ASPHALT MIX DESIGN

1 INTRODUCTION

These notes provide an outline of the process of asphalt mix design and are substantially based on text from the Austroads Asphalt Guide. A detailed guide to selection and design of asphalt mixes for Australian conditions is provided in APRG Guide to Pavement Technology Part 4B, Hot mix asphalt - A guide to good practice

Further information on design criteria for specific application and details of testing procedures may be obtained from referenced publications.

The process of asphalt mix design involves the choice of aggregate type, filler, combined aggregate grading, binder type and determination of a binder content that will optimise the engineering properties in relation to the desired behaviour in service.

Hot mix asphalts are designed with the following considerations:

- Resistance to permanent deformation

  The asphalt mix should not distort or deform under traffic. Resistance to permanent deformation (rutting) is particularly important in hot climates. Resistance to permanent deformation is controlled by selecting quality aggregates with appropriate gradation and selecting appropriate volumetric proportions of aggregate, binder and voids.

- Resistance to fatigue

  The asphalt mix should not crack when subjected to repeated loads over a period of time. Fatigue (resistance to repeated loading) is the structural characteristic of asphalt used in mechanistic pavement design procedures.

- Durability

  The mix must contain sufficient bitumen to ensure adequate film thickness around the aggregate particles, thus minimising bitumen hardening or ageing during production or service.

- Resistance to moisture-induced damage

  Moisture in the voids of the asphalt mixture may cause the loss of adhesion between aggregate and bitumen (stripping), which process may lead to extensive damage, first in the asphalt mix and then in the pavement. Impermeable asphalt mixes usually do not have this problem, and also prevent water ingress into the lower pavement layers.

- Workability

  It is essential that the mix can be placed and compacted with reasonable effort. Mixes with poor workability characteristics are usually difficult to handle and compact, i.e. they may cause segregation and unsatisfactory compaction.

- Skid resistance

  This requirement is applicable only to surface wearing courses, where the mix should provide adequate resistance to skidding and permit normal turning and braking movements to occur.

- Resistance to low temperature cracking

  This requirement is mainly relevant to areas with cold temperatures. Low temperature cracking is primarily influenced by the low temperature properties of the bitumen, therefore the selection of the binder is critical. This requirement has a limited relevance to Australian conditions, but it is most important in the Northern hemisphere.

- Spray generation and noise

  Spray generation and noise are functional requirements under certain circumstances, and are usually addressed by the selection of the mix type, rather than the mix design itself.

2 DESIGN PROCESS

Asphalt mix design involves the following basic steps that are similar in concept, regardless of the actual tests and procedures used:

1. Selection of mix type;
2. Selection of component materials;
3. Combination of aggregates to meet target grading;
4. Selection of target binder content or range;
5. Mixing and compaction of asphalt mix to a density that is representative of in-service conditions;
6. Measurement of volumetric properties of compacted mix;
7. Mechanical testing of compacted samples;
8. Verification of design properties on samples of manufactured asphalt, if required;
9. Selection of job mix.

Procedures for designing asphalt mixes have been generally developed around testing of dense graded mixes and determination of optimum binder content, although most tests can be used for other mix types with suitable interpretation of results.

A flow chart of the design process is shown in Figure 1.

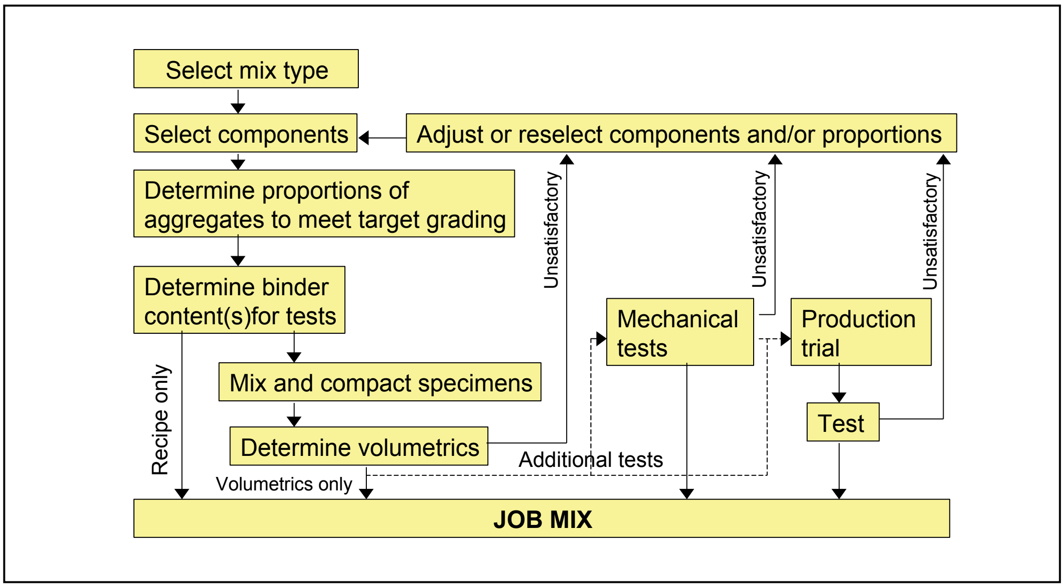


Figure 1 Asphalt mix design process

2.1 SELECTION OF MIX TYPE AND COMPONENT MATERIALS

Selection of mix type for particular performance conditions will set the parameters for aggregate grading, binder type, volumetric properties, and the general performance characteristics of the mix.

Selection of materials must be appropriate to the mix type and performance environment.

2.2 RECIPE CRITERIA

Recipe criteria may be used to define some or all of the components and characteristics of an asphalt mix where characteristics of the mix cannot be readily defined or optimised by conventional tests. Such criteria can also be used for simple mixes for use in minor applications. Examples include:

- Setting grading parameters for open graded mixes, gap graded mixes, stone mastic asphalt, ultra thin mixes and other special mix types;
- Setting binder content ranges for the preceding mix types;
- Setting the binder type or additives in any mix type where particular attributes are desired;
- Using mixes of similar composition to those that have been determined to perform satisfactorily in practice;
- Cold mixes.

In many cases, volumetric properties and mechanical performance tests may still be determined to ensure compliance with voids targets or other performance criteria.

2.3 PREPARATION AND COMPACTION OF TRIAL MIXES

A variety of methods of sample preparation and compaction for laboratory testing of asphalt mixes are used in Australia. The preferred method adopted in the Austroads Australian provisional guide is gyratory compaction using the Gyropac, although the Marshall method of compaction is still extensively used. The Modified Hubbard-Field method that was previously used in NSW has now been totally discontinued in favour of Gyropac.

In most cases, trial mixes are prepared that combine aggregates with different proportions of binder to allow selection of a binder content that optimises the desired volumetric properties. If these are not met at a suitable binder content, the source or proportions of aggregates may be altered and the process of sample preparation and compaction is repeated.

2.4 VOLUMETRIC PROPERTIES

Volumetric proportions and characteristics are the basis of asphalt mix design and largely determine the in-service performance of the mix. For many applications, the asphalt mix design process ends at this point.

The key volumetric properties are aggregate grading, binder content and voids content. These are illustrated in Figure 2.

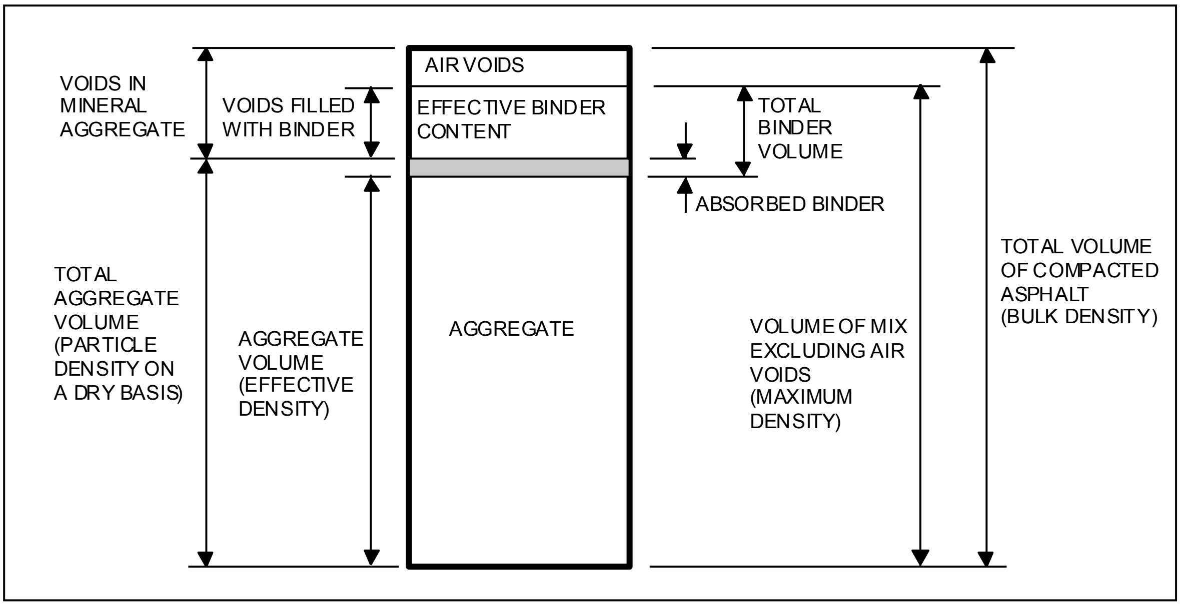


Figure 2 Constituents of a Compacted Dense Graded Asphalt Mix

Binder content and voids are inter-related, and include the important property of voids in the mineral aggregate (VMA). There must be sufficient binder to provide cohesion and durability to the mix, but not so much binder as to cause flushing or instability. There must be sufficient VMA to allow the required volume of binder while ensuring that the air voids are in a suitable range.

For dense mixes, the range of air voids in service should be between 2% and 7%. Below about 2% mixes can become unstable due to the lubricating effect of bitumen almost totally occupying the space between the aggregate particles. Above about 7%, the mix becomes permeable leading to entry of air and moisture causing oxidation of the binder and moisture damage to the mix. Field air voids are a combination of design air voids and compacted density. Poorly compacted mixes also lack structural stiffness and fatigue resistance.

Target design air voids are typically 4% or 5% for the appropriate laboratory compaction level. Air voids in samples of mix taken from production are typically 3% to 6%.

2.5 MECHANICAL TESTING

Ideally, the mechanical properties of asphalt in-situ are required for pavement design purposes. In-situ conditions will vary with a range of factors including temperature, loading time, stress conditions and degree of compaction. Reproduction of in-situ stress conditions in the laboratory is difficult, hence simplified tests have been introduced which may indicate certain aspects of the in-situ behaviour.

Procedures for the mechanical testing of asphalt mixtures may be considered in three groups:

- fundamental tests for stiffness and deformation resistance, and fatigue:
  - repeated load indirect tensile test
  - repeated load dynamic creep test
  - repeated flexural bending
- simulative tests for deformation resistance and other properties:
  - wheel tracking test
  - moisture sensitivity
- empirical tests for design of asphalt mixes:
  - Marshall test
  - Modified Hubbard-Field test.

In some cases, design properties of asphalt mixes may be verified by mechanical tests on samples of plant manufactured or field materials before adoption of a job mix. Such testing should not be confused with process control and assurance testing of asphalt production.

2.6 JOB MIX

The final selected mix is called the job mix (or nominated mix).

The job mix will nominate the type and source of components, target grading and binder content, and volumetric properties of the mix. These are used as the basis for manufacturing process control. Production tolerances allow for variations in the mix composition due to changing feed rates, raw material fluctuations, sampling and testing limitations, etc.

In many cases, manufacturing process control is applied to grading and binder content only, although some agencies also require volumetric testing, and possibly some mechanical testing, to monitor consistency of production.

Any change in the type or source of components, or significant variation in the proportion of any component, generally requires redesign of the mix and determination of a new job mix.

3 AUSTRALIAN PROVISIONAL GUIDE TO ASPHALT MIX DESIGN

The “Selection and design of asphalt mixes: Australian provisional guide” was published by AUSTROADS in 1997 (revised 1998 and 2002a) as Austroads report number AP-T20/02. These procedures are now published in AS2150-2005 : Hot mix asphalt - A guide to good practice

The provisional guide represented the outcome of 10 years of co-operative research by the Australian road agencies and asphalt industry to develop performance based methods for the characterisation of asphalt mixes.

The provisional status of the guide recognises the extent of change and the tentative nature of some aspects of performance criteria. That provisional status will change as greater confidence is developed in use of the test procedures and interpretation of results.

The aim of the guide is a mix design procedure that:

- is performance related;
- enables the in-service performance of mixes to be predicted;
- is relatively affordable (in terms of new equipment cost);
- is rapid and easy to use.

The design procedure for dense graded mixes is based on three levels as shown in Figure 3.

The first level involves:

- Selection of mix type and component materials likely to satisfy the performance requirements;
- Mixing of materials and conditioning of the mix prior to testing to simulate medium term service conditions. Mixing and conditioning of asphalt specimens is described in AS 2891.2.1.
- Gyratory compaction – the gyratory compactor enables selection of different compaction levels to match service conditions as well as simulation of long term heavy traffic by compaction to “refusal density”. Gyratory compaction is described in AS 2891.2.2
- Determination of volumetric properties and selection of design binder content. Determinations include aggregate grading and binder content (AS 2891.3), maximum density (AS 2891.7), bulk density (AS 2891.9) and calculations (AS 2891.8).

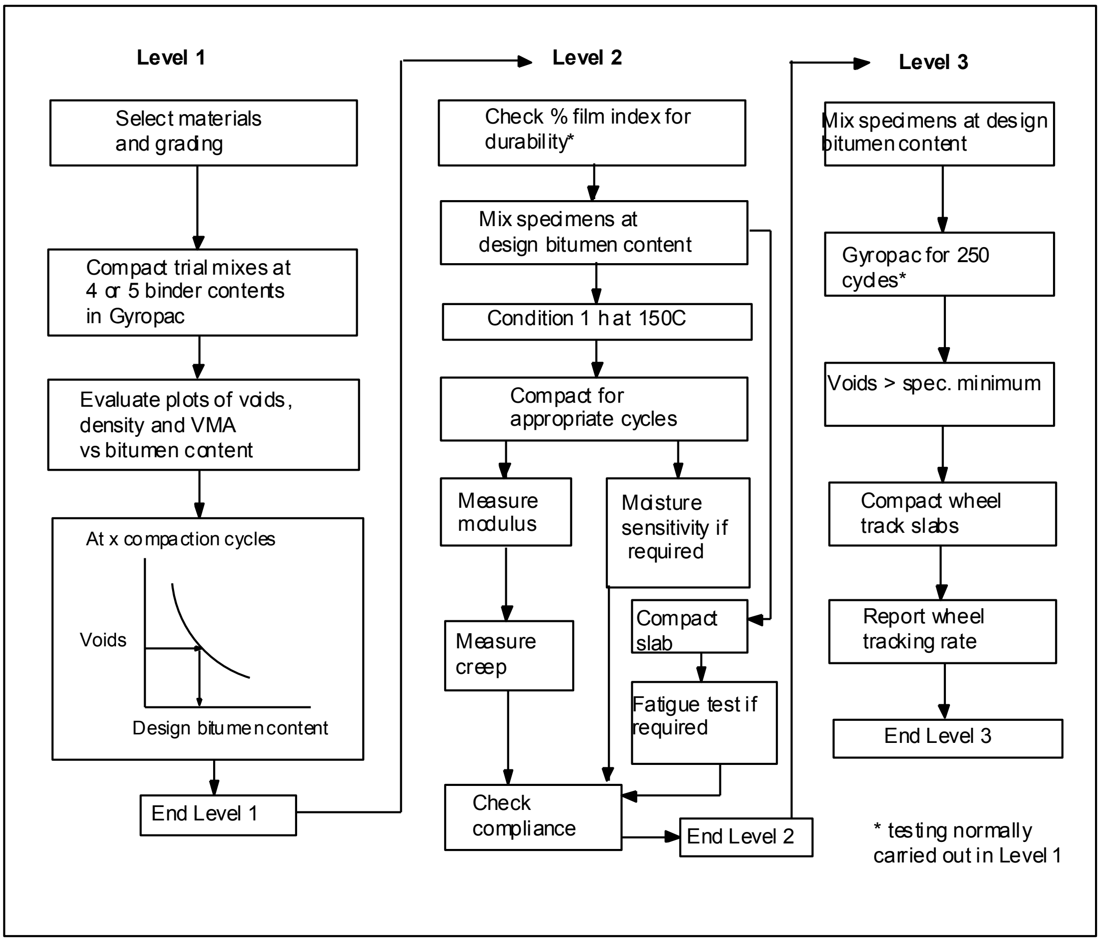
Level two testing involves the application of tests to define structural performance and, if required, moisture sensitivity of the mix.

Level two tests include:

- Check for adequate film index for fatigue and durability. Film index is calculated as a function of the effective binder content and surface area of aggregates (Austroads Test method AST08)
- Mixing, conditioning and compaction of the selected mix using same procedures as Level 1.
- Creep testing (AS 2891.12.1) may also be undertaken at this point although the test procedure is considered to require further development and is largely omitted in favour of wheel tracking tests (Level 3)
- Moisture sensitivity (AST02) is an optional test at this point.
- Fatigue testing (AST03) is a further option test. Fatigue testing is not undertaken as part of routine mix design but applied to research projects and development of asphalt mixes for specific application.

Level three testing is used to evaluate the rutting resistance of mixes intended for use on pavements subjected to high traffic loading and includes:

- Compaction to “refusal density”, being the highest level of compaction likely to be achieved in service by asphalt mixes subjected to heavy traffic. In practice, determination of density at 250 Gyropac cycles is generally obtained at the same time as Level 1 testing.
- Wheel tracking test (AST001).



from AUSTROADS *Selection and Design of Asphalt Mixes: Australian Provisional Guide*

Figure 3 Austroads Mix Design Procedure

3.1 GYRATORY COMPACTION

The principle of gyratory compaction is illustrated in Figure 4. Compaction is achieved by shearing forces obtained by the application of a constant vertical compressive force to the asphalt confined in a cylindrical mould while the mould is rotated about its vertical axis through a small angle. The angle is maintained constant throughout the compaction process.

Compaction can be terminated after a set number of cycles or at a set height representing a predetermined volume and density of asphalt. Monitoring the height of the cylinder during the process enables the density to be estimated at different numbers of cycles. This data can be used to determine density at different compaction levels and provide an indicator of mix workability.

Two forms of gyratory compactor are commonly used in Australia. The Gyropac (Figure 4.5) is used for routine mix design and monitoring tests. The Servopac is a more advanced version that includes more options and control over the compaction process that make it more suited to research applications.

For routine mix design, the level of compaction depends on the traffic level as follows:

- light traffic 50 cycles
- medium traffic 80 cycles
- heavy traffic 120 cycles
- “refusal” density 250 cycles

Test procedures are described in AS 2891.2.2

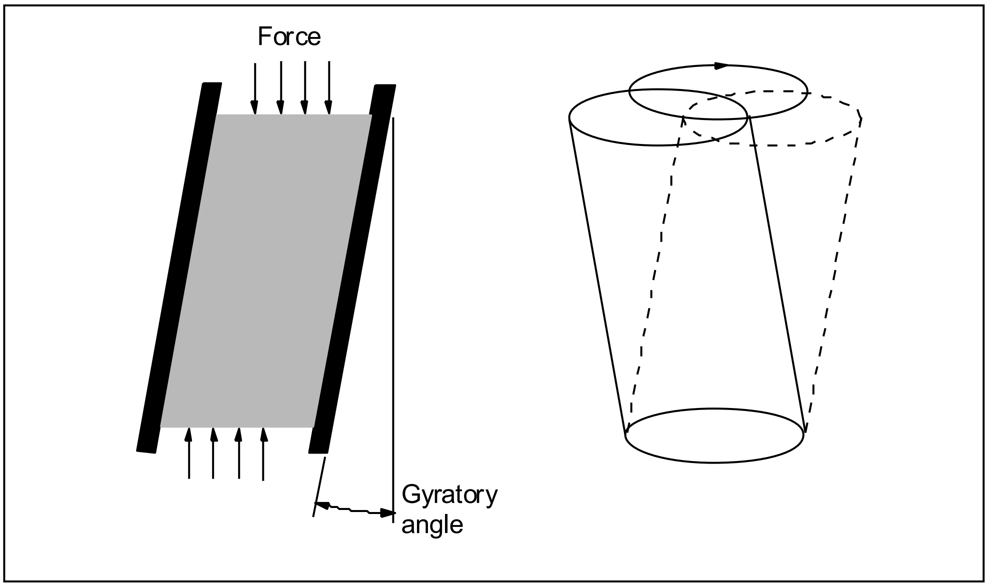


Figure 4 Principle of Gyratory Compaction

3.2 MARSHALL STABILITY AND FLOW

The Marshall method, developed by Bruce Marshall of the Mississippi State Highway Department and improved by the US Corps of Engineers, dates from the early 1940s.

Marshall Stability is a property of the mix that indicates resistance to shoving, rolling, and rutting, or any other plastic (permanent) deformation under load.

There are two mechanisms by which stability in a mix is achieved:

(i) Mechanical interlock between aggregate particles, and

(ii) Binder cohesion

Factors that contribute to improved stability include:

- harder binders
- lower binder contents
- higher compaction
- dense gradings
- crushed aggregates.

Mechanisms based on friction and mechanical interlock are independent of the rate and duration of loading. Hence the most critical condition with respect to stability is a slow moving vehicle, as the resistance of the binder is minimal.

The Marshall method is neither performance-based nor performance-related. The method is concerned primarily with achieving a mix design with a stable, economical balance of aggregate and binder that provides sufficient workability to permit efficient placement of the mix.

Empirical properties such as stability (and flow for Marshall) are used to gauge anticipated performance. However, these methods alone cannot ensure that a trial mix design will meet specific pavement performance criteria.

Procedure

The Marshall compaction method involves the manufacture of cylindrical specimens, 102 mm in diameter and 63 mm high, using a standard compaction hammer and cylindrical mould as described in AS 2891.5. For most applications, 50 blows of the hammer are applied to each face of the cylinder. A higher standard of compaction, involving 75 blows per face, is used for airfield work and some heavy-duty road pavements. Generally, three specimens are prepared for each binder content.

Marshal compaction is limited to mixes with an aggregate size of 28 mm or smaller.

Mechanical testing for stability and flow is described in AS 2891.5.

Compacted specimens are cooled in the moulds and extruded for testing.

Preheated specimens are loaded diametrically in the Marshall apparatus and the maximum load resisted and its vertical deformation are recorded and reported as the stability and flow.

Evaluation of Test Results

The results of the following tests may be presented graphically as shown in Figure 6:

- stability
- flow
- air voids
- voids in mineral aggregate
- bulk density
- voids filled with binder.

These results are used to select the final binder content that should:

- be close to maximum values for stability and bulk density
- be near the minimum value for VMA
- have air voids (and flow) within the specified limits.

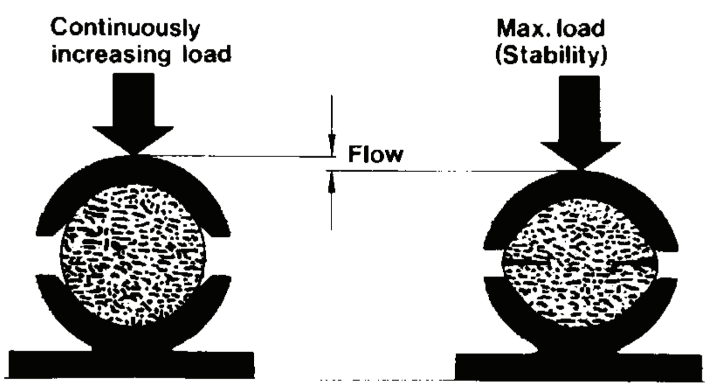


Figure 5 Testing of Marshall Specimen

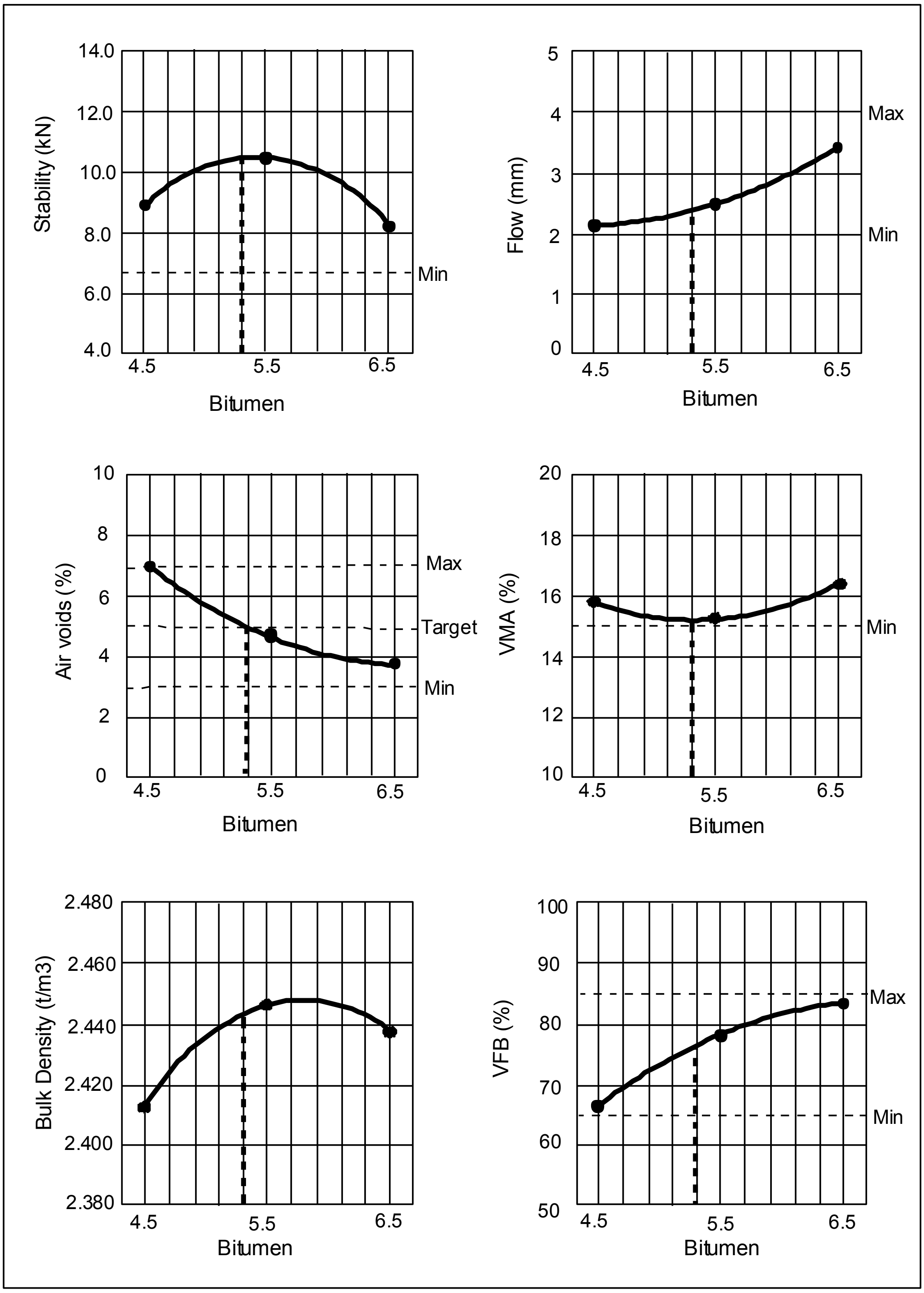


Figure 6 Marshall Test Results

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AS 2891-2008 Methods of sampling and testing asphalt

AS2891.1 Sampling of asphalt

AS2891.2.1 Sample preparation – Mixing, quartering and conditioning of asphalt in the laboratory

AS2891.2.2 Sample preparation – Compaction of asphalt specimens using a gyratory compactor

AS2891.3 Bitumen content and aggregate grading

AS2891.5 Determination of stability and flow – Marshall procedure

AS2891.6 Determination of stability and flow by the Modified Hubbard-Field procedure

AS2891.7 Determination of the maximum density of asphalt

AS2891.8 Voids and density relationships for compacted mixes

AS2891.9 Determination of bulk density of compacted asphalt

AS2891.12.1 Determination of the permanent compressive strain characteristics of asphalt – Dynamic creep test

AS2891.13.1 Determination of resilient modulus of asphalt – Indirect tensile test

AS 4283 Cold mix asphalt for maintenance patching.

Austroads Manual of Test Methods

AGPT/T220 Sample preparation – compaction of asphalt slabs suitable for characterisation

AGPT/T231 Deformation resistance of asphalt mixtures by the wheel tracking test

AGPT/T232 Stripping potential of asphalt – Tensile strength ratio

AGPT/T233 Fatigue life of compacted bituminous mixes subject to repeated flexural bending

AGPT/T234 Asphalt binder content (Ignition oven method)

AGPT/T235 Asphalt binder drain-off

AGPT/T236 Asphalt particle loss

AGPT/T237 Binder Film Index