have used the material in 2001 and 2007 respectively (Prowell et al. 2009). However, China is the leader of SMA use on airfields with over 40 runway surfaces using either a size 13mm or 16mm mixture (CACC 2016; Xin 2015).

The use of SMA in Australia has been limited to roads and only two airfield locations - Cairns and Sydney international airports. Of these airport locations, neither have employed the material on runway surfaces. The Sydney trial was undertaken on a taxiway in 1999 but was unsuccessful, with over 20% of the pavement demonstrating a very coarse, uneven and poor surface finish (Campbell 1999). Cairns airport has resurfaced multiple aprons and taxiways since 1999 with all pavements performing well. Of note is Domestic bay 19, shown in Figure 2. This pavement was resurfaced with SMA in 1999 alongside a DGA mixture during the same works, allowing for a direct comparison of performance over time. The SMA section has demonstrated a higher resistance to fracture, evident by minimal cracking and crack repairs when compared to the DGA section.

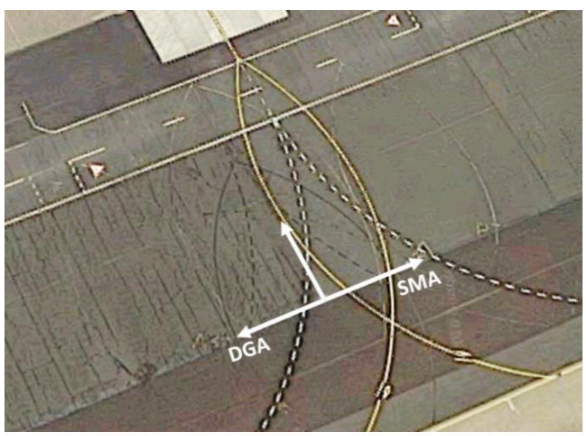

Figure 2. Cairns Airport Aerial View - SMA Bay 19 compared to DGA. (Jamieson and White 2018)

Cairns airport also constructed an SMA patch (4m wide x 130m long) in 2008 at a runway and taxiway intersection, to combat distresses caused by reflective cracking from the base course material. Before the SMA patch, DGA patch repairs were installed approximately once every two years. Since the 2008 SMA patch, maintenance has been substantially reduced with only one patch required to repair a small area of reflective cracking in 2018.

The successful use of SMA as a runway surface internationally, and the common use of the material domestically on roads and at Cairns international airport has demonstrated that the material is likely to be suitable as an ungrooved runway surface. However, for the material to be employed in the Australian airport context, a specification is required, and keeping in line with

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the latest advances of Australian airport HMA technology, the specification must be performance-based.

PERFORMANCE-BASED SPECIFICATION

Developing a specification

Introducing SMA to Australian airports and developing a performance-based specification requires a three-phase translation and validation of overseas airport practice, as well as Australian road pavement practice. The three-phase approach includes (White and Jamieson 2018):

- Review of international and local SMA specifications to develop preliminary performance specifications
- Laboratory performance validation of preliminary specifications
- Field performance validation of preliminary specification.

The first phase, which is the topic of this paper, was a review of international SMA specifications for airfields, and local Australian specifications for roads to develop preliminary prescriptive and performance requirements. Constituent materials, laboratory compaction, volumetrics, and binder drain-off characteristics were analysed. From this review, preliminary prescriptive requirements for constituent materials and required volumetrics were formulated. Included in the specification were laboratory performance requirements that were translated from the Australian airport DGA performance-based specification. It was determined that the most likely specifications to be suitable as an ungrooved runway surface were the German SMA 11S, and Chinese SMA13. The German SMA11S was selected due to it being the original SMA design (EAPA 1998), and therefore its longevity in industry application. The Chinese SMA13 specification was chosen due to its utilisation on over 40 airports with positive performance reported (CACC 2016). Interestingly, the Chinese SMA13 specification is almost identical to the Australian Queensland Transport and Main Roads (TMR) SMA14 specification, initially bolstering the confidence for its successful application in the Australian context.

Constituent materials

Constituent materials for SMA include coarse aggregate, fine aggregate, bitumen, added filler and stabilisers. White (2017c) determined that aggregate and filler properties must be prescribed in a performance-compliance specification for airport HMA. As with the Australian airport DGA performance specification, aggregate and filler qualities are prescription-based. The values created for the ASMA performance specification for constituent material properties were mainly based on the German SMA11S requirements (Blazejowski 2011). Where specific Australian standards had more controlling properties, these values were used in lieu. Also included in the constituent material requirements are the Australian standard (AS) test methods.

Coarse Aggregate

Coarse aggregates for the ASMA specification are those that are retained on the 4.75mm break point sieve and are defined as ‘active’ because they provide the deformation resistance through stone-on-stone contact. Coarse aggregate shape is of particular importance to SMA mixtures, as it allows for the appropriate packing to achieve this contact (Blazejowski 2011). Compared to the Australian airport DGA specification a more stringent flakiness index (≤ 20%

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compared to ≤ 25%) is required. Also, due to the reliance of the stone-on-stone interaction for deformation resistance, source properties such as abrasion resistance, strength and deleterious material content are significant, consequently, premium aggregates must be used. Table 3 details the coarse aggregate requirements for the ASMA performance-based specification.

Table 3. ASMA coarse aggregate requirements.

Dimension	Properties	Test	Requirement
Shape	Flakiness Index	AS 1141.15	≤ 20%
	Crushed particles	AS 1141.18	100% crushed aggregate
Strength & Durability	Wet strength	AS 1141.22	≥ 150kN
	Wet / Dry strength variation	AS1141.22	≤ 30%
	Soundness (using sodium sulphate)	AS 1141.24	≤ 3%
	Los Angeles Value	AS 1141.23	≤ 20%
Contaminants	Material finer than 0.075mm in Agg	AS1141.12	≤ 2.0% for 7mm and larger
	Secondary Mineral Content	AS 1141.26	≤ 20% (basic rock types only)
	Friable particles	AS 1141.32	≤ 0.2%
Other	Particle Density	AS 1141.6.1	≥ 2300kg/m^3
	Water absorption	AS 1141.6.1	≤ 2%

Fine Aggregate

Fine aggregates are the stone particles that pass through the 4.75mm break point sieve and are considered ‘passive’. As with coarse aggregate requirements, fine aggregate needs to be of high quality in terms of strength and durability. If not sourced from the same rock as the coarse aggregate, fine aggregate characteristics must meet all the requirements detailed in Table 3. In addition, fine aggregate must be non-plastic and have suitable angularity.

Angularity has a positive influence on deformation resistance (Blazejowski 2011). Several specifications for SMA either have minimum angularity requirements, and/or minimise or preclude the use of natural sand which tends to have more rounded particles which can lead to an unstable mixture. Although some airports have used natural sand for SMA, for example Beijing international (Prowell et al. 2009); for the purposes of the ASMA performance-based specification, and in line with German heavy duty SMA practice, the use of natural sand is precluded to ensure particles with high angularity are employed.

Filler

Fillers used for HMAs are generally sourced from natural materials such as rock dust and baghouse fines, or from commercially available materials such as hydrated lime, fly ash and ground limestone (Austroads 2014). European countries typically use ground limestone due its affinity with binder (Blazejowski 2011), as evident with the German SMA11S specification with >70% by mass of $CaCO_3$. For Australian roads and airports, hydrated lime is commonly used to limit the risk of stripping. Hydrated lime also has a high Rigden voids value, typically greater

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than 60% (Lesueur et al. 2012), that stiffens the mastic and can increase the resistance to deformation. However, one must be cautious not to stiffen the mastic too much as to prevent 'fixing' the whole binder and creating an asphalt mixture susceptible to cracking and water damage (Blazejowski 2011; Austroads 2013). The ASMA specification requires ground limestone to be used as the added filler. However, it also allows for a blended filler with hydrated lime content to be reported if required to prevent stripping. To prevent excessive mastic stiffness, a limit is placed on the Rigden voids of the combined filler of 28 – 45%, aligning with German SMA practice (Austroads 2013).

Stabilisers

Binder drain-off requirements for international and local specifications are either prescriptive-based (stabiliser additives by mass) or performance-based (binder drain-off by mass). Typically, a performance-based limit of 0.3% binder drain-off by mass of the whole mix is detailed. The German SMA11S specifies stabilising additives by mass of 0.3 – 1.5%; however, best practice is to limit the binder drain off by mass to ≤ 0.15% (Druschner and Schafer 2005). For a performance-based approach to asphalt mixture design, a drain-off test is more appropriate than a prescriptive minimum stabilising additive content. In Australia, stabilisers are typically in the form of cellulose fibres that are added to the mix, although other materials such as glass, polyester and mineral fibres can be used and still satisfy performance requirements (Wan et al. 2014). Defining only a minimum binder drain-off requirement gives the mixture designer the freedom to choose the stabiliser and negates the need to specify stabiliser properties. Therefore, the ASMA performance specification requires stabilisers to limit binder drain-off to a maximum value of 0.15%.

Table 4. ASMA volumetrics to 50 blow Marshall Compaction.

Property	Test Method	SMA-G11S	SMA-C13
VMA (% by volume)	AS/NZS 2891.8	Report	≥ 17
Binder Content (% by mass)	AS/NZS 289.1.3	≥ 6.6	Report
Air Voids (% by volume)	AS/NZS 2891.8	2.5 – 3.0	3.0 – 5.0
VCA_{Mix} / VCA_{DRC}	TMR Q318, or TRMS T646	Report	Report

Binder

As with the Australian airport DGA performance-based specification, a critical element of a performance-based airport HMA specification is allowing the mixture designer to select the binder (White 2017a). Although there is an emphasis for SMA to obtain rutting resistance through stone-on-stone contact of the mix, it has been shown in multiple research studies that the use of a modified binder significantly increases this performance characteristic (Blazejowski 2011). Therefore, the mixture designer could choose any of the existing generic grades of Australian polymer modified binder, or a proprietary product developed for improved airport asphalt surface performance.

Mixture design

The Australian airport DGA performance-specification was the first major step in moving away from prescriptive volumetrics and Marshall testing for Australian airport flexible

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pavements. In the specification, Marshall testing was replaced by performance-indicative tests; however, traditional volumetrics were retained to avoid impacting the empirical balance between surface durability and aircraft skid resistance (White 2017c). Because a reliable laboratory test for surface durability, in particular ravelling potential, is yet to be developed in Australia, the first iteration of the ASMA performance-based specification also includes prescriptive volumetrics.

Aggregate gradation and volumetrics

The ASMA volumetrics and target grading are detailed in Table 4 and Table 5 respectively. Both the German SMA11S based specification and Chinese SMA13 based specification are included. Once laboratory and field validation are undertaken for the mixtures, a single requirement for gradation and volumetrics will be selected based on performance results. In addition to the common volumetrics specified for DGA mixtures, is the inclusion of the mix volume ratio. This ratio is the voids in the coarse aggregate (VCA) of the mixture, divided by the VCA in a dry rodded condition. If this value is less than one, it indicates that the mastic has not over-filled the voids between the coarse aggregate. If the mastic does overfill the voids, it could potentially provide a physical barrier for stone-on-stone contact of the active particles to be achieved, which could lead to an unstable mix (Vos et al. 2006). This would also likely be evident from failed deformation resistance performance testing.

Table 5. ASMA target grading.

AS Sieve Size (mm)	Percent passing by mass (%)	
	SMA-G11S	SMA-C13
19	100	100
13.2	94 – 100	90 – 100
9.5	70 – 82	45 – 65
6.7	42 – 55	-
4.75	33 – 43	22 – 34
2.36	22 – 32	18 – 27
1.18	18 – 27	14 – 22
0.6	16 – 24	12 – 19
0.3	13 – 20	10 – 16
0.15	11 – 17	9 – 14
0.075	8 – 12	8 – 12

Performance requirements

The performance requirements for wheel tracking, indirect TSR and fatigue life were directly translated from the Australian airport DGA performance requirement as in Table 6. Air voids at refusal density testing was not included due to the likelihood of stone crushing from excessive compaction (Prowell et al. 2009). A surface texture test was introduced to determine the mixture's potential to satisfy the regulatory 1mm surface texture requirement.

Surface texture testing is undertaken using a volumetric sand patch test. For texture depths of 1mm and greater, the diameter of the sand patch created is a maximum of 252mm (Austroads

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