Open Graded Asphalt
Design Guide

1997
Cover Photographs:

Open graded asphalt in action! The top photograph shows typical vehicle spray on a conventional surfacing in wet weather, the bottom photograph (taken shortly afterwards on an adjacent section of the same road) clearly shows the spray reducing qualities of open graded asphalt.

COPYRIGHT © Australian Asphalt Pavement Association 1997 (reprinted 2000)

AAPA Implementation Guide IG-1

ACKNOWLEDGEMENTS

This document was prepared by a working group consisting of personnel from ARRB Transport Research, AUSTROADS and asphalt industry representatives from funding provided by the Australian Asphalt Pavement Association. Information from a Master of Engineering thesis by I. Skvarka undertaken at Royal Melbourne Institute of Technology was used in the formulation of the design method. Drafts have been widely circulated within the asphalt industry for assessment and comment.

Members of the editorial committee comprised:

Allan Alderson, ARRB TR
John Bethune, AAPA
John Oliver, ARRB TR
John Rebbechi, CSR Emoleum

Reproduction of extracts from this publication may be made subject to due acknowledgment of the source.

Although the information in this Guide is believed to be correct at the time of printing, the Australian Asphalt Pavement Association does not accept any contractual, tortious or other form of liability for its contents or for any consequences arising from its use. People using the information contained in this Guide should apply, and rely upon, their own skills and judgement to the particular issue which they are considering.
Open Graded Asphalt Design Guide

1997
PREFACE

This guide has been prepared to supplement the Australian Provisional Guide for the Selection and Design of Asphalt Mixes by guiding users through the selection, design and application process for Open-Graded Asphalt mixes.

The Guide is directed at inexperienced mix designers as well as experienced designers who are unfamiliar with the new Australian Provisional Design Method and is intended to be informative rather than mandatory. Additional reference may be required to relevant Australian Standards or public authority manuals and specifications.
CONTENTS

1. INTRODUCTION ........................................................................................................ 5
   1.1 Performance Related Properties .................................................................... 5

2. BACKGROUND .......................................................................................................... 6
   2.1 General .............................................................................................................. 6
   2.2 Skid Resistance ................................................................................................. 7
   2.3 Design Life ........................................................................................................ 8
   2.4 Water Dispersal ................................................................................................ 9
   2.5 Noise Reduction ................................................................................................ 9
   2.6 Strength ............................................................................................................. 11
   2.7 Other ................................................................................................................ 12
   2.8 Manufacture and Placement .......................................................................... 12

3. APPLICATION .......................................................................................................... 13
   3.1 OG Grades ........................................................................................................ 13
   3.2 Terminology ....................................................................................................... 13
   3.3 Selection of Nominal Size .............................................................................. 14

4. MATERIALS ............................................................................................................ 15
   4.1 Aggregate .......................................................................................................... 15
   4.2 Mineral Fillers ................................................................................................... 15
   4.3 Binder ................................................................................................................. 15

5. SELECTION OF COMPONENT PROPORTIONS .................................................. 17
   5.1 Overview .......................................................................................................... 17
   5.2 Selection of Target Aggregate Grading ........................................................... 17
   5.3 Matching the Target Grading .......................................................................... 18
   5.4 Selection of Target Binder Content ................................................................. 19

6. DESIGN METHOD .................................................................................................... 20
   6.1 Selection of Initial Grading .............................................................................. 20
   6.2 Selection of an Initial Range of Binder Contents ........................................... 20
   6.3 Preparation of Compacted Specimens ............................................................ 21
   6.4 Abrasion Resistance ......................................................................................... 21
   6.5 Binder Drain-down ............................................................................................ 23
   6.6 Selection of the Design Binder Content .......................................................... 23
   6.7 Properties of the Design Mix ......................................................................... 24

BIBLIOGRAPHY ......................................................................................................... 27

APPENDICES
   Appendix A: Test Methods ................................................................................... 29
   Appendix B: Worked Example .............................................................................. 33
   Appendix C: Design Outline and Flow Chart ....................................................... 35
1. INTRODUCTION

There is an ever increasing requirement by Road Authorities to use Open-Graded Asphalt as the surfacing on heavily trafficked pavements for environmental and safety reasons. The purpose of this guide is to promote a rational procedure for the design of Open-Graded Asphalt (OG) mixes used as a wearing course on road pavements. Until now the selection and design of these mixes has been based essentially on a recipe type approach which users with little or no experience found difficult to interpret and implement.

The rational procedure described herein is intended to improve the performance of OG mixes, particularly design life, by introducing performance related test methods. The test methods selected are based upon current Australian practice and the findings of overseas workers using equipment that is commonly available in asphalt laboratories.

1.1 Performance Related Properties

The term 'performance related' indicates that the properties used in the mix selection and design process are those which determine its on-road performance. Thus, if good test results for a mix are obtained in the laboratory there is confidence that the material will perform satisfactorily on the road.

The design of OG mixes in the past has focussed on attaining a grading and binder content that gave a range of air void contents. While the provision of a porous structure is crucial to the performance of this type of mix, there are other criteria that also need to be addressed in order for the mix to fulfil its function over the design life.
Open Graded Asphalt

2. BACKGROUND

2.1 General

Open-Graded Asphalt (OG) has been in use as a wearing surface since the 1950s. Its first major use in Australia was about 1973 and it is known under a wide range of names in different parts of the world, such as:

- Open-graded asphalt
- Porous friction mix
- Open-textured asphalt
- Friction course
- Drainage asphalt
- Whisper asphalt
- Porous asphalt
- Pervious macadam.

The use of terminology involving reference to 'friction' is to be discouraged since the frictional resistance of any asphalt mix is dependent on the aggregate quality much more than the type of mix.

OG is a mix with a high air void content (in excess of 20%) that is used generally in thin layers (typically 25 to 40 mm). While it provides a small increase in pavement strength it is not suitable for regulating a deformed surface or in high shear situations. Its main use is in urban areas, particularly on arterial type roads, where it provides:

- enhanced wet weather skid resistance,
- reduced vehicle rolling noise, both external to, and within the vehicle,
- reduced surface water spray,
- improved visibility of road surface markings, particularly in wet weather, and
- a smooth riding surface.

OG is a gap graded mix with intermediate sized and fine aggregate fractions omitted from the grading while dense-graded asphalt has a more continuous grading. Air voids are more inter-connected in OG compared to dense-graded mixes where the voids are often occluded. This is shown diagrammatically in Fig 2.1.
2.2 Skid Resistance

The skid resistance of OG mixes in wet conditions is markedly better than a dense-graded asphalt surfacing. The potential for aquaplaning is much reduced at normal driving speeds and, together with improved visibility, due to a reduction in water spray, may be the most important benefit for using this type of mix. Water is dispersed into the voids thus eliminating the wedge of water that develops in front of tyres moving across films of water. Use of OG increases driver confidence when driving during wet weather and this effectively increases the road capacity although the increase in speed may offset some of the safety benefit.

In dry conditions OG has a lower skid resistance than traditional surfacings as there is less stone in contact with the tyre. However, the selection of an aggregate suitable for a wearing course will provide adequate skid resistance when dry.

When first placed, OG may have an initially lower skid resistance than expected due to the thicker film of binder coating the exposed aggregates. Traffic action, however, should remove this coating within one or two weeks, but the process may take up to several months depending on traffic and environmental conditions. Extra precautions may be needed when placing OG on low-volume high-speed roads at the beginning of the cold season. In critical situations the surface of the fresh asphalt may be "dusted" with a carborundum grit.

Skid resistance is measured in a number of ways, the simplest of which is to use a pendulum style tester (see Fig 2.2). There are a number of specifically designed vehicles that can continuously measure skid resistance.
2.3 Design Life

The major concern when selecting an OG has been the limited life (about 8 to 10 years for normal binders and 12 to 15 years for PMBs) compared to a dense-graded asphalt surfacing. OG layers often fail due to lack of durability, usually indicated by surface fretting and ravelling.

The porous nature of OG mixes exposes the binder-film coating the aggregates to the actions of ultra-violet light, oxidation and moisture. It is critical that the binder-film has sufficient thickness to resist these effects and that resistant binders (eg PMBs) are used when extended life is sought.

If design life is redefined as the retention of surface characteristics, rather than structural integrity, then the design life of OG is generally greater than most other surfacings.

2.4 Water Dispersal

The life of a pavement surfaced with an OG wearing course can be prolonged by ensuring that surface water is drained off the pavement such that it does not cause damage to underlying layers or present a safety problem due to sheet flow over the surface. To achieve this it is essential that the underlying surface be impervious, that there is sufficient crossfall and that side drainage is provided.
Dense graded asphalt can not be considered impervious unless it has an in-situ air void content less than 5%. Trafficking of dense-graded asphalt can assist in creating an impervious surface by reducing the in-situ air void content below that which existed at construction. Dense-graded asphalts with higher air voids are considered to be permeable, and hence may have a reduced service life if placed below an OG. If trafficking of dense-graded asphalt prior to placing the OG is not possible, then application of a very heavy tack coat, a fog-coat or a 7 mm seal to the surface of the dense-graded asphalt, prior to placing the OG layer, can provide sufficient waterproofing. The use of stone mastic asphalt (SMA) directly below an OG is another way of achieving an impervious underlying layer.

There are a number of alternative arrangements for draining water from an OG and several are shown in Fig. 2.3. A common practice is to provide a free-draining edge as in Figs. 2.3a and 2.3b although these can pose a hazard for cyclists. The arrangement shown in Fig. 2.3c applies to new construction whereas those shown in Figs. 2.3a and 2.3b can be applied as overlays to existing pavements. There has also been some experimentation with pavements that are porous in more than the top layer (see Fig. 2.3c) but a discussion of these is beyond the scope of this guide.
Open Graded Asphalt

In some countries OG layers are designed to ameliorate the effects of short high intensity rainfall by acting as a retarding reservoir. In this application, the OG layer is designed to retard peak flows by storing water within the layer and releasing it gradually.

The porosity of OG reduces over time by clogging of the pores with road grime, although it is more often evident in shoulders and between wheel paths. In trafficked areas it has been found that high speed traffic cleans the pores to some extent and thus maintains a high porosity layer. If, however, the pores are blocked and water can not flow from the edge of the layer it will flow over the surface, reducing most of the benefits of using OG. There have been some instances of authorities moving traffic lanes laterally so that traffic is directed over clogged sections of the pavement to help cleanse the layer.

Slippage failure as well as shoving can occur in OG when subject to severe braking and acceleration. In addition, stripping of the cohesive bond between the binder and the aggregate can result from fuel and oil spillages and leaks from vehicles. For these reasons OG is not recommended at intersections. Typical practice requires that an OG layer is terminated 50 to 100 metres from the approach side of an intersection. It is essential to ensure a smooth joint between the different mixes and care should be taken to avoid trapping water at the joint. Similarly OG is not recommended in areas where vehicles will be tracking mud and other detritus on to the road such as in areas with quarrying or farming activities.

2.5 Noise Reduction

Another significant benefit of OG is the reduction in noise levels. A reduction of 3 dB(A) is often quoted as the difference in noise level between a dense-graded and OG surfacing. This is equivalent to a reduction in noise levels of about half, or a doubling of the distance from the noise source. The reduction can be even greater on wet surfaces where reduction in noise from water spray is particularly noticeable inside vehicles.

The reduction in noise level is proportional to the accessible air voids which appears to reach an optimum where 14 mm OG is used with a layer thickness of 35 mm to 40 mm. For cost and other factors a nominal thickness of 30 mm of 10 mm OG is frequently placed.

The reduction in noise is partly achieved by a reduction in the amount of compressed air escaping between the tyre and the pavement surface. Both stone mastic and OG surfaces consist of voids below a plane surface. In addition, for OG mixes, some air is expelled into the pores. There is a further reduction due to the surface texture which reduces the reflected noise, although as the surface aggregate wears, reduction due to surface texture diminishes.

In 1989, noise levels were monitored on a number of road surface types (Samuels, 1990) and the results are presented in Table 2.1. It can be seen that a wide range of noise levels were encountered and OG was found to be the quietest surfacing, with a reduction of 4 dB(A) to 6 dB(A) compared to dense-graded asphalt. Two OG mixes are presented in Table 2.1 (the numbers in brackets represent the years in which the mixes were designed) and it can be seen that the later designed mix (more porous than the 1975 OG mix) gave a greater noise
reduction. There will be an increase in the noise levels with time, but OG will still generate lower noise levels than other surfacing types.

Measurement of noise in Australia is performed to AS 2704 and involves setting up measuring equipment a distance back from the edge of the pavement and recording noise levels of passing vehicles (see Fig. 2.4). Adjustment factors are applied to compensate for a number of variables, including the distance between the instrument and the vehicle where more than one lane is to be monitored.

Table 2.1 - L10(1h) Noise Levels Monitored over a Range of Pavement Surfaces

<table>
<thead>
<tr>
<th>Pavement Surface Type</th>
<th>L10(1h) (dB(A))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement Concrete - Deep Grooved</td>
<td>87.2</td>
</tr>
<tr>
<td>Portland Cement Concrete - Shallow Grooved</td>
<td>83.8</td>
</tr>
<tr>
<td>Dense-Graded Asphalt</td>
<td>83.4</td>
</tr>
<tr>
<td>Cold Overlay Slurry Seal</td>
<td>82.6</td>
</tr>
<tr>
<td>Portland Cement Concrete - Hessian Dragged</td>
<td>80.8</td>
</tr>
<tr>
<td>Open-Graded Asphalt (1975)</td>
<td>79.3</td>
</tr>
<tr>
<td>Open-Graded Asphalt (1987)</td>
<td>77.5</td>
</tr>
</tbody>
</table>

Fig. 2.4 Instruments Arranged for Way-side Measurements
2.6 Strength

In the past, the OG layer has often been disregarded in calculating the structural strength of a pavement. In part, the decision was based on the strength being about one half to two thirds that of dense-graded asphalt, and in part due to it being laid in thin layers. Present practice, however, is to adopt a modulus value of between 800 MPa and 1200 MPa. Despite this reassessment of its strength, OG will not improve the deflection characteristics of an unsound pavement.

If testing of OG in the laboratory is to be undertaken to determine performance characteristics it is well to remember that specimens need to be confined. Tests such as the (unconfined) dynamic creep test do not give an accurate indication of mix properties and, should the rutting performance of the mix be required, it is recommended that the Wheel Tracking test be employed. In general, OG has very good deformation resistance provided it is placed on a sound underlying pavement. Fatigue testing of OG can be undertaken using the four point bending beam test at low temperatures. In general, fatigue life is inversely related to the void content, so that, typically, OG provides about three quarters the fatigue life of a dense-graded asphalt. A further characteristic of OG asphalt is the ability of minor cracks to self heal due to the high bitumen film thicknesses and reorientation of course aggregate particles.

2.7 Other

The dark open surface provides a greater contrast with pavement markings and reduces reflected light thus giving drivers more confidence.

2.8 Manufacture and Placement

Manufacture of an OG mix is similar in most respects to a dense-graded mix, although mixing temperatures are generally lower by 10°C to 20°C to minimise the risk of binder drain-down. Drain-down can also be experienced during transportation to site but good work practices will substantially eliminate this risk. The mix design method proposed in this guide will also assist in reducing drain-down to acceptable levels.

Construction of an OG layer utilises the same equipment as for a dense-graded mix but there are differences in the compaction techniques to ensure a suitable final product. Due to reduced layer thickness and higher air void content, care needs to be exercised to ensure that rollers follow closely behind the paver to compact the mix whilst hot. It is preferable to use steel rollers operating in the non-vibratory mode and to limit the number of passes so that crushing of the aggregate or closure of the air voids is avoided. Rubber-tyred rollers and vibrating steel rollers are not used because the mix has a tendency to stick to the wheels of the former, and the kneading and vibratory effects of the latter can force the binder to the surface, closing up the surface voids. Vibrating rollers can also cause crushing of aggregates due to the high proportion of point to point contacts developed in the mix.

Joints need special attention, to ensure continuity of the drainage paths. Tack coating of the edge of pervious cool OG blocks the drainage paths. Hot longitudinal joints are preferable. Hand work should be minimised, or preferably avoided, as it is difficult to achieve porosity or good finishes.
3. APPLICATION

3.1 OG Grades

Experience in Australia suggests that two grades of OG are sufficient for the anticipated range of applications and these gradings are designated as Type I and Type II. Suggested criteria for the selection of the type to be used are shown in Table 3.1.

Table 3.1 - OG Grade Selection Criteria

<table>
<thead>
<tr>
<th>Open-Graded Asphalt Type</th>
<th>Indicative Traffic Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Commercial Vehicles / lane / day</td>
</tr>
<tr>
<td>Type I</td>
<td>&lt; 500</td>
</tr>
<tr>
<td>Type II</td>
<td>&gt; 500</td>
</tr>
</tbody>
</table>

* Based on a pavement design life of 30 years.

Type I
OG intended to give a modest level of performance where the extended life obtainable with higher binder contents and modified binders is not considered justified.

Type II
OG intended to give premium performance through the use of higher binder contents and/or modified binders. Fibres can be added to such mixes to reduce drain-down at the higher binder contents. Design procedures described in this guide are particularly applicable to optimising the performance of such mixes.

3.2 Terminology

The description of OG uses a format consistent with that used in the ‘Selection and Design of Asphalt Mixes: Australian Provisional Guide’ and is shown below:

OG 14 II 170 R
Mix type — refers to Open-Graded Asphalt (OG).

Nominal size — refers to the largest particle present in the mix. In practical terms this is taken to be the largest nominal aggregate size used in the mix, aggregate nominal sizes being an approximation to the sieve size through which the bulk (usually 95%) of the material passes.

Grade — the design procedure includes two types, Type I and Type II.

Binder type or class — see section 3.3 of ‘Selection and Design of Asphalt Mixes: Australian Provisional Guide’.

Additional suffix — an additional letter may be used, if required, to designate special mix requirements (for example: ‘R’ to signify a bitumen-rich mix).

### 3.3 Selection of Nominal Size

Selection of nominal size is related to the performance functions of the mix and layer thickness and often one will determine the other. OG is available in Australia in 10 mm, 14 mm and 20 mm nominal sizes with 10 mm most commonly used, followed by 14 mm. Typical gradings are shown in Table 5.1.

To allow proper compaction OG should be placed in layer thickness of at least 2.5 times the nominal size of the mix. To avoid instability the maximum thickness of a layer should be limited to 4 times the nominal size of the mix. As a general rule, the greatest economy and overall performance is obtained by selecting the largest available nominal size mix consistent with the desired surface characteristics. The layer thickness may also be designed to accommodate run-off from periodic high intensity rain storms.
4. MATERIALS

4.1 Aggregate

OG comprises 94–97% by mass of aggregate and due to the high level of mechanical interlock of the aggregate skeleton, requires high quality aggregate to ensure that vehicle loads can be distributed to underlying layers. The aggregate needs to be strong, clean, durable, cubical, have good micro-texture, possess a high proportion of crushed faces and have an affinity for bitumen.

Aggregates conforming to wearing course specifications will usually meet these requirements.

A more detailed discussion on aggregates is given in 'Selection and Design of Asphalt Mixes: Australian Provisional Guide'.

4.2 Mineral Fillers

Mineral fillers are defined as that part of the aggregate in a mix that is finer than 0.075 mm. They are derived from the coarse and fine aggregate components and/or from recycling the dust extracted from the crushing and screening plants or from asphalt plants but can also be added materials such as hydrated lime, Portland cement, ground slag, ground limestone or fly-ash. The addition of hydrated lime mineral filler also reduces binder drain-down.

A more detailed discussion on mineral fillers is given in 'Selection and Design of Asphalt Mixes: Australian Provisional Guide'.

Lack of durability and ravelling in OG layers is often due to binder oxidation or low binder contents. It can also be due to loss of adhesion between binder and aggregate, generally known as stripping. Mineral fillers can be chosen to improve binder/aggregate adhesion and hence, reduce the potential for stripping.

In this regard, the strongly preferred mineral filler is hydrated lime, but Portland cement and ground limestone may also be used.

4.3 Binder

The role of the binder is to provide sufficient cohesion for the mix to resist surface fretting and ravelling. Durability is important and the binder should be either resistant to oxidation or be present as a sufficiently thick coating on the aggregate particles so that oxidation hardening leading to cracking and loss of cohesion is postponed until the design life is achieved.

A more detailed discussion on binders is given in 'Selection and Design of Asphalt Mixes: Australian Provisional Guide'.

Use of excessive binder contents is detrimental to the proper functioning of the mix. It will reduce air void contents, and possibly lead to excessive binder drain-down during transport.
Modified binders can be used to improve OG properties through improved cohesion and durability. They may also assist in reducing binder drain-down. Modified binders, such as styrene-butadiene-styrene (SBS), styrene-butadiene-rubber (SBR), ethylene-vinyl-acetate (EVA), crumbed rubber modified (CRM) and multigrade binders have all been used with success.

All of the above mentioned polymer modified binders have shown an improved retention of the binder within the mix when compared to conventional bitumens provided that the benefit is not negated by the use of higher mix temperatures. The skinning effect on the surface of polymer modified binder tends to assist the cleansing of the air voids under the action of traffic.

Fibres (0.3 to 0.5% by mass) are very effective in preventing binder drain-down and helping retain the binder on the aggregate but have little influence on other properties of OG.
5. SELECTION OF COMPONENT PROPORTIONS

5.1 Overview

In the general procedure for determining aggregate component proportions, the first step is to select a target grading. The combined grading of the selected proportions of aggregate components are calculated, compared to the target grading, and the proportions adjusted until a suitable combination is achieved. (CMix, a computer aided mix design program, is useful for determining the proportion of the aggregate fractions needed to meet target gradings.)

Secondly a target binder content is chosen based on performance related criteria pertinent to the functional requirements of OG. The selection of a target binder content is less critical at this stage than the target grading, as testing is carried out at several binder contents spanning the normal working range to determine an optimum binder content.

The design of an OG is a compromise between providing a porous layer and maintaining a road surface function over the design life. Maximum porosity is achieved by providing a mix composed predominantly of a one-sized aggregate. Loads are supported by relatively few contact points between adjacent particles with only a minimum of binder mastic providing cohesion in the mix. This necessitates the use of a gap graded, strong aggregate and a sufficiently strong binder mastic to maintain a coherent mix. Road service function is met by selecting suitable aggregates and designing an open grading. The quality of aggregate and grading selected will influence the micro-texture and porosity of the surfacing, which are the major functional properties of OG.

Design life is extended by ensuring that there is no appreciable stone loss, in either wet or dry conditions, or major change in porosity with time. This is achieved by selecting suitable aggregates, optimising the binder content, ensuring that the binder and aggregate are compatible in the presence of water and that the binder has sufficient resistance to oxidation.

In addition to the functional requirements of the layer there needs to be some assessment of the practical aspects of producing and laying the mix. This is checked by determining the drain-down potential of the mix design.

5.2 Selection of Target Aggregate Grading

One of the main features of an OG is the gap in the grading curve which gives the mix its characteristic high void content; the bigger the gap the greater will be the voids in mineral aggregate and hence air void content. Void contents of up to 30% can be achieved, although 25% appears to be a more typical upper limit. OG should have a minimum void content of 20%. It has been found that the porosity of OG mixes reduces over time due to traffic compaction and detritus and typically reduces in void content by about 5% from the initial void content.

There is a compromise between attaining a highly permeable mix (by using a grading composed of single size particles) and developing an aggregate skeleton that can resist shearing forces by particle interlock (by using a more continuous grading). OG asphalt used in Australia has tended to contain a certain amount
of fines to enhance mechanical stability and reduce risk of binder drainage. Use of recommendations in this guide are likely to result in coarser mixes to provide greater porosity while providing other measures to control risk of binder drain-down.

The target gradings shown in Table 5.1 can be used as an initial starting point in the absence of other data. These may need to be adapted to cater for specific aggregates or specific circumstances. The suggested gradings tend to be coarser than the design grading envelopes in 'AS 2150 - Hot Mix Asphalt' and many State Road Authority specifications but will result in a more porous mix.

Table 5.1 - Typical Centre-Line Target Gradings for OG (Percent Passing)

<table>
<thead>
<tr>
<th>Sieve Aperture (mm)</th>
<th>Nominal Mix Size</th>
<th>Production Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 mm</td>
<td>14 mm</td>
</tr>
<tr>
<td>26.5</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>19.0</td>
<td>100</td>
<td>95</td>
</tr>
<tr>
<td>13.2</td>
<td>100</td>
<td>95</td>
</tr>
<tr>
<td>9.5</td>
<td>90</td>
<td>50</td>
</tr>
<tr>
<td>6.7</td>
<td>40</td>
<td>27</td>
</tr>
<tr>
<td>4.75</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>2.36</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>1.18</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>0.6</td>
<td>6</td>
<td>6.5</td>
</tr>
<tr>
<td>0.3</td>
<td>5</td>
<td>5.5</td>
</tr>
<tr>
<td>0.15</td>
<td>4</td>
<td>4.5</td>
</tr>
<tr>
<td>0.075</td>
<td>3.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

5.3 Matching the Target Grading

The target grading must be matched using the individual aggregate components (or stockpiles) available. The basic formula for combining aggregate is:

\[ P = Aa + Bb + Cc, \text{ etc.} \]

where

\[ P = \text{the percentage of combined aggregate passing a given sieve} \]

\[ A, B, C \text{ etc.} = \text{percentages of material passing a given sieve for each of the given aggregates A, B, C, etc.} \]

\[ a, b, c \text{ etc.} = \text{proportion of aggregates A, B, C, etc, used in the combination and where the total is 1.0.} \]

The procedure is facilitated by using a computer spreadsheet package or CMix. The final combined grading is designated as the 'job mix'.
5.4 Selection of Target Binder Content

Prior to determining an optimum binder content, the absorption of binder by the aggregate should be measured, to permit calculation of the effective binder content. Subsequent references to binder content relate to the effective binder content, unless otherwise stated.

The selection of a design binder content is based upon a number of criteria. There needs to be minimum binder content, related to the maximum particle size, that provides sufficient binder to coat the aggregate, provides a minimum film thickness to resist aging and provides sufficient cohesion to the mix. There is also a maximum binder content above which appreciable loss of binder occurs due to drain-down during mixing or transport. High binder contents may also mean that an adequate air void content is unattainable.

Drain-down is measured using the Basket Drainage test (see Appendix A for a test procedure) which essentially measures the loss of binder residue after a prescribed period at a prescribed temperature. A series of mixes covering a range of binder contents spanning the expected optimum binder content are prepared using the 'job mix' grading. Table 4.1 provides the expected range of binder contents for each nominal mix size that should be suitable for most aggregates. Circumstances may demand binder contents outside these ranges but this should be assessed on the basis of the special requirements of the pavement or aggregates. In practice, OG should contain about 8% to 12% by volume of effective binder depending on the nominal mix size.

Mix cohesion is another important OG property that needs to be addressed during the mix design process. It is assessed using the Cantabro test (see Appendix A for a test procedure). This test abrades compacted cylindrical specimens by tumbling them individually in a Los Angeles device without the steel balls. The single largest remaining fragment is weighed and compared to the original mass. The test is performed on both moisture-conditioned and unconditioned specimens.

The laboratory optimum binder content is determined by balancing binder drain-off and a suitable level of air voids with adequate mix cohesion.
6. DESIGN METHOD

6.1 Selection of Initial Grading

In the absence of other advice/data the gradings suggested in Table 5.1 provide an initial target grading. Both Type I and Type II OG should have a minimum air void content of 20%. Type II OG will have either more binder or better quality binders and thus may be designed with higher void contents (up to 25%) and still be expected to attain a long life.

6.2 Selection of an Initial Range of Binder Contents

The trial binder contents shown in Tables 6.1 and 6.2 are to be used for the trial mixes. Additional trial binder contents may be used but must cover the range specified in Tables 6.1 and 6.2 unless there are special site-specific circumstances.

Table 6.1 - Trial Binder Content
Appropriate for Type I OG of Various Maximum Sizes

<table>
<thead>
<tr>
<th>Binder Content Range</th>
<th>Nominal Mix Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mm</td>
<td>14 mm</td>
</tr>
<tr>
<td>Minimum</td>
<td>4.5</td>
</tr>
<tr>
<td>Mean</td>
<td>5.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>5.5</td>
</tr>
</tbody>
</table>

Table 6.2 - Trial Binder Content
Appropriate for Type II OG of Various Maximum Sizes

<table>
<thead>
<tr>
<th>Binder Content Range</th>
<th>Nominal Mix Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mm</td>
<td>14 mm</td>
</tr>
<tr>
<td>Minimum</td>
<td>5.5</td>
</tr>
<tr>
<td>Mean</td>
<td>6.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>6.5</td>
</tr>
</tbody>
</table>
6.3 Preparation of Compacted Specimens

Prepare sufficient OG mix at each of three trial binder contents, in accordance with AS 2891.1 to permit triplicate specimens to be compacted in a gyratory compactor. (Note: an additional 2500 g of loose mix should be provided for determining drain-down and maximum (voidless) density.) Compact triplicate specimens at each binder content for 80 cycles.

Determine the maximum density for each mix (each binder content) using AS 2891.7.2.

Determine bulk (mensuration) density for each compacted specimen using AS 2891.9.3.

Determine the air void content (AS 2891.8) for each compacted specimen and plot the mean of the triplicates against trial binder content using the design chart in Fig. 6.2. Interpolate the binder content corresponding to 20% air voids and designate this as BC_max (see worked example in Appendix B).

If the air void contents are not within the required limits (see Section 6.1) then if:

- Air void content is too low
  - use a more open grading (will make the mix less cohesive)
  - use a lower binder content (will make the mix less cohesive)

- Air void content is too high
  - introduce more fine or intermediate aggregate
  - use a higher binder content

6.4 Abrasion Resistance

Abrasion resistance of the mix is measured using the Cantabro test (see Appendix A for an outline of the test procedure). At the time of writing there is no Australian Standard for this test.

Compacted specimens for each trial mix are placed within the Los Angeles abrasion drum (see Fig. 6.1) and rotated for 300 revolutions. The single largest remaining portion is weighed and the result expressed as a percentage loss in mass, compared to the initial mass.

Compacted specimens can be conditioned to accentuate moisture damage potential or tested without any conditioning.
The test is conducted on unconditioned specimens in triplicate, within 7 days of manufacture. The mean Cantabro abrasion loss for each triplicate group is plotted against trial binder content.

The binder content corresponding to the maximum Cantabro abrasion loss appropriate to the mix is interpolated and designated as $BC_{\text{min}}$.

The recommended mean maximum loss permitted for unconditioned samples is 20% for Type II OG and 25% for Type I OG.

The mix must be rejected if any individual specimen has more than 50% Cantabro abrasion loss.

If the mean Cantabro abrasion loss is greater than the desired limit then:

- increase the binder content (decrease air void content)
- include more intermediate sized aggregates (decrease air void content).
- use a binder with improved cohesive properties.
6.5 Binder Drain-down

Determine the drain-down at each trial binder content using the Basket Drainage test procedure. There should be no more than 0.3% drain-down.

Plot the drain-down against trial binder content so that the drain-down at the provisional binder content (see section 6.7) can be interpolated. If the drain-down is greater than 0.3% then:

- use fibres (typically 0.3% by mass of total aggregate mass).
- decrease the binder content (increase air void content)
- use a binder with improved cohesive properties (for example PMBs).
- use a mineral filler complying with the recommendations given in section 4.2 or increase the mineral filler content (decrease the air void content).

6.6 Selection of the Design Binder Content

A design chart such as that shown in Fig. 6.2 can be used to select the maximum and minimum binder contents that fulfil the design air void content and abrasion requirements. The minimum air void content limit (20%) will set the maximum binder content (BCmax). The maximum Cantabro abrasion loss (25% for Type I and 20% for Type II) will set the minimum binder content (BCmin).

The provisional binder content is the mean of BCmax and BCmin. The drain-down is linearly interpolated at the provisional binder content. If the estimated drain-down is less than 0.3% then the mix is deemed to be suitable and the design binder content is then found by adding the estimated drain-down to the provisional binder content. (See Appendix B for a worked example.) If the estimated drain-down is greater than 0.3% then the mix will need to be redesigned, see section 6.5.

If the calculated design binder content is less than the appropriate minimum value in either Tables 6.1 or 6.2 then the minimum binder content from the Tables shall be adopted as the provisional binder content. The design binder content shall then be the minimum binder content from the Tables plus the drain-down at the provisional binder content.

If BCmin is greater than BCmax then the mix needs to be redesigned. If 20% air void content is not encompassed in the trial mixes then the grading should be altered.

The design binder content can be altered to accommodate peculiarities of a mix, ie. an increase in the binder content may be required to improve the Cantabro abrasion loss values, this is permitted provided that drain-down or air void content values do not fall outside the recommended limits.
6.7 Properties of the Design Mix

Having determined a design binder content, it is necessary to determine the properties of the design mix. Manufacture sufficient mix to compact 6 specimens at the provisional binder content with an additional 2500 g of loose mix for drain-down and maximum density testing. (Note: it is assumed that little drain-down will occur in the laboratory or that the OG will be briefly re-mixed to homogeneous composition prior to compaction.)

Compact six specimens using the same procedure as previously. All specimens are tested to determine air void content. Three unconditioned specimens are tested to determine the Cantabro abrasion loss as previously described and three are conditioned using the procedure outlined in Appendix A. The conditioned specimens have a binder viscosity approximating one year in service and are tested to determine the Cantabro abrasion losses which should be less than 35% for Type I and less than 30% for Type II mixes. If the mix does not satisfy these limits then the mix needs to be modified, see section 6.4 and the bullet points listed below:

- Increase binder content (within the acceptable range).
- Incorporate mineral filler complying with the recommendations given in section 4.2.
- Select a more cohesive binder (usually PMB), and
- Select a more compatible binder/aggregate combination.

If the mix at the provisional binder content meets all stipulated requirements, it is satisfactory and can be manufactured and placed at the design binder content.

<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Type II</th>
<th>Type I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cantabro Abrasion Loss - Uncond.</td>
<td>&lt; 20</td>
<td>&lt; 25</td>
</tr>
<tr>
<td>Cantabro Abrasion Loss - Cond.</td>
<td>&lt; 30</td>
<td>&lt; 35</td>
</tr>
<tr>
<td>Air void Content (%)</td>
<td>20 - 25</td>
<td>&gt; 20</td>
</tr>
<tr>
<td>Drain Off (%)</td>
<td>&lt; 0.3</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.3 - Summary of Design Limits
Open-Graded Asphalt Design Chart

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Location or Calculation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC_{min}</td>
<td>from upper graph</td>
<td></td>
</tr>
<tr>
<td>BC_{max}</td>
<td>from upper graph</td>
<td></td>
</tr>
<tr>
<td>BC_{provisional}</td>
<td>(\frac{(BC_{max} + BC_{min})}{2})</td>
<td></td>
</tr>
<tr>
<td>Drain-down at BC_{provisional}</td>
<td>from lower graph</td>
<td></td>
</tr>
<tr>
<td>BC_{design}</td>
<td>BC_{provisional} + Drain-down</td>
<td></td>
</tr>
</tbody>
</table>
BIBLIOGRAPHY


APPENDIX A
TEST METHODS
CANTABRO TEST PROCEDURE

Scope:
This test is used to determine the abrasion resistance of laboratory prepared, compacted asphalt specimens. Specimens can be tested with or without conditioning but must be tested within 7 days of manufacture. This method is based upon testing nominally identical triplicate specimens.

Test Specimens:
Test specimens should have air voids contents as specified in Summary Table 6.3.

The specimens should be compacted in a Gyropac such that the finished height of the specimen is 65 ± 1 mm (for 100 mm diameter specimens) or 80 ± 1 mm (for 150 mm diameter specimens).

Apparatus:
Los Angeles Abrasion Loss Drum conforming to AS 1141.
Balance with a capacity of 5000 g capable of measuring to 0.1 g

Temperature controlled environment capable of maintaining a temperature of 25 ± 1°C

Water bath capable of maintaining 25 ± 1°C

Procedure:
1. Ensure that the first test specimen has been dried to constant mass and record this to the nearest 0.1 g as \( m_{11} \).

2. Allow the specimen to attain a temperature of 25 ± 1°C.

3. Place the first specimen into the Los Angeles Abrasion Loss drum and rotate for 300 revolutions (without the steel balls). The Los Angeles Abrasion Loss drum should also be at 25 ± 5°C.
4. Select the largest remaining fragment of asphalt from the drum and determine and record the mass as $m_{12}$. Remove the remainder of the residue.

5. Repeat steps 1 to 4 for the two remaining specimens from the triplicate group recording the masses as $m_{21}$, $m_{22}$, $m_{31}$ and $m_{32}$.

6. Where testing of specimens conditioned for the effect of moisture is to be carried out, place the specimens in the water bath at $25 \pm 1^\circ C$ for 20 to 24 hours.

7. Remove the specimen from the water bath and blot dry the surface with a damp towel and record the mass to the nearest 0.1 g as $m_{11}$.

8. Test moisture conditioned specimens in the same manner as steps 3 to 5, above.

**Calculations:**

The Cantabro abrasion loss (CAL) is calculated as follows:

For each specimen $\text{CAL}_i = \left(\frac{m_i - m_{i2}}{m_i}\right) \times 100$

The mean of the triplicates is calculated as $\text{CAL} = (\text{CAL}_1 + \text{CAL}_2 + \text{CAL}_3)/3$

**Reporting of Results:**

The air void content of each specimen is to be reported along with the specimen preparation procedure. The individual Cantabro abrasion loss for each specimen is reported as well as the mean Cantabro abrasion loss for dry conditioned and moisture conditioned specimens as appropriate. If the CAL for any specimen is greater than 50% the test shall be repeated.
BASKET DRAINAGE TEST

Scope:

This procedure is used to assess the amount of binder that is likely to drain down from a mix during transport to site. It is suitable for all fresh hot mixed asphalts.

This method is suitable for asphalt mixes that have a nominal maximum particle size of 20 mm or less. For mixes with a nominal size greater than 20 mm a greater quantity of asphalt may be required.

Apparatus:

Mechanical mixer of not more than 8 l capacity

Drainage baskets 100 ± 2 mm in all dimensions constructed from a perforated steel plate with 3.5 ± 0.5 mm diameter holes such that there is 44 ± 3 % open area. Feet are to be fixed to each corner that are 3 mm square in cross-section and 5 mm high.

Oven, capable of achieving 170 ± 5°C

Balance, with a capacity of 5000 g readable to 0.1 g

Timer, readable to the nearest second

Heat resistant gloves

Metal drip trays, 150 mm square and 10 mm deep.

Procedure:

1. Line a metal drip tray with aluminium foil, determine the mass and record as \( m_1 \).

2. Weigh a clean, dry drainage basket and record the mass as \( m_2 \).

3. Combine aggregate, binder and additional mix constituents according to AS 2891.1

4. Remove a 1100 ± 50 g representative sample and place in drainage basket. Place the drainage basket on to the drip tray and determine the mass and record as \( m_3 \).

5. Place drainage basket and drip tray into oven and condition the sample for 187 ± 8 minutes according to the temperatures stipulated in AS 2891.1.
6. Repeat steps 1 to 5 for a duplicate sample.

7. Remove the drainage basket and drip tray from the oven.

8. Remove the drainage basket and determine the mass of the drip tray and binder residue. Record as \(m_4\).

Note: Care should be taken to minimise heat loss at all times.

**Calculations:**

The loss of binder is calculated as follows:

\[
\text{Percent Drain-down} = \left( \frac{(m_4 - m_5)}{(m_3 - m_2 - m_3)} \right) \times 100
\]

If the difference in the percent drain-down for duplicate tests is greater than 0.5% then the test shall be repeated. The percent drain-down is the arithmetic mean of the duplicate measurements.

**Reporting of Results:**

Report the following:

- Mix preparation procedure
- Conditioning time and temperature in oven
- Percent drain-down of individual tests and the mean.
APPENDIX B

WORKED EXAMPLE

The example below is for a 14 mm Type II Open-Graded Asphalt. The maximum binder content permissible to achieve a minimum air void content of 20% is 5.2%. The minimum binder content required to ensure that there is less than 20% Cantabro abrasion losses is 4.7%. Therefore the provisional binder content is:

\[
\frac{(5.2\% + 4.7\%)}{2} = 4.95\%.
\]

Then interpolating the drain-down at the provisional binder content it was estimated that the drain-down would be 0.2%. This results in a design binder content of:

\[
4.95\% + 0.2\% = 5.15\%, \text{ say 5.2\%}.
\]
### Open Graded Asphalt

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Location or Calculation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC&lt;sub&gt;min&lt;/sub&gt;</td>
<td>from upper graph</td>
<td>4.8%</td>
</tr>
<tr>
<td>BC&lt;sub&gt;max&lt;/sub&gt;</td>
<td>from upper graph</td>
<td>5.2%</td>
</tr>
<tr>
<td>BC&lt;sub&gt;provisional&lt;/sub&gt;</td>
<td>( (BC_{\text{min}} + BC_{\text{max}}) / 2 )</td>
<td>5.0%</td>
</tr>
<tr>
<td>Drain-down at BC&lt;sub&gt;provisional&lt;/sub&gt;</td>
<td>from lower graph</td>
<td>0.2%</td>
</tr>
<tr>
<td>BC&lt;sub&gt;design&lt;/sub&gt;</td>
<td>BC&lt;sub&gt;provisional&lt;/sub&gt; + Drain-down</td>
<td>5.2%</td>
</tr>
</tbody>
</table>

Triplicate specimens were produced at the provisional binder content and the means are plotted on the above figure. The mean Cantabro abrasion loss for the unconditioned specimens is shown by a diamond and the mean Cantabro abrasion loss for the conditioned specimens is shown by a triangle while the void content is shown by a circle. It can be seen that both Cantabro abrasion loss values are below the permitted limits and the air void content is above 20% thus indicating a satisfactory mix.
APPENDIX C

Design Outline and Flow Chart

Notes for the Design of Open-Graded Asphalt (OG)

1. Select mix components which can include: aggregate, binder, mineral filler and other (eg cellulose fibres).

2. Components are selected against job specifications which address the most suitable nominal mix size (eg 10 mm, 14 mm, etc). Will depend on layer thickness and desired surface characteristics (and possibly water storage capacity).

3. Need to decide if a Type I or Type II OG is required which will impact on the quality of the materials required and the cost of the mix.

4. A target grading is required and advice on these is given in section 5.2.

5. Select trial binder contents (minimum of three) which will depend upon the nominal mix size and Type of the OG (see sections 5.4 and 6.2).

6. Prepare sufficient mix for three specimens at each trial binder content and compact for 80 gyratory cycles to AS 2891.2.2. Ensure an additional 2500 g of loose mix is prepared.

7. Determine drain-down for each trial binder content and plot drain-down versus binder content (see design chart).

8. Determine the bulk density using method AS 2891.9.3, maximum (voidless) density using AS 2891.7.1 and volumetric properties using AS 2891.8. Plot air void content versus bitumen content (see design chart) and find BC max at 20% air void content.

9. Test each compacted (unconditioned) specimen to determine Cantabro abrasion loss.

10. Plot Cantabro abrasion loss against binder content (see design chart) and determine BC_{min} at the appropriate level of loss which depends on the OG type.

11. BC_{min} should be less than BC_{max}. If not, the mix will need to be redesigned.

12. BC_{provisional} is the mean of BC_{max} and BC_{min}.

13. The drain-down at the provisional binder content must be less than 0.3%.

14. BC_{design} is BC_{provisional} plus the drain-down at that binder content.

15. Check that the design binder content is greater than the allowable minimum given in Tables 6.1 and 6.2.

16. Prepare 6 specimens at the provisional binder content for 80 cycles.

17. Condition three specimens and test in Cantabro test. Test the remaining three specimens in the Cantabro test.

18. Calculate Cantabro abrasion losses and compare with acceptance criteria in Table 6.3. If not acceptable then the design will need to be altered.

19. Accept design if losses are acceptable.
1. OGFC Design

2. Select mix components

3. Select nominal size

4. Type I or Type II or Type II grade?
   - Type I
   - Type II

5. Select target grading

6. Select trial binder contents

7. Prepare specimens at 80 cycles

8. Binder drain-off
   - Is Drain-off < 0.3%?
     - Yes
     - No

9. Determine voids and find BCmax

10. Cantabro test

11. Determine BCmin

12. Is BCmin < BCmax?
    - Yes
    - No

13. Calculate BCprovisional

14. Is BCdesign > allowable minimum?
    - Yes
    - No

15. Calculate BCdesign

16. Prepare 6 specimens at 80 cycles

17. Cantabro test, wet & dry
    - Yes
    - No

18. Are losses acceptable?
    - Yes
    - No

19. Accept design

20. OJ.