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ROAD MATERIALS BEST PRACTICE GUIDE

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Department of Infrastructure, Transport, Regional Development and Communications

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Australian Local Government Association

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Hon Michael McCormack MP

Deputy Prime Minister and Minister for Infrastructure, Transport and Regional Development

Foreword

I am pleased to support the Australian Road Research Board's suite of Best Practice Guides for Local Governments, which seek to expand Local Governments' understanding and capacity to manage road infrastructure.

Australia's Local Governments manage a majority of the road network, meaning capacity building for our Local Government road managers is vitally important. These Best Practice Guides will support national and international best practice in procurement, design and management of materials for road construction and for essential structures such as bridges.

As our nation's National Transport Research Organisation, the Australian Road Research Board has an important role in road management research and advice.

Road safety is a key priority of mine as the Federal Member for Riverina in regional New South Wales and as Minister for Infrastructure, Transport and Regional Development, especially as rural and regional roads currently account for a disproportionate level of road casualties.

With a user-friendly focus, these Guides aim to provide technical information in a simple-to-understand format that will be readily available and accessible for all road managers.

The Australian Government provided the Australian Road Research Board with $2.6 million as part of the 2019-20 Federal Budget, in recognition of the importance of road management.

This funding enabled ARRB to deliver these Best Practice Guides and a Portable Assessment Device project to assess in-situ road infrastructure conditions across a variety of national Local Government and council infrastructure networks.

I applaud the collaboration between ARRB and Local Government in the development of these Best Practice Guides, which will be an important road management resource.

Australian Government

Department of Infrastructure, Transport, Cities and Regional Development

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Acknowledgements

The authors greatly appreciate the contributions of the Local Government and other industry representatives who attended the Best Practice Guides workshops and provided initial feedback.

Acknowledgement is also given to the work of those involved in the development of this guide, including the following people:

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Summary

Local Governments fulfil a vital part in the provision and management of Australia's road assets and are responsible for over 80% of the Australian road network. The construction and management of these road assets is challenging considering the significant and diverse assets Local Governments are responsible for while often being under pressure to obtain better value from their budgets.

The purpose of the Best Practice Guide for Road Materials is to provide Local Government authorities, state and territory road agencies and other agencies responsible for the management of sealed and unsealed roads with guidelines on ways to best manage their road materials including the use of recycled materials, to achieve both a sustainable and cost-effective outcome.

The selection and testing of road materials is an integral part of pavement design, construction and ongoing in-service operation. Having a holistic understanding of road materials also provides a roads practitioner with the tools and abilities to produce and maintain a cost-effective, durable asset while maximising sustainable practices and road user safety.

The Guide provides a strong focus on the understanding and management of road materials and addresses the main topics of materials in relation to pavement design, construction, management and operation, which includes the following aspects:

1. Design: covers material components and property requirements, recycled materials, stabilisation methods and summaries of typical laboratory test methods relevant to road materials
2. Construction: includes sourcing, extraction and specification of materials in addition to stabilisation applications and construction, and field quality testing techniques
3. Asset management: covers the economic evaluations of alternative material choices and fit-for-purpose material techniques including the process of undertaking a material options assessment
4. Operation and maintenance: includes materials which can be utilised for rehabilitation and maintenance of assets to ensure cost-effective whole-of-life outcomes.

This Guide is part of a suite of guides including Sealed Roads, Unsealed Roads, and Bridge Management and the reader should refer to these for details on these topics.

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1.1 Background

Local Governments fulfil a vital part in the provision and management of Australia's road assets and are responsible for over 80% of the Australian road network. The construction and management of these road assets is challenging considering the significant and diverse assets Local Governments are responsible for while often being under pressure to obtain better value from their budgets.

The Best Practice Guide for Road Materials is one of a suite of guides developed for Local Government with the aim of expanding the understanding and capacity to manage road infrastructure. The guides will assist Local Government and other organisations that manage lower volume roads across Australia to manage their road assets effectively and fulfil their obligations to the community while also improving mobility and safety.

Each guide reflects current global best practice and information and has been tailored to Local Government requirements.

1.2 Road Materials

The selection and testing of road materials is an integral part of pavement design, construction and ongoing in-service operation. Having a holistic understanding of road materials also provides a roads practitioner with the tools and abilities to produce and maintain a cost-effective, durable asset while maximising sustainable practices and road user safety.

Understanding the various material components of a pavement in addition to the material property requirements are therefore two of the main components of this Guide. This knowledge is supplemented by various tools, techniques and alternatives which can be considered and implemented to reduce costs and increase sustainable outcomes while not jeopardising safety, performance and durability. This holistic materials approach includes:

- use of recycled materials as material alternatives or supplemental additives
- stabilisation methods and appropriate applications to improve material properties and performance
- explanation of formal laboratory test techniques which provide an understanding of a material
- sourcing, extraction and specification of locally available materials to increase the efficiency of sustainable sources
- field quality tests for material construction to ensure a compliant outcome
- fit-for-purpose use of local material including the process of undertaking a material option assessment
- materials used in maintenance and rehabilitation works to prolong the life of current assets.

1.3 Purpose and Scope of the Guide

The purpose of the Guide is to provide Local Government authorities, state and territory road agencies and other agencies responsible for the management of sealed and unsealed roads with guidelines on ways to manage their road materials, and to achieve both a sustainable and cost-effective outcome.

Throughout the guide, readers are directed to other publications and resources as these documents provide further detailed design and construction information as well as information suitable for the readers' jurisdictions.

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This Guide is part of a suite of guides including Sealed Roads, Unsealed Roads, and Bridge Management and the reader should refer to these for details on these topics.

1.4 Limitations

While this Guide presents best practice information for the use of road materials, it is important to understand that there are significant regional differences when it comes to road materials and the performance within a pavement, and therefore proven local practices should be maintained.

This publication is also not intended to replace any existing mandated design guidance, material specifications, operational instructions or other guidelines. It is intended to supplement these resources while providing a foundation of knowledge regarding road materials to a range of readers, both technical and non-technical.

2 Asset Management

2.1 Fit-for-purpose Material Techniques

A fit-for-purpose material has properties and performance characteristics which are directly suited to the chosen design application. The use of a fit-for-purpose material permits budget resources to be optimised over the entire life cycle of the pavement while continuing to meet a required level of service.

Understanding what parameters influence material performance and how to balance this with perhaps use of locally available materials which permit budget optimisation and meet level of service requirements is the key to a fit-for-purpose material.

How a pavement performs either loaded or unloaded throughout the intended design life depends on the following aspects:

- selection and use of appropriate pavement materials
- pavement structural design and drainage
- a construction process and achievement that meets the design intent.

Pavement design and construction achievement are controllable variables with a specification often provided to guide these processes.

The pavement material aspects of pavement performance are less controllable and dependent on a range of factors including:

- material properties related to structural stability
- intensity of traffic loads
- climate and environmental moisture regimes
- limited availability of material sources
- budget constraints
- no experience or prior knowledge of material performance.

A material risk assessment holistically considers these performance factors to provide an indication of the likely performance of a material within a specific design scenario.

Very low risk materials (generally assumed to be those that meet a specification) are expected to be well suited to the design application and loads and therefore have a very low risk of poor performance during the design period. Very high-risk materials (assumed to have some non-conforming specification attribute/s) are often expected to perform poorly in the design scenario. The result is that higher maintenance intervention is assumed to be required for the road to perform at a minimum level throughout the design period.

Depending on available material sources, a high-risk material may be unavoidable and, in these instances, risk management techniques can be implemented. The degree of risk analysis required will depend on the required level of service.

2.1.1 Material Information

The intrinsic properties of a material are the most important aspect of using fit-for-purpose pavement materials as they directly influence the performance of a pavement. The material properties also shape the risk profile of the pavement performance throughout the chosen design life.

Material source information includes the following:

- source geological composition and extraction requirements, commercial availability

- haulage distances and condition of public roads used as material haul roads
- material volumes required
- material properties to meet desired pavement performance outcome.

Material source information is important for undertaking a material options assessment. A low risk material may have large haulage distances and low required volume which may deem this option less fit-for-purpose compared to a nearby high required volume, high risk material.

It is important to understand all possible material options within a region and have a big picture understanding of source locations, source materials and volumes to be able to assess all fit-for-purpose options for any design scenario.

2.1.2 Understanding Loads and Loading Combinations

The performance of a material in a pavement system is determined by the material properties in conjunction with the following external loads:

- traffic loading
- operating moisture environment (and drainage)
- a combination of moisture and traffic.

As moisture in the pavement and traffic loads increase, the risk of pavement failure also increases (Figure 2.1).

As the risk increases, the required material properties become more stringent implying higher priority consideration scenarios. The consideration to use a high quality or standard material also becomes more appropriate at the highest risk levels, where management of a non-standard material becomes complex and expensive.

Moisture

How pavement materials perform under traffic load is determined by the pavement design and thickness of pavement materials but is also dependent on the moisture condition of the materials. This is especially true for lower quality and non-standard materials.

Moisture infiltration into a pavement comprising non-standard or marginal materials has been identified historically as the most detrimental factor influencing performance.

Rainfall Levels

Historically, non-standard materials used in areas with annual rainfall volumes above 500 mm/year have often been observed to perform worse than those in areas with less than 500 mm/year.

Moisture limiting design

Unlike traffic, the moisture in a pavement and the potential moisture condition can be controlled with appropriate drainage techniques. Being able to control the moisture aspect of a pavement can therefore allow a larger range of materials to be appropriate to the required application.

Design considerations which limit moisture infiltration and create a drier environment for the road pavement to decrease material risk include:

- sealing shoulders to at least 1.0 m

- deepening side and table drains
- raising embankments above potential flood levels
- providing adequate pavement crossfall on both sealed and unsealed wearing surfaces.

Traffic

The traffic load on a road pavement determines a range of pavement characteristics which in turn determine the purpose for which a chosen pavement material must be fit for purpose. These characteristics also influence whole-of-life cost implications. Pavement characteristics determined by traffic level include the following:

- pavement structural design
- road importance
- required performance criteria
- functionality requirements.

Traffic, in most design scenarios, is a design variable which is unable to be controlled or limited.

Design Traffic

Traffic volume

- *both passenger car and truck traffic*
- *determines the road importance and level of service of the pavement*

Heavy vehicle component

- *determines the design traffic*

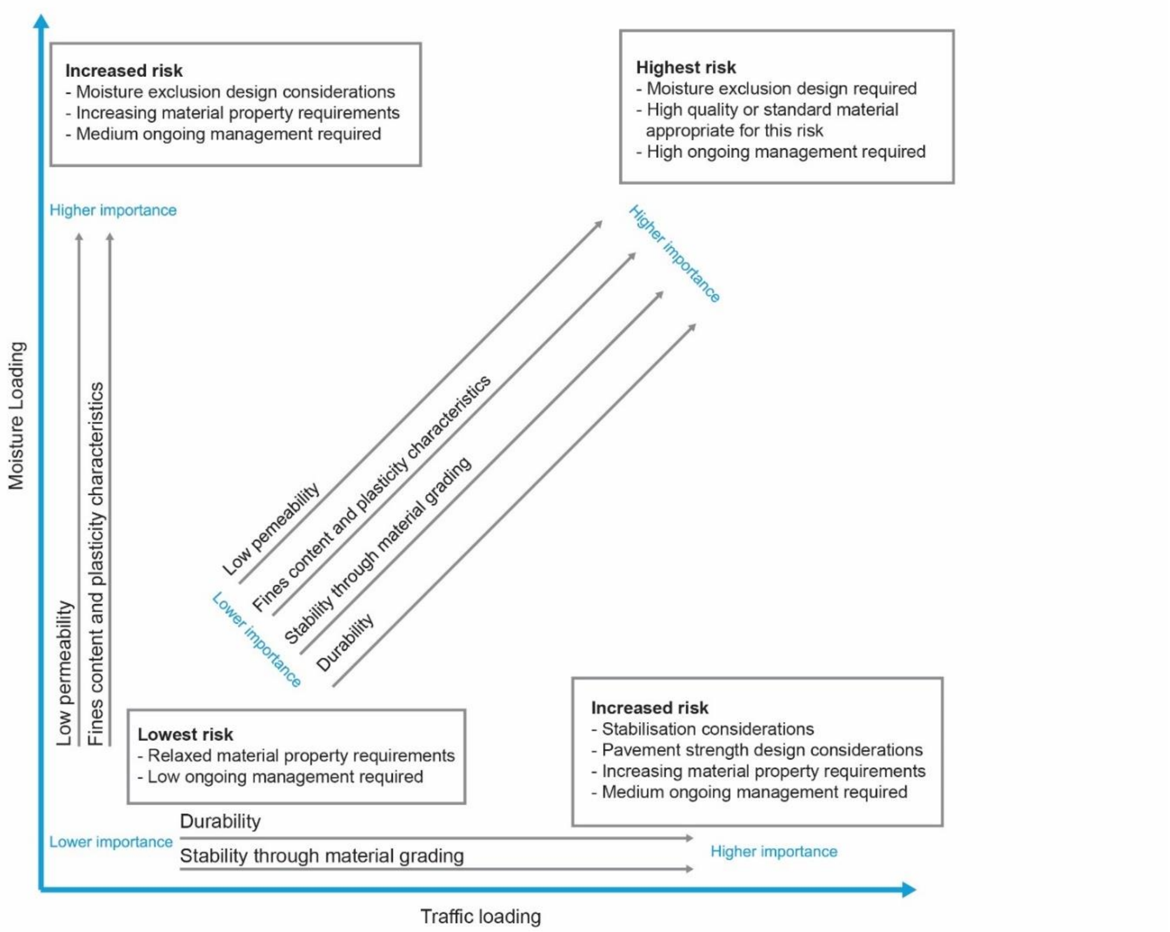
Traffic growth

- *determines the design traffic over a chosen design life period*

Seasonal traffic variations

- *due to harvesting calendars or other agricultural and industry cycles*
- *account for worst case traffic levels*
- *account for moisture conditions during periods of heaviest traffic loading*

Figure 2.1: External loads, failure risk and material properties



Source: Rice and Toole (2019).

2.1.3 Understanding the Material

Experience has shown that in many cases practitioners rely on local knowledge when assessing the suitability of various pavement materials in borrow pits rather than obtaining laboratory tests to determine the soil/aggregate properties of materials used. Commonly the lack of material assessments is associated with depletion of local experience and understanding of material properties in addition to unavailability of materials laboratories and consideration of costs.

In most cases it may be prudent for a local authority in a rural and/or remote location to invest in basic laboratory equipment and application of testing. Whilst local experience (if available) to assess the performance of pit/quarry materials may suffice, a better approach is to conduct some practical testing to gain an objective measure and understanding of local materials available.

By obtaining a better understanding of the properties of local materials, often of marginal quality, strengths and weaknesses can be determined and the possible measures that need to be taken to minimise any adverse effects.

Alternatives to formal laboratory testing

To assist practitioners to gain a better understanding of the properties of local materials, the following section outlines simple and practical methods to carry out testing of local materials that should provide a better assessment of soil properties than using subjective assessments. These results can then be compared to the specifications or performance attributes to assess the suitability of a material for a given application.

Material type

The following checklist can be used to help identify different material types and provide a characterisation description.

Material Type

Soil test check list

1. *No reaction to the shaking test, a tough thread that dries out slowly, and a crusty residue that is hard to remove and stains the hand suggests the soil is clay.*
2. *Rapid reaction to the shaking test, a weak or crumbly thread and powdery residue that washes easily from the hands without staining indicates the soil is silt.*
3. *Intermediate or conflicting reaction to the hand test indicates silt as well as clay.*
4. *Enough clay to soil the hands when a sample is kneaded but not enough to form a lump indicates sand or gravel with silt fines.*
5. *Dusty or gritty fines indicate sand or gravel with silt fines.*
6. *When water is added it soaks in immediately without making mud – indicates clean sands and gravels.*

Source: After AS 1726 (Standards Australia 1993) and Geological Society Engineering Group (1990).

Gradation

For a dry granular soil spread a sample on a flat surface. Use a piece of cardboard as a rake to sort the larger soil particles to one side (Figure 2.2a).

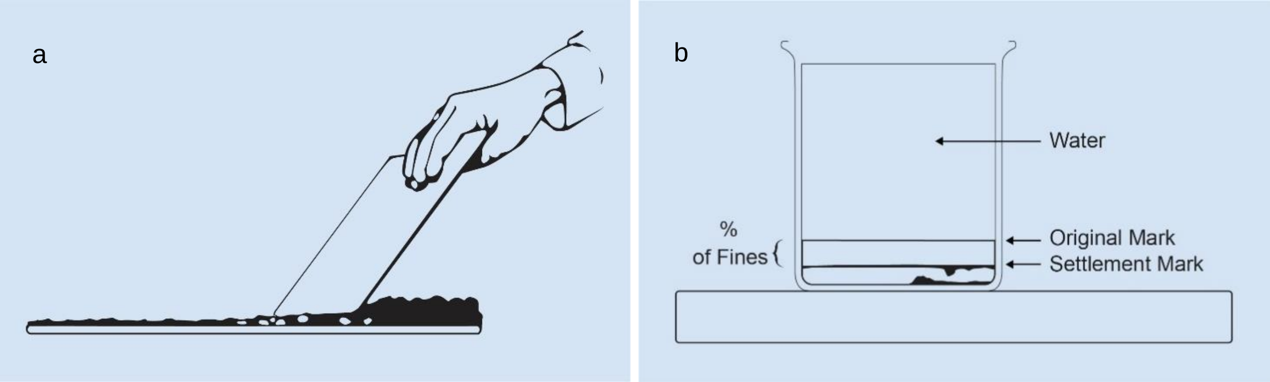
1. Estimate the percentage of particles larger than 6 mm (fine gravel) and the percentage of fines (sands, silts and clay).
2. Estimate whether the larger particles have a uniform size (poorly graded) or large, medium and small size (well-graded).

To find the percentage of fines put 3 mm of water into a clear glass jar and then add enough soil to fill the glass one-quarter full.

1. Add water until the soil is just covered. Mark this level with a rubber band.
2. Fill the jar three-quarters full with water and stir the mixture vigorously.
3. Allow the mixture to settle for 2 minutes and mark the height of the soil that has settled out (Figure 2.2b).

The difference between the two marks represents the percentage of fines.

Figure 2.2: Assessing material gradings (a) coarse material assessment (b) fine material assessment



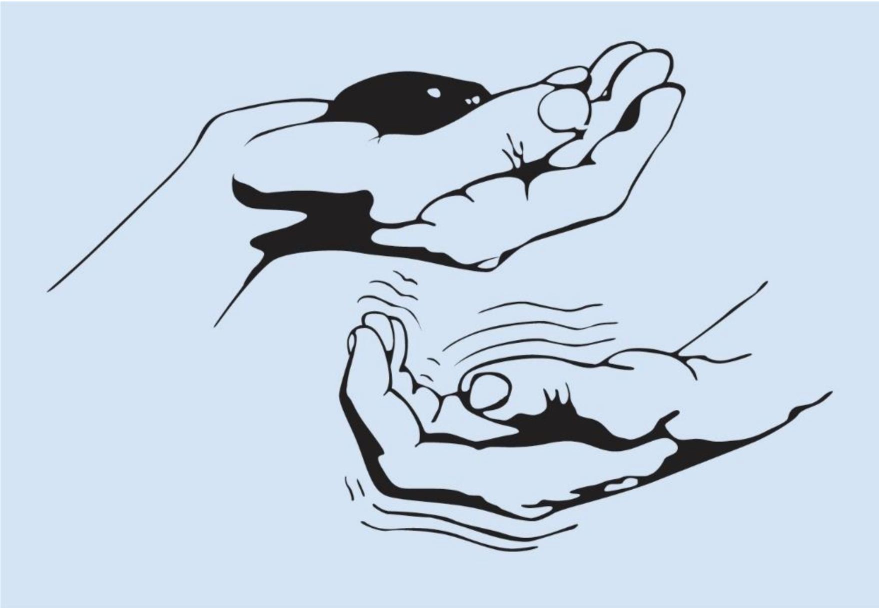
Plasticity and fine-grained material characterisation

The shaking test can be used as a simple way to estimate the plasticity of a material and if the fine grained component is a silt or clay.

1. Pick up a lump of fine-grained soil and knead it together, working out as many large grained particles as possible.
2. Add water gradually and knead the soil until it begins to get sticky.
3. Hold the ball of soil in the palm of the hand and tap the back of that hand with the fingers of the other hand (Figure 2.3).

If the ball gets shiny and wet on the surface it is mostly fine sand or silt. Clays have little or no reaction to this test and simply get messy.

Figure 2.3: The shaking test for plasticity assessment



<u>Toughness test</u>

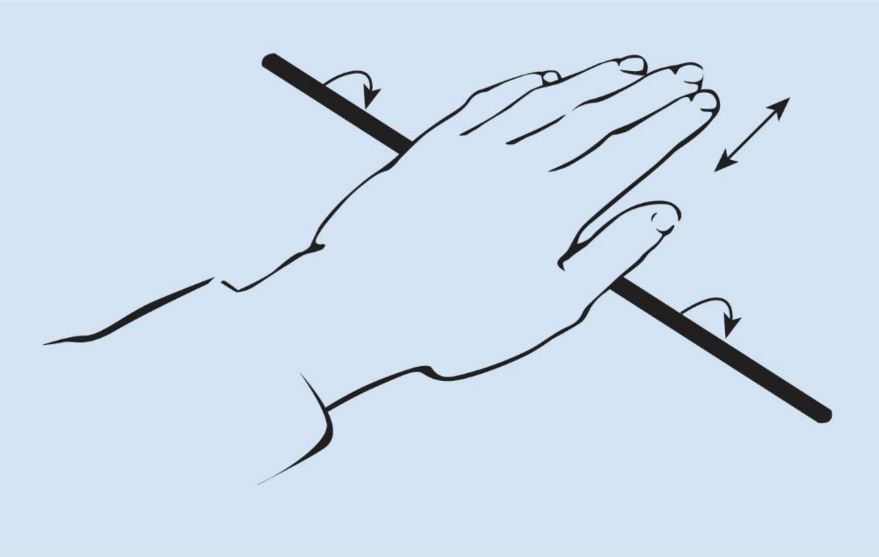
The toughness test can help identify the type of materials and if the fine grained component is a silt or a clay.

1. Take about half the ball of soil from the shaking test and knead it between the thumb and forefingers to get it to dry out.
2. Attempt to roll the soil sample into a 3 mm thread or 'worm' (Figure 2.4).

a. If the worm cannot be formed at all the soil is definitely a silt or fine sand.

b. Highly plastic soil takes a long time to dry out. It gets hard and waxy and considerable pressure is required to form a worm that just breaks at 3 mm.

Figure 2.4: Toughness test



Take half of the ball of soil from the shaking test and knead it into a ball. Set it aside to air and dry. When the soil is dry, crush it and select a jagged pointy fragment. Try to crush this fragment between thumb and forefinger. A silt will turn to powder with little effort. A clay will be like a rock and almost impossible to crush with the fingers.

<u>Hand washing</u>

After handling silts and sands on the fingers will feel dusty and rubbing the fingers together will almost clean them. Water flowing gently from a tap will rinse off the soil.

When clays are handled a crusty stain will form on the fingers that cannot be rubbed off when dry. Hands must be rubbed together under water to cleanse them.

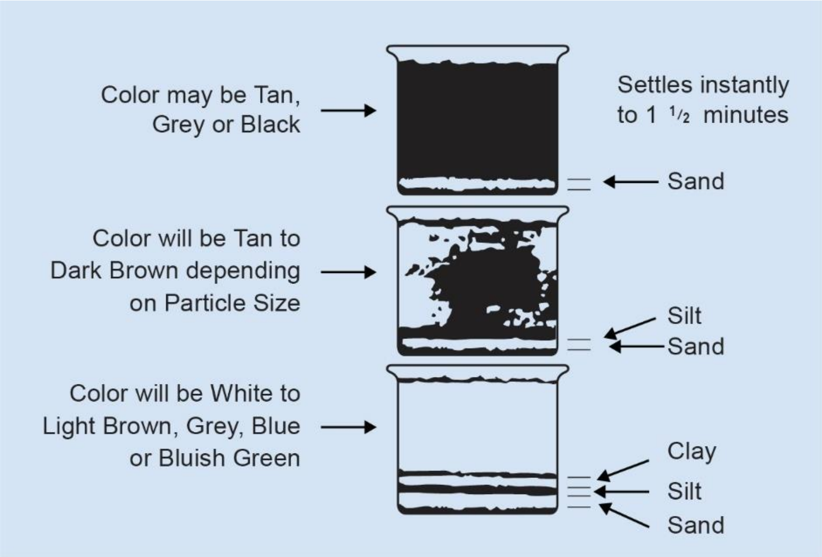
Dispersion test

In addition to the field tests described above, the dispersion test can be used to determine percentages of soil grain sizes as well as how difficult it will be to compact the soil. All that is needed is a clear glass, water, and a representative sample of the soil to be tested (Figure 2.5).

1. Fill the glass about one-third full with the material.
2. Fill the container with water to about 15 mm from the top.
3. Stir the mixture well and observe how the material settles.
4. The material will settle in three distinct layers:
   a. The sand will be at the bottom, silt next and finally clay.
   b. Besides showing the various groups the results will show whether the soil is well-graded.
   c. Although the silt and clay particles are smaller than the eye can see, gradation changes can be observed by colour differences. Also the longer it takes to settle the smaller the particles.

There are several things that can be learnt from a dispersion test. It will show the basic materials and gradation of each and the settling time will indicate the fineness of the particles. In most cases a single particle size (poor gradation) and small particle size will mean more difficult compaction than a mix where there is good gradation of all particle sizes.

Figure 2.5: Dispersion test



Material strength

Table 2.1 and Table 2.2 present descriptions of field tests which can be undertaken to assess the strength of a cohesive material (material containing clay) or the strength of rocks and hardened material.

Table 2.1: Strength of cohesive soils

Descriptive term	Undrained shear (kPa)	Approximate CBR strength (%)	Field test
Very soft	< 12	< 1	Exudes between fingers when squeezed in hand.
Soft	12–25	1	Easily penetrated by thumb. Moulded by light finger pressure.
Firm	25–50	2–4	Penetrated by thumb with effort. Moulded by strong finger pressure.
Stiff	50–100	4–7	Indented by thumb. Cannot be moulded by fingers.
Very stiff	100–200	7–10	Indented by thumbnail. Penetrated by knife to about 15 mm.
Hard	> 200	> 10	Can be indented with difficulty by thumbnail.

Source: AS 1726 (Standards Australia 2017).

Table 2.2: Strength of rock fragments and hardened materials

Descriptive term	Point load index (MPa)	Field test
Extremely low	< 0.03	Easily broken by hand to a material with soil properties.
Very low	0.03–0.1	Broken by leaning on sample with hammer. Crumbles under firm blows with a pick. Can be peeled with a knife.
Low	0.1–0.3	Broken in hand by hitting with hammer. Easily scored with knife. Sharp edges may be friable.
Medium	0.3–1.0	Easily scored with a knife. Broken against solid object with hammer.
High	1–3	Difficult to break against solid object with hammer, rock rings under hammer.
Very high	3–10	Requires more than one blow of hammer to fracture sample, rock rings under hammer.
Extremely high	> 10	Sample requires many blows with a hammer.

Source: AS 1726 (Standards Australia 2017), and Geological Society Engineering Group (1990).

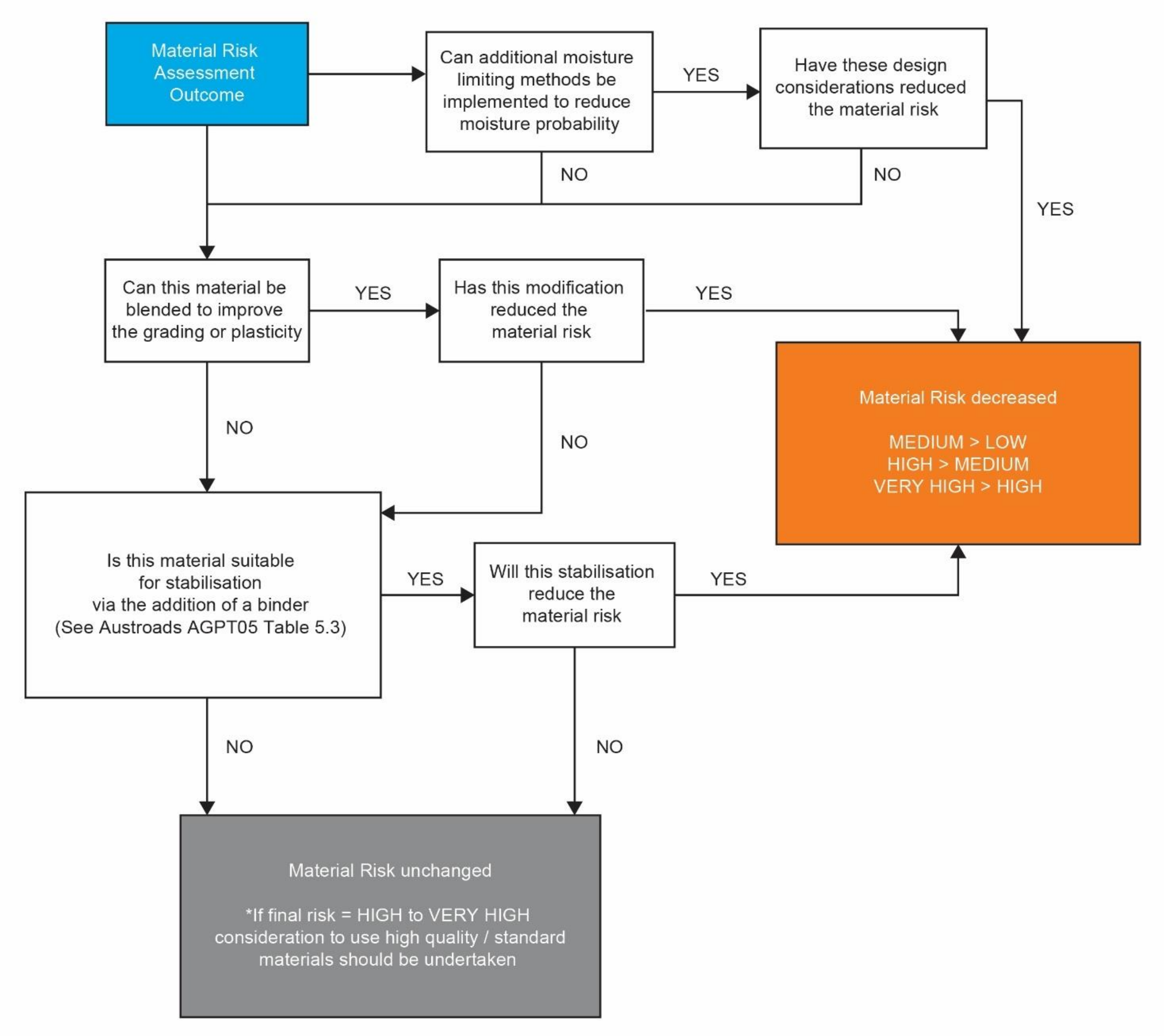
2.1.4 Reducing Risk

Risk management techniques may reduce the risk of poor pavement performance by altering material properties, controlling moisture, or ensuring good construction and ongoing maintenance practices.

When considering any type of risk management technique an assessment should be made which compares the cost of undertaking the risk management with the expected benefits or reductions in risk caused by applying the chosen method.

To assess the effect of risk management techniques, a risk assessment should be undertaken for both scenarios to identify if the chosen techniques will in fact change the risk outcome. Figure 2.6 presents a general risk reduction options process.

Figure 2.6: Risk reduction options process



Source: Rice and Toole (2019).

Material management

Material risk management options may consider stabilisation to alter material properties or character in order to decrease risk and ultimately increase how fit it is for a specific design purpose.

The performance of a material is governed by the in-service traffic and climatic environment, in addition to the geological nature of the material itself (Austroads 2019). It is a combination of these factors in conjunction with an understanding of the whole-of-life costs of a specific design scenario which ultimately determine the most appropriate stabilisation option to be implemented.

Before selecting the appropriate stabilisation or modification option for a specific scenario, there needs to be an understanding of what the properties of the material in question are (grading, plasticity and strength) and which of these properties needs to be corrected to ensure ongoing performance.

Moisture management

Unlike traffic, the moisture in a pavement and the potential moisture condition can generally be controlled. Being able to control the moisture aspect of a pavement can therefore allow a larger range of materials to be appropriate to the required application.

However control of moisture may not always be possible e.g. in terms of areas of flooding which in this case material selection is based upon resistance to moisture sensitivity i.e. loss of strength and erosion.

Incorporating additional moisture limiting factors through design considerations such as crossfall and sealed shoulders can also be implemented through the management options assessment in order to reduce the moisture probability to a level that may result in a lower risk assessment category and possibly a lower material risk.

The performance of a fit-for-purpose material is directly related to keeping the pavement structure as dry as possible.

Good practice techniques

Good practice techniques have a positive effect of ensuring a fit-for-purpose use of available materials. Employing good practice techniques ensures that the risk profile of a design scenario is appropriate and consistent throughout design life. These techniques do not necessarily decrease risk but ensure operating conditions are favourable and close to that assumed during design and risk assessment.

Good practice techniques should be undertaken regardless of the road importance and represent the minimum requirements to ensure correct construction and ongoing management of a pavement.

Construction management

Construction management may have a positive or negative impact on a fit-for-purpose material as the material may change due to handling, mixing or placing methods. To maximise fit-for-purpose performance the following good practice techniques should be implemented during construction:

- correct material mixing, drying and placement methods
- scheduling of earthworks construction during dry months
- selection and implementation of construction drainage
- compaction to specification
- ample compaction verification
- sufficient dry-back of pavement layers before placement of successive layers or seal
- ensuring uniformity throughout the construction process.

The density benefits of compaction with specific machinery needs to be assessed against the risk of material breakdown, and a closely monitored compaction trial may be required to choose appropriate construction equipment to minimise changes in a material.

Ongoing maintenance

Ongoing maintenance which is appropriately timed and designed will ensure a consistent operating environmental for fit-for-purpose materials through the chosen design period. These works should include the following as a minimum:

- free flowing, working drainage with no silt build up or erosion
- no pavement cracks left unsealed when above medium severity
- no encroaching grass and/or vegetation on shoulders

- allowances for future seal rejuvenation.

The predominant path of moisture entry into a pavement is through the unsealed shoulder and through cracks in the wearing course. Regular surface seal and shoulder maintenance will help in maintaining the optimum fit-for-purpose operating environment.

2.1.5 Materials Options Assessment

A materials options assessment allows different material scenarios to be compared. Material options assessment considers the use of other sources, risk reduction options or a combination of both where available. The steps for undertaking a materials options assessment are included in Appendix C.

3 Design

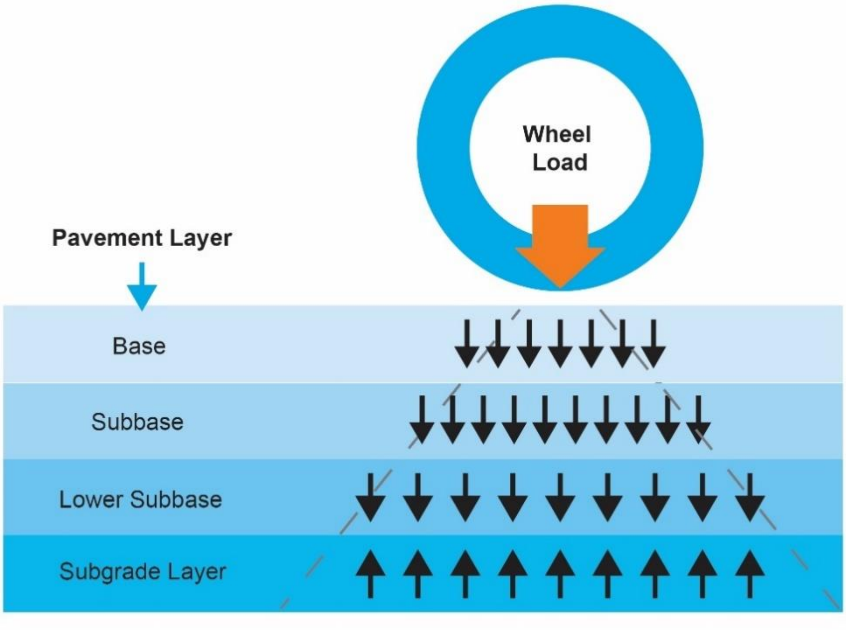
3.1 Material Components of a Pavement

A pavement structure is made up of various layers of materials (Table 3.1). Each layer of the pavement spreads the imposed traffic load to the underlying layers. The stress imposed by the traffic load is highest at the surface and lowest at the subgrade level. The quality of pavement materials is highest at the surface where load induced stresses are higher and decrease to lesser quality materials in the lower layers where stresses have reduced (Figure 3.1).

Table 3.1: Pavement layers and materials

Pavement layer	Material options
Wearing course Section 3.2	• Hot mix asphalt • Bituminous spray seal • Bituminous slurry seal (micro-surfacing) • Unsealed
Basecourse Section 3.3	• Hot mix asphalt intermediate course or basecourse • Concrete • Unbound granular • Modified unbound granular • Lightly bound or bound stabilised granular
Subbase Section 3.3	• Concrete • Unbound granular • Modified unbound granular • Lightly bound or bound stabilised granular
Subgrade Section 3.4	• In situ granular • Stabilised granular

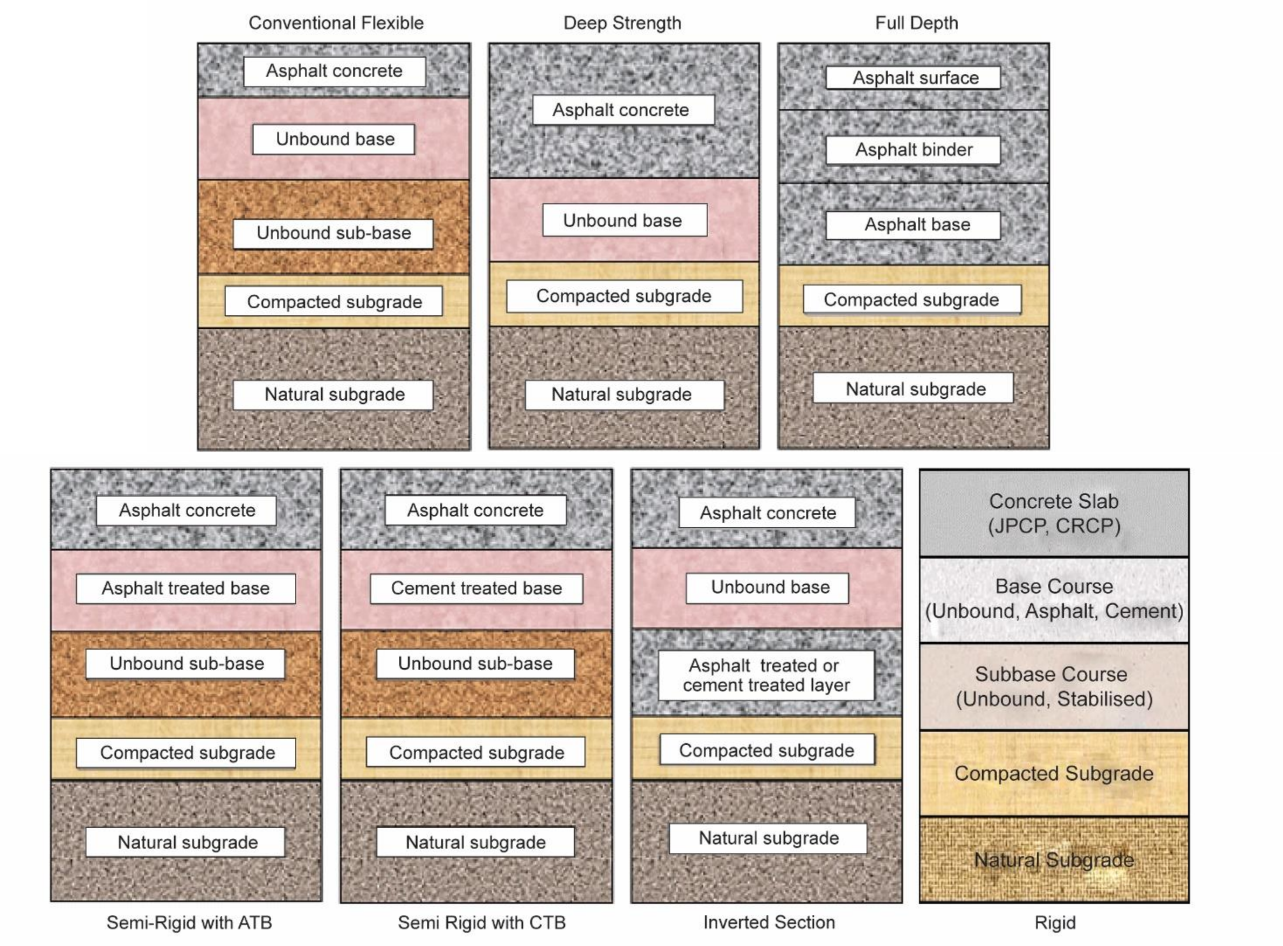
Figure 3.1: Pavement layers and load spreading characteristics



Source: adapted from SANRAL (2013)

There are various types of pavement structures which utilise different material types at different layers of the pavement system. Choosing a suitable pavement type depends on design traffic, functionality and serviceability requirements, budget constraints, material availability, local climatic conditions and a range of other factors. Figure 3.2 presents common sealed pavement types used throughout Australia.

Figure 3.2: Common sealed pavement types in Australia



Source: Adapted from SANRAL (2013) and AGPT04B-14 (Austroads 2014).

3.2 Wearing Course

The surfacing of a pavement structure is also referred to as a wearing course. It is the very top of a pavement structure and can either be made of a hot mix asphalt, a spray seal, or it may be unsealed gravel or soil material.

Wearing Course Purpose

- *provide a safe, economical and durable all-weather surface*
- *protect lower layers of a pavement from moisture*
- *provide surface characteristics to reflect community expectations*
- *provide a dust-free surface*
- *extend the life of the pavement*
- *reduce vehicle operating and maintenance costs.*

3.2.1 Hot Mix Asphalt Surfacing

A hot mix asphalt (HMA) is a blend of bituminous binder, rock aggregates, and fillers. The proportion of each of these components in a blend is designed through a method called volumetric design.

There are different types of HMA surfacing mixes depending on the type of binder and the grading of aggregate used. Different types of surfacing HMA have different purposes and provided different functionality characteristics.

A HMA surfacing is designed to provide a durable wearing course which will not rut or crack with the application of traffic or environmental loads such as heat, cold or moisture.

Hot mix asphalt mix design

Undertaking a HMA mix design determines the optimised proportions of each component which make up the final mix (Table 3.2). The components include:

- bituminous binder
- fine and coarse aggregates
- filler material
- mix voids.

In Australia, the Marshall mix design method is used to optimise the proportions of each of the above components in order to achieve the desired structural performance, durability, functionality and workability characteristics appropriate to the intended application whilst also being economical. These proportions are called mix volumetrics.

Table 3.2: Volumetric properties of a HMA mix design

Volumetric property	Description	Determined by	Comments
Binder content	The amount of binder chosen for a mix	• HMA mix type	• Aggregate absorption will decrease mix binder content • Unabsorbed binder termed the effective binder content
Voids in mineral aggregate (VMA)	The voids within the aggregate/filler matrix which are either filled with air or binder	• Aggregate and filler grading • Stone shapes • Surface texture • Packing characteristics	• Low VMA: mix may flush or bleed easily • High VMA: mix may require higher binder content (more expensive)
Voids filled with bitumen (VFB)	The proportion of VMA which is filled with binder only	• VMA • Aggregate absorption • Binder content	• Low VFB: reduced durability and fatigue resistance • High VFB: reduced rut resistance
Air voids	The proportion of VMA which is filled with air only	• VMA • Degree of compaction • Binder content	• Influences mix stiffness, workability and fatigue resistance • Determines functionality characteristics such as low noise

Source: Austroads (2014).

Hot mix asphalt binder

A bituminous binder or bituminous material also referred to as bitumen is a by-product of the oil refinery process and is typically black or dark brown in colour. It is highly viscous (i.e. a solid) at room temperature and becomes much less viscous (i.e. a liquid) when heated. It provides both adhesive properties to the aggregate mix and waterproofing properties to the combined mix.

The binder within a HMA holds the mix constituents together and also prevents the mix from flowing and segregating. Binders may also be modified through the addition of polymers or other additives.

Hot mix asphalt surfacing binder types

Different binder types have different viscosity characteristics which determine performance under traffic and environmental loads. This also determines the most appropriate type of binder for different pavement applications and mix types.

Binder types are classified by class which are based on the viscosity of the binder at a standard temperature of 60 °C. Table 3.3 presents typical unmodified wearing course binders used throughout Australia.

Table 3.3: Typical unmodified HMA wearing course binder classes

Grade designation	Abbreviated name	Typical viscosity 60 °C (Pa.s)*	Typical uses
Class 170	C170	140–200	• Light and medium traffic • Residential streets, car parks and foot traffic • Workable and durable mixes • Cooler climates • Mixes containing reclaimed asphalt pavement (RAP)
Class 320	C320	260–380	• General purpose for a range of applications • Light to heavy traffic • Alternative to C170 in warmer climates for low traffic • Heavily trafficked intersections • Areas of slow-moving traffic
Class 450	C450	750–1150*	• Less common • Heavy traffic applications • Warmer climates
Class 600	C600	500–700	• Heavy duty or industrial applications • Critical traffic applications at heavy traffic levels

Notes:
** – Viscosity after rolling thin film oven treatment.*
Traffic definition:
- *Light – free flowing traffic < 100 heavy vehicles/lane/day (hv/l/day)*
- *Medium – free flowing 100 < hv/l/day < 500 or slow moving and stop/start <100 hv/l/day*
- *Heavy – free flowing 500 < hv/l/day < 1000 or slow moving and stop/start 100 < hv/l/day < 500*
- *Very heavy – free flowing > 1000 hv/l/day or slow moving and stop/start > 500 hv/l/day*

Source: AGPT4F-17 (Austroads 2017c).

Polymer modifiers

Polymer modified binders (PMBs) are binders enhanced through the addition of a manufactured synthetic polymer which typically increases viscosity. PMBs can be used in heavy traffic applications and high stress locations (i.e. high lateral stresses on the pavement surface such as braking and turning at intersections, roundabouts etc.) in order to enhance both rutting and transverse shear resistance and fatigue properties of HMA. PMBs can also increase deformation resistance in high temperature applications.

Unlike unmodified binders which use viscosity to designate a class, PMBs used for HMA are described using an ‘A’ prefix followed by an arbitrary two-digit code and finally a letter to designate the type of polymer used to modify the binder. Table 3.4 presents typical polymer modifier binder classes used throughout Australia.

Table 3.4: Typical polymer modified binder classes

PMB class	Type of polymer	Modification type	Typical uses
A10E, A15E, A2, A25E	Elastomeric	High (A10E) through to low (A25E) elastomeric modification	• Improved DGA fatigue and rut resistance • Improved OGA and SMA durability
A35P	Plastomeric	High plastomeric modification	• High rut resistance in heavy duty applications
A27RF	Rubber	Dry process	• High fatigue resistance for reflection crack areas

Source: AGPT04B-14 (Austroads 2014).

Hot mix asphalt aggregates

The aggregate within a HMA provides the mix with the stability and strength to withstand the imposed traffic loads and correctly spread the loads to the underlying pavement layers through aggregate interlock and intrinsic hardness of the source rock. Aggregates also provide wearing course skid resistance properties through resistance to polishing.

The particle grading is the range of particle sizes of aggregate material and is designed based on the type of HMA mix chosen. The fine fraction is any particle between 0.075 mm and 4.25 mm in size, while the coarse fractions are coarser than 4.25 mm. Particles finer than 0.075 mm are considered filler material.

Aggregates for HMA may comprise:

- crushed and screened quarry products i.e. aggregates and sands
- natural sands and gravels
- recycled materials e.g. comingled glass.

Different aggregate properties are often dependent on the source of the aggregate and influence the performance and strength of the overall HMA mix (Table 3.5). Rock source also determines the properties of an aggregate.

More information on the influence of rock sources on aggregate properties can be found in Austroads Guide to Pavement Technology Part 4B (2014).

Table 3.5: Important aggregate properties

Property	Implications
Particle grading	Determines HMA type and mix stability
Particle shape and surface texture	Influences stability and workability; rough surface, angular, cubic particles increase strength
Polishing resistance	Influences skid resistance
Abrasion resistance	Influences particle interlock and skid resistance
Durability	Influences decomposition of aggregate and performance under traffic and environmental loads
Strength	Influences particle resistance to high stress loads, important for wearing course layers
Cleanliness	Influences overall HMA mix stability and strength
Absorption	Influences binder and water absorption. Important factor for mix design
Affinity for bitumen	Influences how well binder will adhere to the aggregate. Influences stripping resistance of HMA. Can be altered using hydrated lime filler.

Source: AGPT04B-14 (Austroads 2014).

Nominal size

The nominal aggregate size of a HMA is rounded to the smallest sieve size which all aggregate particles pass through.

Common nominal sizes for asphalt mixes and corresponding sieve sizes are shown in Table 3.6.

Table 3.6: Common nominal sizes for asphalt mixes and corresponding sieve size

Nominal size of AC	100% aggregate passing sieve
20 mm	26.5 mm
14 mm	19 mm
10 mm	13.2 mm
7 mm	9.5 mm
5 mm	6.5 mm

Different nominal sizes of aggregate provide different performance and functionality characteristics.

Filler

Filler material is any particle smaller than 0.075 mm and is incorporated into a HMA to increase stiffness and strength by reducing mix flow. It can also increase the affinity to bitumen of the coarse and fine aggregate but may also reduce workability. Filler material fills voids within the aggregate skeleton and can decrease the amount of binder needed.

The amount of filler will depend on the aggregate grading and surface texture in addition to the filler properties such as particle size, surface areas and density. Common filler materials are presented in Table 3.7.

Table 3.7: Common HMA filler materials

Filler type	Advantages	Disadvantages
Hydrated lime	• Readily available in small amounts (bags) • Increases aggregate affinity to bitumen • High surface area (very fine)	• Expensive • Reduces workability • Less available in bulk amounts
Portland cement	• Readily available in small and bulk amounts	• Expensive • Difficult to handle
Ground limestone	• Inexpensive • Easy to handle	• Restricted availability • Inconsistent size
Cement kiln dust	• Inexpensive • Industry by-product	• Very restricted availability • Inconsistent material properties
Fly ash	• Inexpensive • Easy to handle	• Very restricted availability • Inconsistent material properties • Can harden binder
Ground slag	• Inexpensive • Industry by-product	• Inconsistent material properties
Baghouse dust (created by asphalt manufacture process from mix aggregate)	• Inexpensive • Readily available from asphalt plant production	• Inconsistent material properties

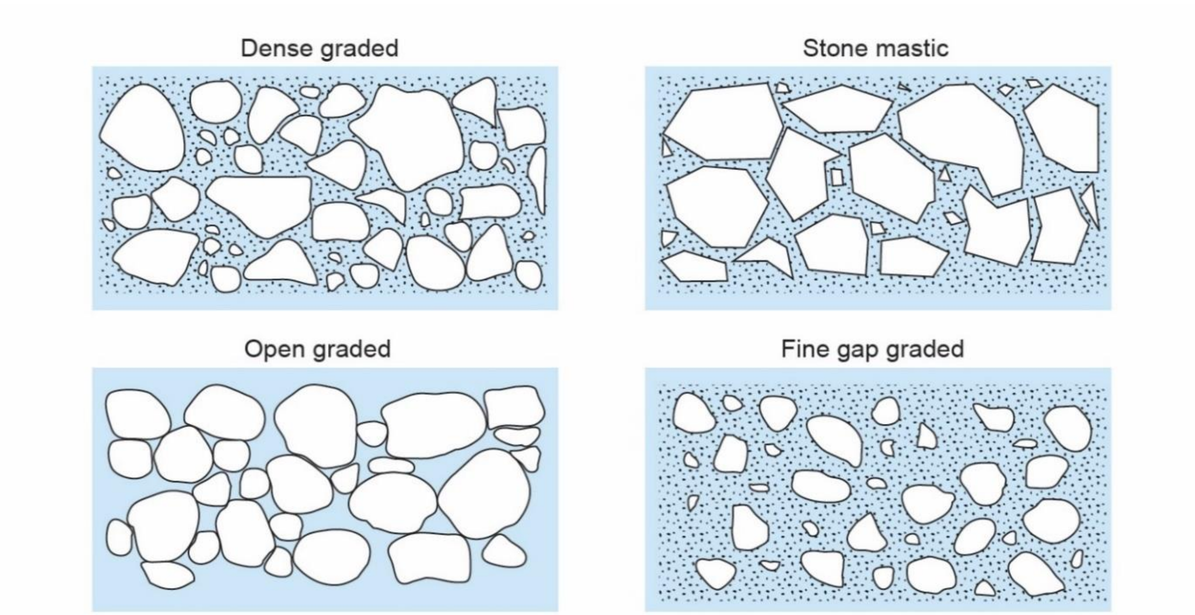
Source: AGPT04B-14 (Austroads 2014).

Hot mix asphalt surfacing mix types

There are different types of HMA surfacing mixes depending on the type of binder and the grading of aggregate used. Different types of surfacing HMA have different purposes and provide different functionality characteristics. Figure 3.3 presents a schematic of the different asphalt surfacing types, and Source: Adapted from AGPT04B-14 (Austroads 2014).

Table 3.8 provides a summary of each.

Figure 3.3: Schematic diagram of different asphalt surfacing types



Source: Adapted from AGPT04B-14 (Austroads 2014).

Table 3.8: Summary of HMA surfacing mix types

Asphalt mix type	Abbr.	Mixture characteristics	Typical nominal size	Typical layer thickness	Load applications
Dense graded asphalt	DGA	• Well graded aggregate • Structurally strong layer • All rounder	7 mm	20–25 mm	• Light traffic • Residential streets and secondary collectors
			10 mm	25–35 mm	• Light to medium • Primary collectors and arterials
			14 mm	35–45 mm	• Medium to heavy • Freeways and urban highways
Open graded asphalt	OGA	• Coarse aggregate with high air voids • Lowest noise • Good drainage of surface water • Good skid resistance	10 mm	25–30 mm	• Medium to heavy • Freeways and urban highways
			14 mm	30–40 mm	• Medium to heavy • Freeways and urban highways
Stone mastic asphalt	SMA	• Coarse aggregate and filler • Good rut resistance • Reduces reflective cracking • Good skid resistance • Good durability • Low noise	10 mm 14 mm	25–30 mm 30–40 mm	• Light to heavy • Secondary and primary collectors • Arterials • Freeways and urban highways • Not intended for intersections or high stress locations
Fine gap graded asphalt	FGGA	• Fine aggregate and filler • High workability • Economical • Long lasting	7 mm 10 mm	20–25 mm 25–35 mm	• Light • Residential streets and secondary collectors

3.2.2 Sprayed Seals

A sprayed seal consists of a thin layer of bituminous binder that is sprayed as a liquid, and covered with a layer of crushed aggregate (Figure 3.4). Sprayed seals may be applied onto a pavement basecourse, or as a 'reseal' over an existing bituminous surface.

A sprayed seal is a very cost-effective treatment, and is the most frequently used pavement surfacing treatment in regional areas. Sprayed seals may be used where asphalt production is not available, or located too far away.

Figure 3.4: Sprayed seal construction

The functionality of a spray seal surface is different to that of an asphalt surface especially in terms of structural strength, shear stress resistance and road noise. They are not usually suited for heavily trafficked intersections or built-up urban areas.

There are a number of spray seal types which are suited to different design scenarios and operating conditions. Figure 3.5 demonstrates the difference between a single seal and double seal.

Common Spray Seal Types

Single/single

- *Most common type*
- *One application of sprayed binder with one layer of single sized aggregate*
- *Low traffic, low stress environments*

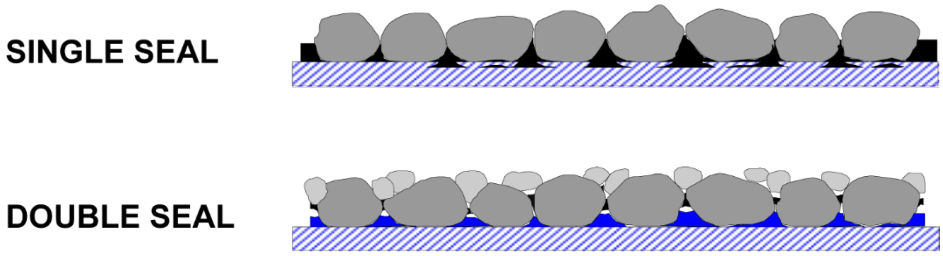
Single/double

- *A single application of sprayed binder and a double application of aggregate*

Double/Double

- *One application of sprayed binder with one layer of aggregate followed by a second application of binder and a final layer or slightly smaller aggregate*
  - *14/7 mm or 14/5 mm double seal implies a 14 mm first layer followed by a 7 mm or 5 mm second interlocking layer*

Figure 3.5: Single seal and double seal cross-sections



Source: Adapted from SANRAL (2013)

Prime

A prime is an application of specifically formulated bitumen emulsion or cutback bitumen sprayed over a prepared basecourse, without a cover aggregate. The function of the prime is to penetrate into the underlying granular base to increase the bond between the overlying bituminous layer and the underlying granular material, in addition to assisting with waterproofing. A prime should not be trafficked, and is applied before the overlying hot mix asphalt or a spray seal.

Primer seal

A primer seal is a prime with small size (usually less than 10 mm) aggregate applied. The purpose of a primer seal is to provide a temporary bituminous wearing surface until the final wearing course can be applied which may be some months afterwards.

Initial seal

An initial seal is an application of a sprayed seal directly to a prepared basecourse that has not been primed. Initial seals adhere to the base materials and provide a wearing course for traffic, however it can be expected to have a higher risk of failure and potentially shorter life span than a prime covered with a sprayed seal.

Special purpose seals

Special purpose seals include:

- fibre reinforced seals (FRS): reinforcement from chopped fibres placed onto sprayed binder
- geotextile reinforced seals (GRS): reinforcement from a geotextile layer to resist cracking
- high stress seals (HSS1 and HSS2): uses light to medium modified PMBs to accommodate moderate traffic stresses
- extreme stress seals (XSS): uses medium to heavily modified PMBs to accommodate extreme traffic stresses
- strain alleviating membrane (SAM): uses heavily modified PMB to resist cracking
- strain alleviating membrane interlayer (SAMI): interlayer between asphalt layers – not traffickable.

More information on special purpose seals can be found in the *Sealed Roads: Best Practice Guide*.

Sprayed seal binder

Bituminous binders that are by-products of the oil refinery process are used for sprayed seals.

Sprayed Seal Binders

- ***Conventional bitumen***
  - *C170, C240, C320*
- ***Multigrade bitumen***
  - *M500*
- ***Polymer modified binder***
  - *S10E, S15E, S20E, S25E, S35E (elastomeric polymers)*
  - *S15RF, S18RF, S45R (crumb rubber)*
- ***Emulsions***
  - Manufactured to AS 1160:1996 or proprietary grades

Descriptions of the uses of conventional binders and PMBs are listed in Table 3.9 and Table 3.10, respectively. Emulsion versions of these binders may be used, alongside proprietary grades detailed in AAPA Advisory Note 20 (AAPA 2015).

Table 3.9: Typical conventional binder classes for sprayed seals

Binder	Typical viscosity 60 °C (Pa.s)	Attributes and typical uses
C170	140 to 200	• Light traffic / low stress • Cool climates • Common and versatile
C240	190 to 280	• Light traffic / low stress • Warmer climates
C320	260 to 380	• Light traffic / low stress • Warm to hot climates

Source: AGPT04F-17 (Austroads 2017c), AS 2008: 2013.

Table 3.10: Typical PMB classes for sprayed seals

Binder	Maximum viscosity 165 °C (Pa.s)	Attributes and typical uses
S10E	0.55	• Typically manufactured with SBS polymer • SAM for slow rate of crack activity • Aggregate retention
S15E	0.55	• Typically manufactured with SBS polymer • SAM for rapid rate of crack activity, small cracks
S20E	0.55	• Typically manufactured with SBS polymer • SAM for rapid rate of crack activity, low and high crack severity • High stresses

Binder	Maximum viscosity 165 °C (Pa.s)	Attributes and typical uses
S25E	0.8	• Typically manufactured with SBS polymer • SAMI
S35E	0.55	• Typically manufactured with PBD polymer • SAM for slow rate of crack activity • Aggregate retention
S45R	4.5	• Plant manufactured crumb rubber binder • Similar uses to S15E and S20E for high stress applications
S15RF	–	• Field blended crumb rubber binder • Similar uses to S45R
S18RF	–	• Field blended crumb rubber binder • SAM and SAMI for rapid rate crack activity with high cracking severity

Source: AGPT04F-17 (Austroads 2017c), AGPT-T190.

Different binder types have different viscosity characteristics which determine performance under traffic and environmental loads. This also determines the most appropriate type of binder for different pavement applications.

Bituminous binders for spray seal applications may also be modified through the addition of additives into the binder such as polymers and rubber.

Conventional bitumen

Conventional bitumen is a by-product of the oil refinery process, and is typically black or dark brown in colour. It provides adhesive and waterproofing properties. It is highly viscous at room temperature and becomes much less viscous when heated. Bitumen is delivered to site and sprayed at high temperatures.

Cutback bitumen

Bitumen that has temporarily reduced viscosity by the addition of cutter oil (e.g. kerosene).

Multigrade bitumen

Multigrade bitumen is processed to reduce temperature susceptibility, with increased binder stiffness at higher temperatures whilst retaining suitable low-temperature characteristics.

Polymer modified binder (PMB)

PMB is bitumen blended with a synthetic polymer or crumb rubber. It provides enhanced performance and is typically used for high traffic and stress situations, and adverse climatic conditions.

Bitumen emulsion

A bitumen emulsion is a mix of binder droplets in water with an added emulsifier agent to keep the binder suspended in the water. Emulsions are typically a 60% bitumen and 40% water and 'high float' bitumen is sometimes available with 80% bitumen and 20% water.

The emulsifier agent may be positively (cationic) or negatively (anionic) charged which aids in the bitumen emulsion adhering to aggregate. Cationic bitumen emulsions are most common in Australia due to aggregates being predominantly negatively charged.

Sprayed seal aggregates

The aggregate in sprayed seals provides texture and skid resistance for traffic, and spreads vehicle wheel loads to the pavement. The aggregate is typically crushed rock of substantially uniform size. Nominal sizes of up to 20 mm are commonly used in sprayed seals (Table 3.11).

Table 3.11: Sprayed seal aggregate sizes and common uses

Aggregate size	Common applications
5 mm 7 mm	• Low volume roads • Low speed environments • Second layer of double/double • Fine surface texture
10 mm 14 mm	• Higher volume roads • First layer of double/double • Higher surface texture
16 mm 20 mm	• Primarily used in first layer of double/double • Sprayed seals requiring high binder application rates

The suitability of aggregate for use in sprayed sealing is evaluated by a series of Australian Standard tests and road agency specifications. Key properties include:

- average least dimension (ALD) – average height of aggregate particles with their least dimension vertical (see Section 3.7.10)
- flakiness index – proportion of aggregate particles with an ALD less than 0.6 of their average dimension
- polished aggregate friction value (PAFV) / polished stone value (PSV) – measure of resistance of an aggregate to polishing under the action of traffic
- Los Angeles value (LAV) – measure of aggregate to withstand abrasion and impact (see Section 3.7.9).

Additives

Products used in the construction of sprayed seals include:

- aggregate pre-coating material – bitumen-based material applied to aggregate to ensure initial adhesion and longer-term retention of aggregate
- adhesion agent – promotes adhesion to the cover aggregate, added to aggregate pre-coat or sprayed sealing binder
- cutter – for temporarily reducing the viscosity of bitumen

3.2.3 Unsealed Surfacing

The wearing course material of an unsealed pavement should be durable and of consistent quality to ensure it wears away evenly. The suitability of an unsealed wearing course can be assessed by understanding the material properties such as the particle size distribution and plasticity characteristics.

Unsealed Surface

The desirable characteristics of the wearing course of an unsealed road are:

- *skid resistance*
- *smooth riding characteristics*
- *well-graded with a maximum size of 19 mm*
- *cohesive properties*
- *resistance to ravelling and scouring*
- *wet and dry stability*
- *low permeability*
- *load-spreading ability.*

Ideal unsealed wearing course material

- *Well-graded gravel–sand mixture with a small proportion of clayey fines*

Least ideal wearing course material

- *Fine-graded silts and silty-sand lacking gravel-sized particles*

3.3 Basecourse and Subbase Materials

The basecourse and subbase layers provide support to the overlying surface materials and distribute the load to the underlying subgrade.

For granular pavements the basecourse consists of crushed rock or other granular material which may be unmodified, modified or bound through the addition of stabilisation agents. A granular subbase is typically lower quality than the overlying base material but can consist of the same types of materials as a granular basecourse.

For deep strength and full depth asphalt pavements the basecourse consists of a combination of HMA intermediate course and HMA basecourse layers. These HMA intermediate and basecourse layers may overlie a granular subbase layer or sit directly on the subgrade.

For rigid pavements the base can be one of the many types discussed in this guide. The type of the selected base dictates the jointing design and reinforcement details. The role of the subbase is to provide uniform support to the base layer, and the subbase can be unbound granular, bound and lean mix concrete, depending on the traffic levels anticipated.

3.3.1 Hot Mix Asphalt Basecourse and Intermediate Course

A HMA basecourse is designed to provide support to the overlying intermediate and surface courses.

A HMA intermediate course (or binder course) is the layer directly underlying the surface layer. The intermediate course can be considered the upper portion of a HMA basecourse layer. It may comprise a different HMA mix type to the underlying HMA basecourse.

Hot mix asphalt mix design

See Section 3.2.

Hot mix asphalt binder types – Base course and intermediate course binder

See Section 3.2.

Hot mix asphalt basecourse and intermediate course binder types

Different binder types have different viscosity characteristics which determine performance under traffic and environmental loads. This also determines the most appropriate type of binder for different pavement applications and mix types.

Binder types are classified by class which are based on the viscosity of the binder at a standard temperature of 60 °C. Table 3.12 presents typical unmodified basecourse and intermediate binder class types used throughout Australia.

Table 3.12: Typical unmodified HMA basecourse and intermediate course binder classes

Grade designation	Abbreviated name	Typical viscosity 60 °C (Pa.s)	Typical uses
Class 600	C600	500–700	• Intermediate and basecourse

Source: AGPT04B-14 (Austroads 2014).

Hot mix asphalt aggregates

See Section 3.2.

Filler

See Section 3.2.

Hot mix asphalt intermediate and basecourse mix types

There are different types of HMA intermediate and basecourse mixes depending on the type of binder and the grading of aggregate used. Table 3.13 provides a summary of basecourse and intermediate course mix types sued throughout Australia.

Table 3.13: Summary of HMA basecourse and intermediate course mix types

Asphalt mix type	Abbreviation	Mixture characteristics	Typical nominal size	Typical layer thickness	Load applications
Dense graded asphalt	DGA	• Well graded aggregate • Structurally strong layer • All rounder	14 mm	35–45 mm	• Medium to heavy traffic • Freeways and urban highways
			20 mm	> 50 mm	• Heavy traffic • Freeways and urban highways

3.3.2 Concrete Basecourse and Subbase

Base materials

The structural capacity of a rigid pavement is primarily provided by the concrete base layer, and the design thickness for heavily trafficked applications is governed by flexural fatigue of the concrete base. For heavily trafficked roads (exceeding 10^6 HVAG), the design life is usually between 30 to 40 years.

Whilst the flexural strength (modulus) of the concrete mix is the governing parameter for structural design it is essential that full compaction of the base layer is achieved to assure pavement performance.

The construction of a concrete base (and subbase) is generally undertaken using a paving machine with a vibrating screed and vibratory immersion probes (Figure 3.6).

Figure 3.6: Concrete paver

Types of concrete base

There are different types of concrete base, namely PCP, JRCP, CRCP and SFCP. Each type of concrete base has different slab dimensions, reinforcement details and minimum corner angles. For heavily trafficked roads, there are strict requirements on the slab dimensions (i.e. joint spacings). However, for lightly trafficked roads, relaxation of these requirements is often acceptable. Table 3.14 provides a summary of the types and characteristics of various concrete base types.

Table 3.14: Types and characteristics of concrete base

Concrete base type	Typical transverse joint spacing (lightly trafficked)	Typical transverse joint spacing (> 10^6 HVAG)	Joint and reinforcement	Pavement application
Plain concrete pavement (PCP)	< 4.2 m	< 4.2 m	• Unreinforced transverse contraction joint • Tiebars in longitudinal joint	• Shared paths, medium to high volume freeways • Regular shaped slabs (approximately square shaped)
Jointed reinforced concrete pavement (JRCP)	8–12 m	< 8 m	• Dowelled transverse contraction joint • Tiebars in longitudinal joint • Steel wire mesh reinforcement	• Slabs with a reduced number of transverse contraction joints
Continuously reinforced concrete pavement (CRCP)	n/a	n/a	• No transverse contraction joint • Transverse and longitudinal reinforcements	• High volume freeways and urban highways with only transverse construction joints. • Road tunnels

Concrete base type	Typical transverse joint spacing (lightly trafficked)	Typical transverse joint spacing (> 10^6 HVAG)	Joint and reinforcement	Pavement application
Steel fibre reinforced concrete pavement (SFCP)	n/a	< 6.0 m	• Unreinforced transverse contraction joints • Tie bars in longitudinal joint	• Roundabouts • Irregular shaped (non-rectangular) and acute cornered slabs

One specific application of concrete pavements in rural town applications is in the use of roundabouts where the concrete provides resistance to transverse shearing forces particularly from tandem and triple axle groups.

Joint types

A concrete base will naturally crack under the environmental actions (shrinkage, curling and warping). Depending on the type of concrete base, joints are designed to minimise undesired cracks. There are different types of joint used in concrete pavement:

- transverse contraction joints
- transverse construction joints
- expansion and isolation joints
- longitudinal (hinge) joints.

Concrete mix design

Concrete mixes use a range of binder and aggregates gradations. A concrete mix used for the base layer needs to meet both the strength and workability requirements.

For concrete basics, CCAA (2010) has provided a good reference document.

Aggregate properties

The typical aggregate properties are:

- particle grading
- particle shape
- cleanliness
- toughness
- durability and soundness
- density
- water absorption/porosity
- surface micro texture
- chemical properties, including alkali reactivity
- thermal expansion.

Undertaking a concrete mix design determines the optimised proportions of each component which make up the final mix. The typical methods to determine the optimum particle size distribution for concrete mixes are:

- 'Shilstone' Coarseness workability chart
- optimum sand method
- American Concrete Institute
- Texas Department of Transportation (DoT)
- Haystack Mix maximum density
- optimised graded concrete pavement (NCPTC 2014).

Cement binder

There are different cement types used in concrete base and subbase. Two types of cement are used:

- shrinkage limited cement (Type SL) – cement with a low drying shrinkage limit of 750 micro strain at 28 days with a mean limit of 600 micro strain
- general blended cement (Type GB) – Portland cement with greater than 5% of fly ash or ground granulated iron blast furnace slag.

To enhance the surface durability, a minimum cement content of 280 to 300 kg/m^3 (for base concrete) is recommended. To enhance the early age strength, a minimum cement content of 90 kg/m^3 is often specified.

Steel reinforcing materials

There are a number of steel reinforcement types provided in concrete pavements (Table 3.15). They are provided mainly to control temperature induced shrinkage and expansion opening of cracks, restraining separation of slabs at the longitudinal joints and provide load transfer between slabs where it is required.

Table 3.15: Reinforcement type used in concrete

Reinforcement type	Role
Steel reinforcement (bar or mesh)	To restrict the opening of cracks in slabs
Steel fibres	To restrict the opening of cracks in odd-shaped and/or acute angle cornered slabs (such as roundabouts)
Tiebars	To prevent longitudinal joints from opening, while allow some rotation from curling/warping movements
Dowel bars	To provide load transfer across wider transverse joint spacings where the aggregate interlock is inadequate

Concrete pavement repair and maintenance

To maximise the life of the concrete pavement, there will be times when repair and restoration works are needed. Depending on the distress and loading application, repair and maintenance work can be broadly categorised into:

- full-depth repair e.g. full depth pavement slab removal and replacement
- partial-depth repair e.g. base replacement or slab stitching
- crack and seating
- crack/joint resealing.

For urban environments, repair works may need to be completed and open the road to traffic within a short window timeframe. This can be achieved using rapid set products which will enhance the early strength.

Further discussion on methods for repair and maintenance work on concrete pavement, readers are referred to *Concrete Pavement Maintenance / Repair* published by CCAA (2009) for more details

Bikeways and footpaths

For Local Government applications, bikeways and footpaths can be a large asset group. Since these concrete pavements are not generally designed for vehicular loading, a lower standard may be applicable. Readers are referred to *Guide to Residential Streets and Paths* published by CCAA (2004) for further details.

Subbase materials

Subbase under a concrete pavement provides uniform support to the concrete base layer. For heavily trafficked applications, lean-mix concrete subbase or bound subbase are recommended to prevent erosion of subbase/subgrade. However, for lightly-trafficked applications, the likelihood of erosion and pumping is small and an unbound granular subbase is typically adequate.

Unbound granular subbase

For lightly trafficked applications, granular subbase (crushed rock) is typically used for flexible pavement construction.

Bound and lean mix-concrete subbase

For moderate and heavily trafficked applications, bound and lean mix-concrete subbase is often provided to prevent erosion of the subbase/subgrade. Experience in Australia has proven that the lean-mix concrete subbase provides excellent erosion resistance and outstanding long-term load-transfer support under unreinforced transverse joints (e.g. PCP). Subbase materials may include:

- cement stabilised crushed rock with not less than 5% by mass cementitious content to ensure satisfactory erosion resistance (verifiable by laboratory erodibility testing) – the cementitious content may include cement, lime/fly ash and/or ground granulated blast furnace slag
- dense graded asphalt
- lean-mix concrete.

Compressive and flexural strength

A concrete pavement carries bending stress due to traffic and environmental actions, and the ability to resist bending is expressed in terms of flexural strength. Where flexural strength was not measured (for example for lightly trafficked roads, the compressive strength is usually measured and used to estimate the flexural strength). Table 3.16 presents typical strength requirements.

Table 3.16: Typical concrete strength requirements (values are only provided as a guide)

Property	Flexural strength	Compressive strength
Concrete base (> 10^6 HVAG roads)	4.5–5.0 MPa (28 days)	35–45 MPa (28 days)
Concrete base (lightly trafficked roads)	4.0 MPa (28 days)	32 MPa (28 days)
Steel fibre reinforced concrete base (> 10^6 HVAG roads)	5.0–5.5 MPa (28 days)	–
Lean mix concrete subbase	–	5–7 MPa (7 days) 15 MPa (28 days)

Compressive strength can be measured by a cylinder (AS 1012 Parts 8 and 9), and flexural strength can be measured by breaking a beam in flexure (AS 1012 Parts 8 and 11). Road agencies may have their own test methods to determine the above properties.

3.3.3 Granular Basecourse and Subbase

A basecourse and subbase pavement layer constructed from a granular material can either be unbound or modified by the addition of a second granular material or a small quantity of cementitious, bituminous or chemical stabilisation binder.

Granular layers can comprise a number of different materials types including:

- unbound granular
  - crushed rock
  - natural gravels and sands
  - recycled materials
- modified unbound granular materials.

The requirements for subbase material are typically less stringent than those for basecourse and can have a larger nominal size due to the lowered stress in the pavement layer.

The appropriate choice of base or subbase material will be based on material properties, traffic loads, climate, road importance, cost and allowable risk.

Unbound granular

An unbound granular material is considered to be a flexible material which has no tensile strength. The distress mechanism of these materials in a pavement is rutting or shear failure.

Crushed rock

Crushed rock is a quarry product which has been produced in a single crushing operation and may involve a number of crushing and screening processes to refine the material properties to conform to a specification. Due to the processed nature, crushed rock can be expensive to produce and haul and is therefore not typically suited for low traffic applications or locations far from the source.

There are typically three grades of quality for a crushed rock product produced commercially viz:

- Class 1 – the highest quality crushed rock commonly used for the construction of urban freeways, highways and other high traffic, high importance pavements.
- Class 2 – is an intermediate quality crushed rock commonly used as subbase beneath Class 1 applications and as basecourse in lower trafficked pavements and local roads.
- Class 3 – A lower quality crushed rock most suited to subbase applications in light trafficked pavements and local roads.

Natural gravels and sands

Natural gravels and sands are generally extracted from local borrow pits located close to a remote or isolated project site and mobile crushing and screening plants may be an option (Figure 3.7).

Figure 3.7: Mobile crushing and screening plant

Natural granular materials are often of lower quality to a Class 1 crushed rock product due to the variability of the material properties. Modification or stabilisation can allow these materials to be used as both a base quality material or subbase quality material.

There are many different types of natural gravels and sands depending on local geology and climate. The following categories encompass most of what is encountered within Australia (Table 3.17):

- laterite gravels
- ridge gravels
- calcrete limestone and silcrete
- river gravels
- residual soils.

Detail on types of geological deposits common to Australia from which these materials are commonly extracted is included in Section 4.1.2.

Table 3.17: Summary of common natural pavement material types

	Description	Suitability	Properties
Laterite gravel	• Deep isolated deposits • Sand clay gravel mix • Iron oxide staining • Typically gap graded	• Unsealed wearing course • Base and subbase • Sealing aggregate	• High clay content • Rounded gravel • Moisture sensitive • Can be located with the help of vegetation patterns
Ridge gravel	• Angular gravel located on ridges or higher elevations • Often mixed with sand and clay	• Unsealed wearing course • Base and subbase • Sealing aggregate	• Very variable • May require ripping, screening and grading control

	Description	Suitability	Properties
Calcrete and silcrete	• Massive beds, nodular gravel or calcified sand	• Unsealed wearing course • Base and subbase	• Massive calcrete may require quarrying and can produce basecourse quality crushed rock with appropriate processing
River gravels	• Found in riverbeds and old water courses	• Unsealed wearing course • Base and subbase • Sealing aggregate	• Rounded particles decrease stability • Coarse material with little non-plastic fines • Poor cohesion • May require blending or crushing
Residual soils	• Weathered remains of rocks	• Unsealed wearing course • Base and subbase	• Gravels and sands • Clay plasticity will depend on parent rock type • May require blending

Source: Robinson, Giummarra and Oppy (1999).

Modified unbound granular material

A modified unbound granular material is a conventional unbound granular material where a second granular material is added to alter the PSD and/or the plasticity of the parent material.

In addition, modified materials may also be produced from adding a small amount of stabilisation binder (less than 1% by mass for cementitious binders). The amount of stabilisation binder added is such that it does not provide tensile strength to produce a lightly bound or bound material but is still considered to be flexible and unbound.

The maximum unconfined compressive strength (UCS) (see Section 3.7.7) of a modified granular material is 1.0 MPa. Above this the material is considered bound (see Figure 3.8).

The modification can change the performance attributes of the material in the following ways depending on the stabilisation agent used:

- increase bearing capacity
- decrease moisture sensitivity
- increase stiffness.

The distress mechanism of these materials is rutting or shear failure.

Lightly bound and bound granular material

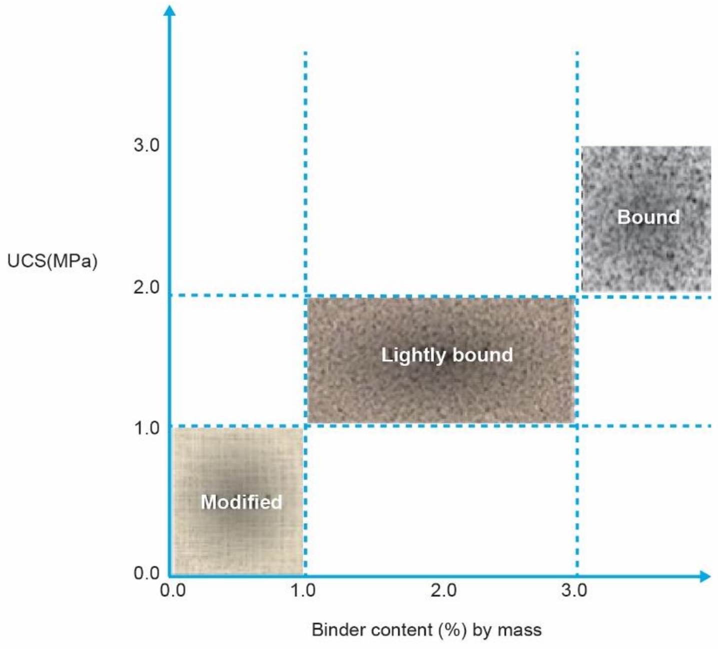
A granular material may be stabilised by the addition of a stabilisation binder such that it has the capacity to develop tensile strains at the bottom of the layer. The selection of a stabilised basecourse or subbase is also based upon consideration of parent material composition and properties, traffic loads, climate, road importance, cost and allowable risk (see Section 3.6).

A lightly bound or bound granular material is a conventional unbound granular material with enough stabilisation agent added to provide a level of tensile strength. The amount of tensile strength gained will either classify the material as lightly bound or bound.

The maximum unconfined compressive strength (UCS) (see Section 3.7.7) of a lightly bound material is between 1.0 MPa and 2.0 MPa. Anything over 2.0 MPa is considered to be bound (see Figure 3.8). Further information on lightly bound and bound materials can be found in AGPT-04D (Austroads 2019).

The modification can change the performance attributes of the material depending on the stabilisation agent used. The distress mechanism of these materials is fatigue cracking.

Figure 3.8: Modified, lightly bound and bound granular material



3.4 Subgrade Materials

The subgrade is the bottom layer of a pavement system and is the foundation for the overlying materials. The subgrade is commonly the in situ material which has been prepared to make a formation above the natural surface. The formation is subsequently shaped and compacted before placement of the overlying layers. Alternatively, the subgrade may be formed by removal of in situ soil to form a boxed out formation upon which subsequent pavement layers are placed.

The strength of the subgrade determines the required thickness of the overlying layers and the traffic loading pertinent to the design life of the pavement.

Stabilisation or modification of the in situ subgrade can also be undertaken to increase foundation strength. Lime stabilisation is commonly used to stabilise subgrade material. More information on stabilisation can be found in Sections 3.6 and 4.2.

3.5 Recycled Materials

There are many waste and recycled materials that can be used in road infrastructure. These include:

- reclaimed asphalt pavement (RAP) generally in the form of profilings or slab asphalt which is subsequently crushed and screened
- crushed recycled concrete (CRC) from which steel is removed and the concrete crushed and screened
- construction and demolition waste (C&D)
- crumb rubber mainly sourced from shredding tyres
- glass comingled and crushed
- plastic shredded
- industrial wastes such as slags, fly ash and tailings
- toner.

Figure 3.9: Recycling plant processing demolition waste

3.5.1 Asphalt Applications

Waste resources and recycled materials can either be blended with the bituminous binder to produce a modified binder or used as a replacement for a portion of the fine and coarse aggregate fractions of the mix.

Recycled Materials and Asphalt

Blended with the bitumen

- *Waste products that can be blended with bitumen include crumb rubber, plastics and filler materials.*
- *These are expected to give some kind of enhancement to the properties of the resultant asphalt mixture.*

Aggregate replacement

- *Recycled aggregates can be added to asphalt as a replacement for certain portions of the aggregate particles including recycled crushed glass, some plastics, larger crumb rubber particles, slags and fly ash.*
- *Typically, these materials are used to replace some of the smaller aggregate particles in the range of 5 mm or below.*
- *Recycled concrete and C&D waste could be added at larger size ranges in hot mix asphalt but should be limited unless appropriate mix designs are undertaken.*

Reclaimed asphalt pavement (RAP)

Large proportions of reclaimed asphalt are recycled back into pavement applications. It is estimated that in Australia about half of all reclaimed asphalt pavement (RAP) is re-used in hot mix asphalt applications. Most of the remainder is used in base or subbase materials, with a small amount being used in cold recycling or as fill.

The main use of RAP is as a component in the manufacture of new hotmix asphalt. Other processes that incorporate the use of RAP include:

- in situ hot asphalt (hot in place asphalt recycling (HIPAR)
- in situ cold asphalt recycling
- cold plant (pug mill) mixing of RAP material.

RAP is previously placed HMA which has been removed from a pavement by cold milling or profiling. The removed material may have reached the end of functional life due to age or may have reached a terminal condition through the application of traffic or environmental loads. Some RAP material may also be surplus from asphalt plant production which has been stockpiled.

Once processed, RAP material is used as a substitute for various sizes of the fine and coarse aggregate fraction in a new HMA or for a spray seal.

The amount of RAP material and the type of HMA the RAP material is combined with will influence the properties and stiffness of the new mix.

RAP Rules of Thumb

- ***Applications***
  - *HMA wearing course, basecourse and intermediate course*
  - *spray seal surfacing aggregate*
- ***HMA: under 15% RAP content***
  - *direct substitution of aggregate*
- ***HMA: over 15% RAP content***
  - *requires binder grade adjustments*
  - *binder blend viscosity design method required*

The use of reprocessed RAP to produce hot mix asphalt is the most common type of asphalt recycling. The addition of up to 20% RAP has little impact on the properties of the asphalt mix. Limited change is required to asphalt mix design procedures or production methods other than the preparation of separate mix designs for the specific proportion of RAP and the establishment of protocols for handling, stockpiling and adding of RAP.

If the RAP content exceeds 20% and forms up to 40% of the asphalt mixture, the bitumen grade should be adjusted to one grade softer than otherwise specified to compensate for the stiffness of the aged RAP binder.

When higher RAP contents are incorporated, modified asphalt plants that provide improved heat transfer, reduced emissions and better mixing of recycled materials are desirable. Higher proportions of RAP also require greater control over the uniformity of the RAP materials. Crushing and screening into separate size fractions is generally recommended.

High RAP contents

Typically, an upper limit of RAP content in hotmix asphalt is considered to be 40–50%. This is due to the heat capacity, gaseous hydrocarbon emissions and the additional costs of processing and testing of the RAP materials to ensure consistent properties of the manufactured asphalt. Specialist asphalt plants have been developed using microwave technology and other indirect heating methods to limit the gaseous emissions from asphalt production with very high RAP contents (up to 100%). Such plants have seen limited use due to high energy costs and the need for significant materials testing.

Recycled plastic

Polymers have been incorporated into asphalt mixes to improve properties and performance. This has typically been done by incorporating polymers to modify bituminous binders. Similarly, recycled polymers may also result in enhanced performance, provided that a rigorous selection of plastic waste and suitable production conditions are used.

Generally, there are two ways to add polymers or recycled plastics into asphalt mix. These are the dry process through which solid particles are added directly into the mix with the aggregate particles and the wet process, where the virgin binder is modified with the plastics.

Dry process

In the dry mixing process, the solid modifiers (waste plastic materials) are added directly to hot aggregate prior to the addition of the binder. This is followed by prolonged mixing to ensure a homogenous mixture is achieved.

Wet process

Typically, recycled plastics are shredded or ground to a desirable size for easier blending with the bituminous binder. These polymer or plastic modifiers are then added to the binder and blended prior to mixing with the aggregate. This occurs on or off site, with the latter method requiring good storage and transportation facilities to ensure a storage stable product.

Role of the recycled plastics

Much research has been carried out looking at using recycled plastics as a replacement for fine aggregates in concrete mixes. Now the focus has shifted to looking at the use of recycled plastics in road construction.

Waste plastic can either be an extender or a modifier. As an extender, its role is to substitute for a portion of the raw materials to decrease the amount of virgin materials required. When it is used as a modifier it can alter the properties of an asphalt mixture to provide some enhancement in terms of properties. Some recycled plastic products:

- can act as an aggregate extender (or replacement) or asphalt extender
- can be melted into the bituminous binder and extend its volume without any performance improvement
- can melt, extend and modify the bituminous binder. This is the most valuable method as it provides an efficient use of the waste material, which would otherwise become landfill. It leads to a reduction in the volume of raw material used and improves the performance of the resultant asphalt mix.

Recycled rubber

Crumb rubber is obtained from the recycling of motor vehicle tyres. Mixes with up to 20% of crumb rubber by mass of bitumen binder are regularly used in sprayed seal work in polymer modified applications.

Crumb rubber modified (CRM) binders have been used in hotmix asphalt to produce flexible mixes with good crack resistance.

The rubber component is tyre rubber. This is a blend of natural rubber, synthetic rubber and carbon black. Production typically involves shredding, followed by ambient or cryogenic grinding to produce crumbs in a size range from 0.5 to 5 mm.

Dry process

A dry process is one in which the rubber is added directly into the hot mix asphalt mixing process. Typically, the crumb rubber particles are mixed with the hot aggregate prior to the addition of bitumen. Although this is the case, it is still considered part of the bitumen. An extended mixing time is required to ensure adequate blending of the crumb rubber and the bitumen.

The advantage of this process is that it provides an easy way for the manufacturer to produce CRM asphalt. However, during this process only partial blending of the crumb rubber with the bitumen occurs. This can limit the performance of the final product. It is also essential to make sure the crumb rubber does not come into contact with any heating flames.

Wet process

The wet process describes any process that involves blending the crumb rubber with bitumen. This blending can take place in an asphalt plant or in the field with an on-site blending and storage unit. CRM binders have been shown to produce asphalt with similar properties to elastomer modified binders, but higher binder contents are required in the asphalt mx.

Crumb rubber can be blended with high or low shear mixing. The resultant modified binder is then moved to a storage tank that provides continuous circulation to prevent separation. Storage at high temperatures leads to a gradual degradation of the product.

A process known as the no-agitation method (terminal blends) may improve the workability and stability of the mix, which can allow storage without the need for continuous agitation. These mixes are made by blending crumb rubber into bitumen at high temperatures (200–300 °C) using high shear stresses and pressure. This process results in better homogenisation than binder produced using the high viscosity method. However, terminal blends have lower viscosity resulting in lower optimum binder content hot mixes, which can result in reduced performance life.

The wet process produces a better controlled product. They are more commonly used than the dry process due to the enhanced digestion and chemical interaction between the crumb rubber and the binder which produces a more homogenous product.

CRM binders produced through the wet process may also include extender oils. These can enhance the interaction of the crumb rubber with the bitumen.

Role of the recycled rubber

CRM asphalt has the potential to reduce pavement noise. Additional benefits of using CRM binders in asphalt include:

- increased durability and resistance to age hardening
- improved fatigue resistance for surface cracking
- decreased temperature susceptibility

- improved resistance to permanent deformation
- decreased particle loss attributed to thicker binder films.

One of the major concerns around the used of CRM asphalt is that at the high temperatures associated with hotmix manufacture, emission of hazardous fumes can occur, which may have an adverse effect on the health of production staff and road workers. Using CRM in combination with warm mix asphalt (WMA) technology has been suggested as a way to reduce these issues as it would allow production at lower temperatures.

Toner

A large amount of toner is produced for photocopiers and printers every year. Some of this toner does not meet the requirements to be fit for purpose and becomes a waste product. This waste product along with residue from toner and printer cartridges normally goes to landfill. However, it has been shown that it can be used as a modifier to stiffen bituminous binder.

However, it has also been shown to make binders more susceptible to low temperature cracking. It has been found to have poor storage stability and therefore needs prolonged agitation or mixing to make a homogenous asphalt toner mix.

Glass

Comingled glass cullet which is crushed glass may be used as a substitute for various sizes of the fine and coarse aggregate fractions in a HMA, and granular pavement materials as sand (Figure 3.10).

Figure 3.10: Crushed recycled glass cullet and glass sand

The performance of recycled glass as a fine/coarse aggregate substitute is highly dependent on the shape of the crushed glass particles and also the cleanliness of the glass.

'Glassphalt' is a common term for asphalt that uses crushed glass and has been used as an alternative to conventional bituminous asphalt pavements since the early 1970s.

Recycled Glass Documented Experience

HMA basecourse and intermediate course applications:

- *up to 14% by weight of aggregate*

Wearing course applications:

- *up to 5% by weight of aggregate*
- *over 20% may increase rutting and stripping potential*
  - *addition of hydrated lime or use of a PMB may combat stripping potential*

Source: Grenfell and van Aswegan, (2019).

Slag aggregate

There are several slag types that are available in Australia which depend on the industry they come from. The materials that have potential use in asphalt are derived from iron and steel manufacture and consist of three main types.

Blast furnace (BF) slag

BF slag is derived from the production of molten iron. It produces a light grey vesicular material when cooled slowly that can be crushed and screened using normal aggregate processing methods. This material generally does not have the strength and abrasion resistance for use in asphalt except in lightly trafficked situations.

Basic oxygen steel (BOS) slag and electric arc furnace (EAF) slag

BOS and EAF slags produced in the manufacture of steel from molten iron and scrap metal are similar in characteristics. When they are cooled slowly, they produce a hard, dense material. Their density can be up to 20% higher than normal aggregates. Such aggregates have good resistance to abrasion and polishing and can be used in situations when high levels of surface friction are required. Processing costs and the lack of availability of consistent supplies have restricted their use in Australia.

Foundry sand

Used foundry sand comes from the metals casting industry. When the sand has been classified as inert, it has the potential for use in asphalt. Some trials have been undertaken in Australia with promising results.

Hot mix asphalt fillers

A number of waste materials can be used as fillers and fines to replace the finer fraction of aggregates in HMA. They can also be used to help adjust gradings to meet specifications. These include:

- sweepings
- baghouse fines
- kiln dust
- mine waste
- fly ash.

Cold plant recycling

Cold plant recycling is similar to cold in situ recycling, except that the mixing of RAP, binder and additional materials is performed in a separate mixing plant. Cold plant recycling can be more versatile than in situ recycling. It has a number of advantages:

- Processing of RAP is the same as required for hotmix asphalt, so there is no need for specialist reclamation equipment.
- RAP from different sources can be combined.
- Additional processing of RAP can be used to provide greater control over the grading of materials, the use of additives and efficiency of mixing.
- Only minor modifications of mixing equipment are required for other stabilising or asphalt mixing applications.

Cold plant recycled asphalt is suitable for the following applications

- intermediate or basecourses in deep lift pavements
- shoulder surfacing
- asphalt pavement patching
- pavement shape correction prior to resurfacing.

In terms of environmental and efficiency issues, cold recycling provides the following benefits:

- No heating is required.
- High production rates can be achieved.
- Mixes with up to 100% RAP can be produced.
- Materials can be transported and stockpiled for later use without the loss of workability.
- Specialised asphalt paving equipment is not necessarily required.
- Materials cure more rapidly than conventional cold mixes manufactured with cutback bitumen binders, thereby providing improved deformation resistance and reduced risk of bleeding through subsequent surface treatments.

3.5.2 Granular Applications

Recycled materials within unbound granular basecourse and subbases are mainly sourced from recovery and/or the reuse of in situ stabilised materials or construction and demolition waste.

Construction and demolition waste consists of:

- primary materials – the main source of stone, making up more than 80% of the product. Examples of this include concrete, which may contain steel reinforcement and brick
- supplementary materials – stone-based materials that are additional to the primary material. These materials can include brick, crushed stone, tiles, masonry and glass
- friable materials – can be tolerated, but if there is too much, they will be detrimental to the product quality and performance. These materials include plaster and clay lumps
- foreign materials – these are detrimental to performance and undesirable, however they cannot be completely eliminated. These can include rubber, paper, plastic, cloth, paint, wood and vegetable matter
- bituminous materials – these can be tolerated in unbound materials (as long as they are not stabilised with cementitious binders). They could be stabilised with the addition of bituminous binders (hot or cold). Examples include asphalt (slabs or profilings) and sprayed seals.

- Contaminants - this may include asbestos which must be managed within the recycling facility.

Additional advice can be found on the use of recycled concrete and masonry in the manufacture of pavement products such as granular materials and concrete in Australian Standard HB 155-2002.

Recycled materials can exhibit properties that do not conform to traditional specifications for crushed rock or natural gravels, in terms of particle size distribution, plasticity or hardness. However, specifications for these recycled materials have been developed in many Australian jurisdictions and in New Zealand. These specifications are still based on the traditional engineering properties of strength and durability, which are applicable to natural materials.

In addition, some specifications require performance-based testing. This can include repeated load triaxial testing or in some cases crushing strength due to the 'self-cementing' properties of some industrial by-products.

Particle size distribution (PSD) requirements for recycled materials are the same as those for quarried products. Atterberg limits are also measured on recycled materials. As the porosity of cement mortar is higher, the liquid limit (LL) and PL of most recycled materials is higher than quarried products such that they are low PI or non-plastic. Strength properties of recycled aggregates should be measured using the Los Angeles abrasion test, the wet/dry strength test, the wet/dry strength variation test or the unconfined compressive strength (UCS) test.

Supplementary and deleterious materials in construction and demolition products

Recycled construction and demolition materials that originate from building sites or roadworks can be contaminated with a range of undesirable materials. Specifications typically place an upper limit on the amount of supplementary and deleterious materials that are allowable. In the case of potential asbestos, specific stockpile management and contaminant monitoring is undertaken to ensure levels do not exceed those of 'background' levels

Granular bituminous materials (reclaimed asphalt pavement (RAP))

RAP can also be used for granular base and subbase applications. Processed RAP material can be blended with conventional base and subbase granular materials.

Recycled asphalt in the form of crushed slab asphalt or asphalt profilings have been used as an unbound subbase and basecourse material on minor roads and as a low dust surfacing in unsealed road applications.

Asphalt which is milled and directly reconstituted into unsealed wearing courses should contain sufficient fine material to approximate to a Class 2 granular material in order to provide a tight surface.

See also Section 3.5.1

Recycled glass

Australia consumes about 1.36 million tonnes of glass packaging per year, the majority of which ends up in landfills or storage due to reprocessing being commercially less viable. These storage stockpiles can be processed as glass cullet.

Uses of recycled crushed glass:

- basecourse and subbase layers on sealed roads
- fine aggregate for concrete production
- fine aggregate for bituminous slurry emulsions
- bedding and backfilling material for underground pipes/cables and services
- bedding material for block paved pavements and footpaths.

Glass cullet is recycled container glass which has previously been used for bottles, jars and similar glass vessels (i.e. comingled glass). This material is collected via bottle banks, kerbside collection schemes and from premises handling large quantities of containers. The term cullet also refers to waste glass produced as a result of breakage and rejection through quality control during the manufacturing process.

Ideally, the aim of processing glass is to return it to the glass making process to manufacture glass containers or other products, however in some commercial operations it is incorporated in granular materials.

Glass cullet used in granular materials has typically been broken into smaller fragments and may contain other materials. These can include:

- metals, generally in the form of container lids and seals which are removed magnetically at the processing plant
- organics, such as paper labels, wood, plants, food residue, etc. These materials are removed through washing and screening.

Recycled Glass: Rules of Thumb

Granular pavement applications:

- *Up to 5% reclaimed glass in the form of cullet is allowed in granular pavements*
- *Glass cullet is a hard, granular material and can be used as a fine aggregate when crushed*
  - *crushed glass cullet has very similar physical and mechanical properties to sand*
  - *can be more economical than natural sand*
- *Powdered glass cullet is pozzolanic*
  - *will react with lime to stabilise materials*
  - *contribution to strength development is less than that of Portland cement*
  - *produces a lower compressive strength material*
  - *can be more economical than cement*

Crushed recycled concrete

Concrete from most sources including buildings, road pavements and other infrastructure can be recycled and used as an unbound granular base and subbase material. It can also be recycled as an aggregate in new concrete mixes.

As with conventional quarry products, any desired grading can be produced by making appropriate adjustments to processing equipment.

The optimum moisture content of CRC subbase and base materials can be 30% higher than a virgin granular material due to the presence of the adsorption of cement mortar.

Crushed demolition waste

Demolition waste encompasses a range of waste materials and can be used as a granular basecourse or subbase layer. Some of the materials are more suitable than others. Table 3.18 presents a summary of the suitability of the different types of crushed demolition waste (CDW). A stockpile of CDW is presented in Figure 3.11.

Table 3.18: Suitability of various components of crushed demolition waste

Material description	Material	Suitability
Primary material	• Concrete	• Base or subbase quality • Should form at least 90% of the final product for base applications • Some steel reinforcement may be present
Supplementary	• Brick • Crushed stone • Tiles • Masonry	• Small to medium amounts with primary material for subbase quality • Small amounts with primary material for base quality
Friable materials	• Plaster • Clay lumps	• Tolerable but can be detrimental to quality and performance • Avoid in base quality materials • Low amounts suitable for subbase quality
Foreign materials	• Rubber • Plastic • Paper • Cloth • Paint • Wood • Organic matter	• Detrimental to performance • Hard to fully eliminate
Bituminous materials	• Asphalt • Sprayed seals	• Tolerated in unbound materials • Suitable for both base and subbase quality • Cannot be stabilised with cementitious binders • Can be stabilised with bituminous binders

Source: Austroads (2009a).

Figure 3.11: Stockpile of processed demolition waste

Crushed brick

Crushed brick and crushed tile are allowed in the supply of recycled materials for granular roadbases. It is only allowable up to 30% by mass for lightly trafficked roads (N < 10^6 ESA) and up to 20% for more heavily trafficked roads (N > 10^6 ESA).

Industrial slags and fly ash

Industrial slags have the potential to be used in granular bases and subbases. It is important to understand their properties before using them. There are also limits on the amounts of industrial slags that can be used, dependent on the application, due to their poorer quality. For example, a maximum of 10% fly ash by mass of aggregates is allowable in road base.

- GBFS – granulated blast furnace slag
- BFS – blast furnace slag
- BOS – basic oxygen steel slag
- EAF – electric arc steel slag
- CCP – coal combustion products including fly ash and furnace bottom ash.

About 0.42 Mt or 7% of CCPS has been used in non-cementitious applications such as flowable fills, structural fills, road bases, coarse/fine aggregates.

3.5.3 Stabilised Material Applications

Unbound granular materials originating from construction and demolition waste can be used in the manufacture of stabilised materials using a range of binders. More information can be found in Austroads Guide to Pavement Technology Part 4D (Austroads 2019).

Typical applications involve:

- use of crushed concrete in combination with cement to manufacture modified and bound cement stabilised basecourse
- the use of RAP or previously cement treated materials in combination with foamed bitumen and hydrated lime to manufacture a foamed stabilised bound basecourse
- the use of RAP in combination with bitumen emulsion to manufacture a bound basecourse and subbase (Figure 3.12).

Figure 3.12: Bitumen stabilised basecourse with recycled aggregate

3.5.4 Concrete Applications

In terms of use of waste resources in concrete for road construction, options involve replacing virgin aggregate with recycled alternatives or using fine graded materials which can act as pozzolans and therefore can be blended with cement itself to give binding properties.

Recycled aggregates

A variety of waste resources can be used as recycled aggregates in concrete. The most commonly used are:

- recycled concrete aggregate
- recycled crushed glass
- steel and blast furnace slags'

Aggregates from recycled concrete

The manufacture of coarse aggregates from demolition concrete for incorporation into structural concrete is well established and a national Australian guide exists (AS HB 155-2002).

The guide suggests two classes of aggregate. A class 1A – RCA having a composition entirely of crushed concrete and little or no brick and class 1B– RCA having a composition that may have up to 30% brick within the crushed concrete. The particle size distribution and the stone hardness are no different to the specifications that apply to virgin materials (AS 2758.1).

Contaminants in the recycled aggregates can adversely affect the concrete properties.

Trial batches should be prepared to determine appropriate mix proportions in relation to the desired properties. Typically blending coarse RCA with natural aggregates at substitution rates below 30% is not detrimental. Coarse aggregates should be pre-wetted to obtain workability due to their high absorption rates. Fine RCA aggregates should be avoided as they give rise to serious reductions in workability, strength and finish.

Recycled crushed glass

Glass cullet can be used as a replacement for fine aggregate in concrete however it has a very small commercial take-up due to the abundance of natural sands. The primary issue is associated with product contamination. The presence of sugar can be detrimental to the cement hydration process.

Concrete containing glass cullet as an aggregate typically displays higher resistance to abrasion than equivalent materials made using quartz sand or similar materials as fine aggregate. Glass cullet aggregate containing mixes have also been observed to have reduced drying shrinkage.

Steel and blast furnace slags

Steel and blast furnace slags have been used in the manufacture of concrete primarily as coarse aggregates. However, ground slags and fly ash are blended with commercial cements.

Air-cooled blast furnace slag is considered suitable for use as a concrete aggregate. Compressive strength of concrete containing slag aggregate is comparable with that containing virgin aggregate. However, steel slag aggregates have the propensity to expand due to the presence of free calcium oxide (quicklime). This reaction can be controlled through the ageing of aggregate.

Plastics

Plastics have been used in concrete as a small aggregate replacement for structural applications. It would be used to replace the sand fraction in the aggregate.

Coal combustion products

In Australia in 2018 12.6 million tonnes of coal combustion products were generated. Of those 44% were utilised effectively in various value-add products such as fly ash cementitious binder.

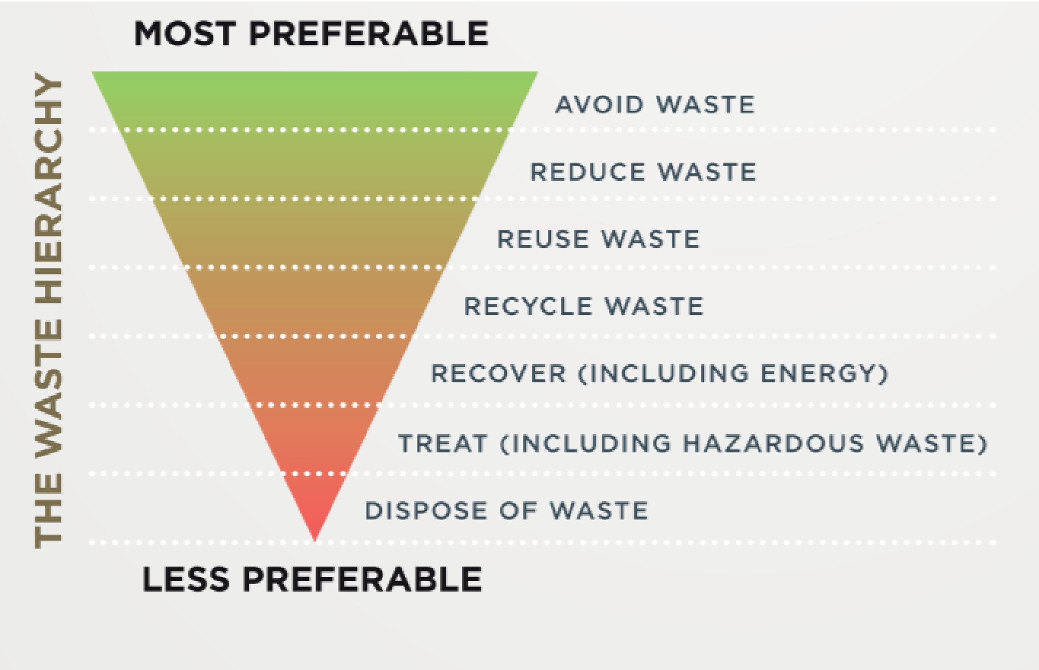
Fly ash

Over 1.983 Mt of fine grade fly ash were used in high value add products such as cementitious binders, concrete manufacture or mineral fillers in 2018. In addition, fly ash is used in the manufacture of blended cement (Type GB).

3.5.5 Implications of Using Recycled Materials

All Australian states and territories have an environmental policy associated with resource recovery and recycling. Attached to these policies are target achievements for the various waste streams and landfill reductions. However, waste will always be generated, therefore it is important to use waste resources in the best possible way (Figure 3.13).

Figure 3.13: The waste hierarchy



Source: https://www.environment.gov.au.

Traceability and contamination

Documenting

As with any material it is important to keep a record of which materials have been used in what locations and in what quantities on road infrastructure projects. This allows appropriate rehabilitation methodologies to be adopted at the end of life. It also allows traceability of materials for separation or stockpiling purposes when reclaimed.

Presence of contaminants

Environmental authorities place tight restrictions on the spread of harmful metals, pesticides and carcinogens into the environment. It is important that appropriate controls are in place to prevent the spread of undesirable chemicals through the use of recycled waste materials and industrial by-products. The presence of asbestos as either fragments or fibres is strictly controlled by the Environmental Health Commission.

Leaching

Contamination and leaching are big issues for recycled materials. Cleanliness of recycled materials is also of considerable importance.

Specified limits are available through the National Environment Protection Council for contaminants in relation to land use, ranging from Level A (standard residential usage) to Level F (commercial and industrial applications) (Table 3.19).

Table 3.19: Environmental contamination intervention levels

Substance	Health investigation Level A (mg/kg)	Health investigation Level F (mg/kg)
	Metals	
Arsenic	100	500
Cadmium	20	100
Chromium (VI)	100	500
Copper	100	500
Lead	300	5 000
Mercury (inorganic)	15	50
Nickel	600	3 000
Zinc	7 000	35 000
	Organics	
Aldrin/Dieldrin	10	50
Chlordane	50	250
Polyaromatic hydrocarbons (PAH)	20	100
Petroleum hydrocarbons C16-C35 aromatics	90	450
Petroleum hydrocarbons C16-C35 aliphatics	5 600	28 000
Petroleum hydrocarbons > C35 aliphatics	56 000	280 000

Source: Austroads (2009a).

3.6 Stabilisation Materials

Granular materials can be modified by the addition of various categories of stabilising binders to improve their performance as a pavement material. Stabilisation is a treatment to improve a range of material properties critical to pavement performance including (Austroads 2019):

- strength
- permeability
- volume stability
- durability.

3.6.1 Granular Material

Granular stabilisation involves blending two or more granular materials together or screening a single material with the aim of altering the overall material grading and plasticity characteristics.

See also Section 3.3 and Appendix B.3.

3.6.2 Cementitious Stabilisation

Cementitious stabilisation is undertaken either in situ with a spreader truck applying the cement at the required dosage rate or through a plant mix pugmill operation. Cementitious binders react with moisture within the granular material to form a lightly bound or bound material. This is often undertaken to reduce the moisture susceptibility of a material and increase stiffness through increased tensile strength.

Cementitious stabilisation is most suited to granular materials with some clay content, or clayey material with low plasticity. See also Section 4.2.2.

3.6.3 Lime Stabilisation

Lime stabilisation is undertaken in a similar manner to in situ cementitious stabilisation, however the tensile strength of a material stabilised with lime is much less than those stabilised with cement (Austroads 2019). Soil physical properties such as plasticity, grain size and resistance to moisture penetration are changed by stabilisation with lime.

Lime stabilisation is most suited to clayey materials with a plasticity index (PI) above 10%.

There are various types of lime including hydrated lime and quicklime which all produce a stabilised material with similar performance properties (Table 3.20). Quicklime has approximately 30% more effective lime for stabilisation than hydrated lime. This must be considered when choosing the percentage of stabilisation agent.

Other forms of lime are dolomite lime (calcium/magnesium carbonate) and agricultural lime (i.e. limestone or calcium carbonate). Agricultural lime is not associated with pavement stabilisation but can be used in acid sulphate applications as a pH neutraliser. Each type of lime has specific construction considerations such as cost, dust generation and water requirements. See also Section 4.2.3.

Table 3.20: Properties of different lime types

	Quicklime	Hydrated lime	Slurry lime
Composition	CaO	$Ca(OH)_2$	$Ca(OH)_2$
Form	Granular	Fine powder	Slurry
Equivalent $Ca(OH)_2$	1.32	1.00	0.33–0.56
Bulk density	1.05	0.45–0.56	1.25

Source: Austroads (2019).

Types of Lime Stabiliser

Quicklime

- *Quick-lime is supplied in bulk as a fine granular powder and is spread with a mechanical spreader.*
- *It is slaked (water added) after spreading and before mixing.*

Hydrated lime

- *Hydrated lime is a lightweight fine powder, which will easily be blown away on a worksite.*
- *It may be supplied bagged or in bulk.*

3.6.4 Bitumen Stabilisation

Bitumen stabilisation provides cohesion in granular soils and waterproofing properties in clayey soils and can include the addition of the following (Austroads 2019):

- bitumen emulsion
- foamed bitumen.

Bitumen stabilisation is most suited to granular materials and sandy soils. See also Section 4.2.4.

3.6.5 Chemical Additives

The primary function of chemical stabilisation is to bind the fine fractions such that they hold the aggregate fractions in place for a longer period of time. This is enhanced by the binder providing bonding and waterproofing of the fines to maintain the dry strength of the fine material.

Chemical binders are generally separated into either dust palliatives or stabilisers.

It should be noted that some chemical binders are subject to leaching and/or biodegrade over time so their binding effect can be reduced. See also Section 4.2.5.

3.6.6 Other Stabilisation Materials

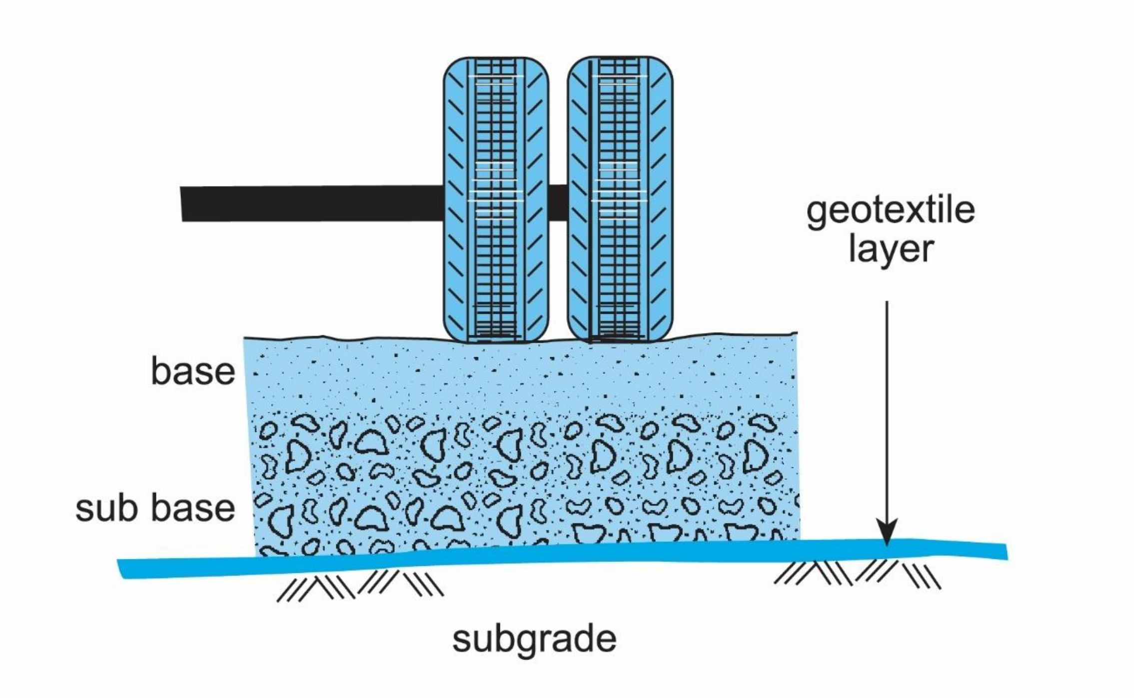
Geotextiles

Geotextiles or geofabrics are a permeable, synthetic fabric reinforcement which can be used for various applications including:

- separation of materials (Figure 3.14)
- reinforcement of a sealed wearing course
- reinforcement of a low strength subgrade
- filter layer
- drainage layer.

Geotextiles are classified by a strength index rating commonly designated as G. See also 4.2.6.

Figure 3.14: Geotextile layer separating subgrade and overlying pavement layers



Geogrids

Geogrids are formed by a regular network of tensile elements with apertures of specific size to allow interlock with the surrounding granular material (Austroads 2009b). This interlock and tensile strength provides reinforcement of the surrounding material.

In pavement applications geogrids are often using the reinforce granular base and subbase layers (Austroads 2009b). Geogrids can also be combined with geofabrics in situations which require reinforcement in addition to separation of layers.

When considering stabilisation an assessment should be made which compares the cost of undertaking the stabilisation with the expected pavement performance benefits or reductions in design requirements caused by applying the stabilisation method.

Before selecting the appropriate stabilisation binder for a specific scenario, there needs to be an understanding of what the properties of the material in question are (grading, plasticity and bearing strength) and which of these properties needs to be corrected to ensure ongoing performance in the specific operating environment.

3.7 Laboratory Testing

The following section provides a description of laboratory tests which are typical for pavement and subgrade materials. This includes information on the following:

- purpose of the test
- summarised method of testing
- presentation and descriptions of test results
- how the test results influence material performance in a pavement.

Common laboratory tests which are discussed in the following sections are summarised in Table 3.21.

Table 3.21: Laboratory tests and pavement performance

Laboratory test	Material relevance	Performance influence
Grading (PSD)	• All granular materials • HMA and spray sealing aggregates	• Stability • Stiffness • Density/particle packing • Particle interlock
Plasticity/consistency	• All granular materials	• Stability • Cohesion and suction • Moisture sensitivity • Volumetric instability
Moisture content	• All granular materials	• Stability • Cohesion and suction
Density/moisture relationship	• All granular materials	• Stability • Stiffness • Bearing capacity
California bearing ratio (CBR)	• All granular materials	• Bearing capacity
Repeated load triaxial	• All granular materials	• Stiffness • Permanent deformation • Bearing capacity
Unconfined compressive strength (UCS)	• Modified and cemented granular materials	• Stability • Stiffness
Marshall flow	• Hot mix asphalt	• Stiffness
Marshal stability	• Hot mix asphalt	• Stability • Bearing capacity
Aggregate durability	• HMA and spray sealing aggregates	• Strength • Hardness • Toughness • Soundness
Average least dimension (ALD)	• Spray sealing aggregates	• Surfacing durability • Particle shape

3.7.1 Particle Size Distribution

Purpose of the test

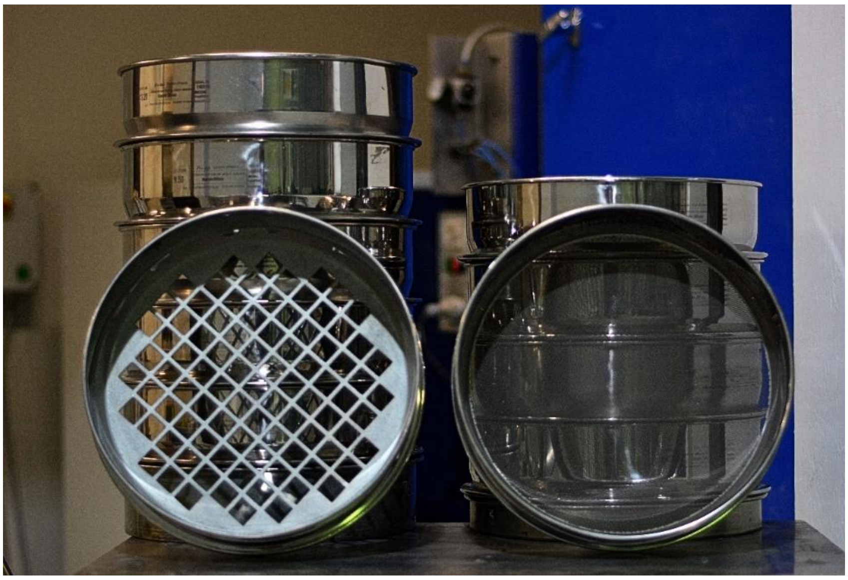
A particle size distribution or grading of a material is the distribution of various particle sizes and the amount of each size within a material.

Test method

Material grading is determined using a range of sieves with standardised aperture sizes typically between 26.5 mm and 0.075 mm (Figure 3.15).

Material finer than 0.075 mm can also be further characterised using a hydrometer analysis and is a measure of silt and clay fractions. This test is not typically required for pavement applications and the amount passing the 0.075 mm sieve is sufficient information.

Figure 3.15: Sieves for grading material



Presentation and descriptions of results

Granular pavement materials

The grading of a granular material can be presented in tabular form or graphical form. The sieve size and amount of particles passing that aperture size as a percentage of the overall sample mass is calculated and presented. When presented in graphical form the sieve sizes are plotted along the x-axis with a logarithmic scale.

PSD results may also be plotted on a log-log scale in which the slope (gradient) of the line represents the Fullers Index ‘n’ where close to n = 0.5 represents a continuous grading with almost zero voids and maximum stability.

Different types of gradings can sometimes have specific names which provide insight into the expected performance of a material. These can include:

- fine graded
- coarse graded
- coarse gap graded
- gap graded or armchair grading
- well graded
- uniformly graded.

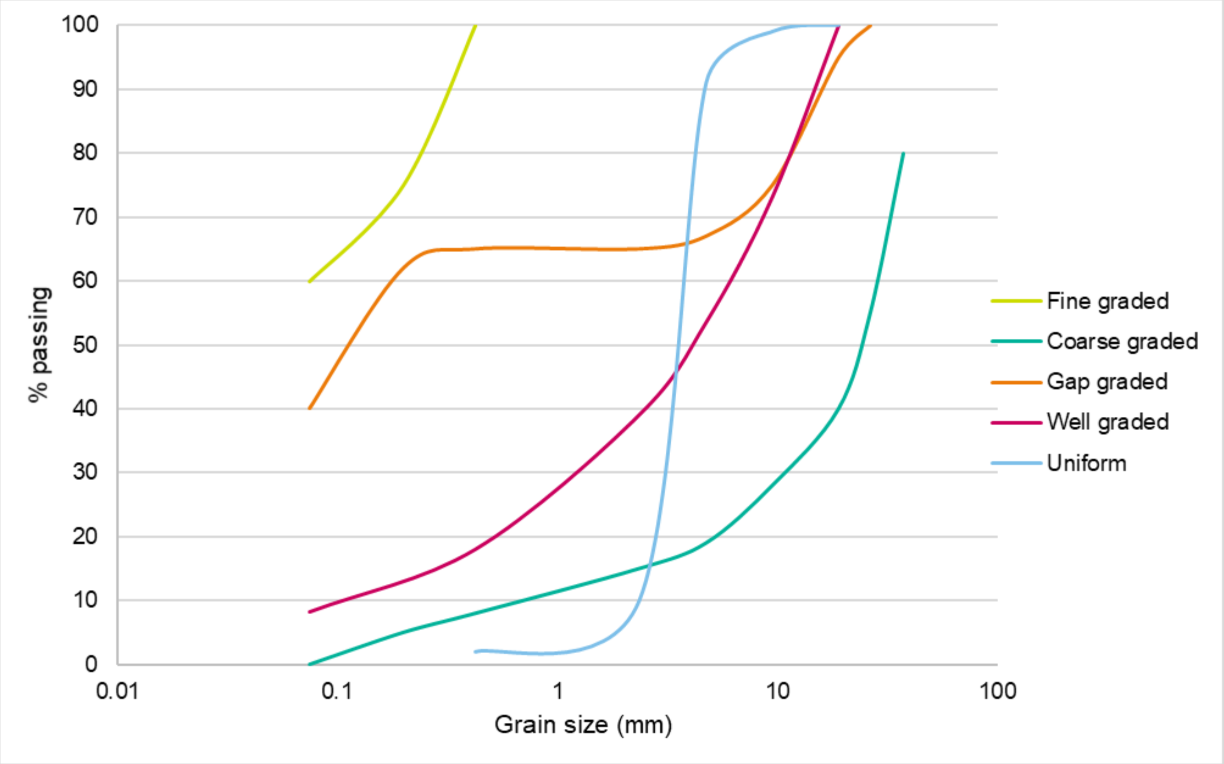
A graphical display of these different gradings is shown in Figure 3.16.

Asphalt and sealing aggregates

Aggregates are typically one sized i.e. 100% passing and 100% retained on the next smallest sieve such that the grading curve is near vertical.

Fine aggregates comprise washed sands again of an essentially single size.

Figure 3.16: Graphical display of different grading types



Influencing pavement performance

Granular pavement materials

The grading of a granular material will determine the ability of the material to pack together and achieve a high density when compacted. This achievable density and subsequent mechanical interlock between the material particles of a granular material determines:

- stability under traffic loading
- permeability and potential for moisture infiltration.

Soils with maximum density gradings are generally more workable and easier to place.

Grading characteristics such as the fines ratio (also known as dust ratio) and the grading modulus can be calculated using information from the grading results. These characteristics are good for comparing the grading characteristics of materials quickly and can also be used in specifications (see Section 4.1.3). A summary of the fine ratio and grading modulus are presented in Table 3.22.

Table 3.22: Grading characteristics

Property	Calculation	Comments
Fines ratio	$$FR = \frac{P_{0.075}}{P_{0.425}}$$ where FR = fines ratio $P_{0.075}$ = percentage passing 0.075 mm sieve $P_{0.425}$ = percentage passing 0.425 mm sieve	• A good representation of the grading with a focus on the fine material • Fine material influences performance the most • Fines provide suction and cohesive forces • Fines can also cause instability and moisture sensitivity • 0.20–0.65 typically a stable material
Grading modulus	$$GM = \frac{(300 - (P_{2.36} + P_{0.425} + P_{0.075})}{100}$$ where $GM.$ = grading modulus $P_{2.36}$ = percentage passing 2.36 mm sieve $P_{0.425}$ = percentage passing 0.425 mm sieve $P_{0.075}$ percentage passing 0.075 mm sieve	• Entire grading curve represented by a single value • Allows coarser and finer grading envelopes to be compared easily • Values > 1.5 coarse material • Values < 1.5 fine material

Asphalt and sealing aggregates

The grading of the aggregate component of a hot mix asphalt or spray seal determines the ability of the aggregate to pack together and achieve a high density when compacted. This achievable density and subsequent mechanical interlock between the aggregate particles determines the stability of a HMA under traffic loading.

The grading is also an important factor during the mix design of HMA as it influences the voids of the designed mix.

Different HMA mix types will have different aggregate grading requirements depending on the design applications and functionality requirements of the HMA.

3.7.2 Consistency (Atterberg) Limits

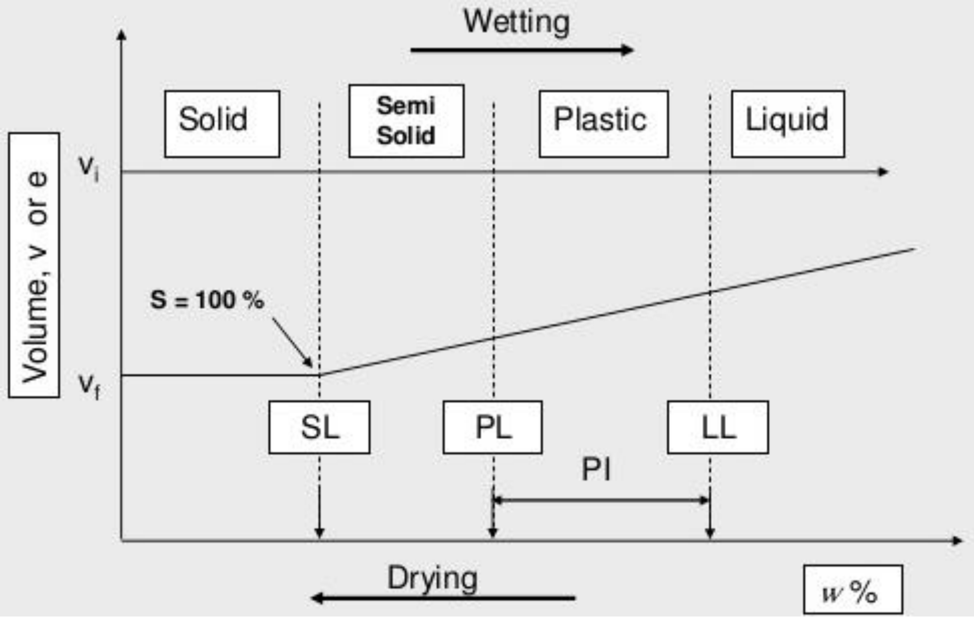
Purpose of the test

Consistency limits of a granular material provide insight into the characteristics of the fine-grained component of a material (particles smaller than 0.075 mm) particularly clay particles (particles smaller than 0.002 mm). They are also known as Atterberg Limits (Figure 3.17).

The consistency limits include the following test parameters:

- plastic limit (PL)
- liquid limit (LL)
- plasticity index (PI)
- linear shrinkage (LS)
- shrinkage limit (SL).

Figure 3.17: Consistency limits of a soil



Test method

The Atterberg Limits are determined on all fractions passing the 0.425 mm sieve only.

Plasticity limit

The plastic limit is the moisture content at which the material ceases to be malleable (i.e. plastic). It is determined by hand rolling the material on a glass plate to a thread no more than 3 mm in diameter to a point where it begins to crack or break (Figure 3.18). The plastic limit is indicative of the optimum moisture content for compaction.

Figure 3.18: Determining the plastic limit

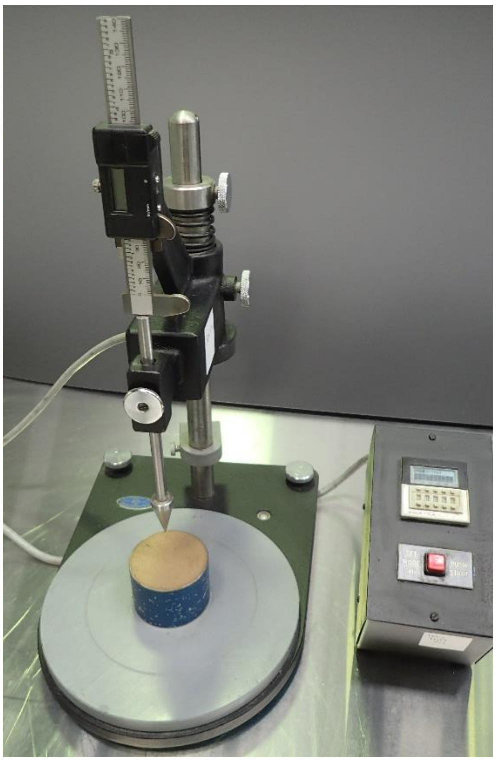
Liquid limit

The liquid limit is the moisture content at which the material ceases to be a liquid as indicated when fluid flow is instigated by mechanically tapping the Atterberg cup until a formed groove joins. The moisture content at which the material joins at 25 blows is termed the liquid limit (Figure 3.19).

The liquid limit may also be determined using the penetrometer method (Figure 3.20).

Figure 3.19: Atterberg cup apparatus

Figure 3.20: Penetrometer method



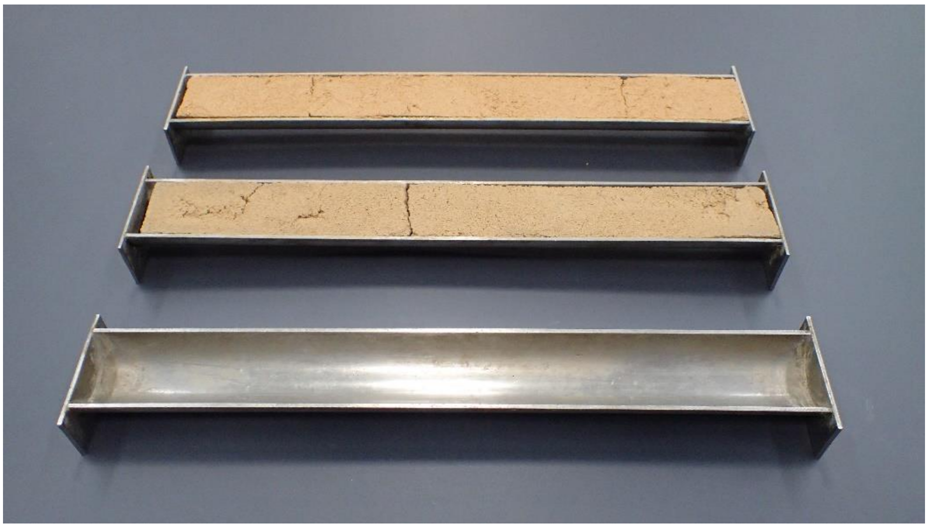
Plasticity Index

The plasticity index is not a test. It is the calculated difference between the liquid limit and the plastic limit.

Linear shrinkage

The linear shrinkage is determined by drying material prepared at the liquid limit and measuring the subsequent shrinkage in a linear mould (Figure 3.21). The length change of the material during the drying process is measured and the percentage volume change is calculated as the linear shrinkage.

Figure 3.21: Linear shrinkage mould



Shrinkage limit

The shrinkage limit is not commonly determined but is defined as the moisture content at which a material dilates or increases in volume with the addition of water.

Presentation and descriptions of results

The consistency limits are presented in tabular form. The plastic limit, liquid limit and linear shrinkage are expressed in terms of percentage. The plasticity index is calculated based on the difference between the liquid limit and the plastic limit. It is a unitless parameter.

Depending on the value of the plasticity index the material may be classified as one of the following:

- non-plastic
- low plasticity
- medium plasticity
- high plasticity.

Table 3.23 summarises the plasticity descriptor for soils depending on the values of the plasticity index, liquid limit and liner shrinkage.

Table 3.23: Plasticity descriptor for soils

Plasticity index	Liquid limit	Linear shrinkage (%)	Plasticity descriptor
0	0	0	Non-plastic
0–25	0–35	0–10	Low plasticity
25–35	35–50	10–14	Medium plasticity
> 35	> 50	> 14	High plasticity

Source: AS 1726:2017.

Influencing pavement performance

Consistency limits have a strong influence on material performance within a pavement and are linked to the type of clay minerals present and moisture sensitivity.

Plasticity Index and Linear Shrinkage

Plasticity index

- *Moisture sensitive potential; affects stiffness and strength*

Linear shrinkage

- *Easy, repeatable test especially for low clay content materials*
- *Can be used as an approximation of the plasticity index, **PI ≈ 2.5 x LS***
- *Moisture sensitive potential; affects stiffness and strength*
- *Volumetric instability; potential to shrink or swell, reactive soils*

Weighted consistency limits

As the consistency limits are determined by testing the proportion of the overall material which is smaller than 0.425 mm, the influence on pavement performance of these limits also depends on the amount of fine material in the overall material mass.

Weighted plasticity index and weight linear shrinkage are often calculated and used as a more representative indication of material performance in a pavement. In this manner the influence of plasticity (PI) can be moderated by the percentage of material finer than 0.425 mm in the complete grading.

Calculating Weighted Consistency Limits

Weighted plasticity index (WPI)

WPI = % passing 0.425 mm x PI

Weighted linear shrinkage (WLS)

WLS = % passing 0.425 mm x LS

3.7.3 Moisture Content

Purpose of the test

The moisture content of a pavement material will directly influence the stability of the material, and the ability of the material to be compacted to an adequate level.

Test method

Determining the moisture content of a material is undertaken by weighing a small amount of the wet material and weighing it again after drying inside an oven at 105 °C or a microwave oven until the weight of the material is constant.

The difference in mass before and after drying represents the mass of water which has evaporated and is expressed as a percentage of the dry mass as the moisture content.

Presentation and descriptions of results

Moisture content of a material is presented in tabular form. It is expressed as a percentage.

Influencing pavement performance

The moisture content of a granular material, especially those with high fines or high plasticity, will directly influence the performance of a pavement structure. High moisture can cause instability and low stiffness which can lead to high risk of permanent deformation. This is especially true for lower quality and non-standard materials.

The moisture content also influences the field density that can be achieved.

See also Section 3.7.4.

Equilibrium Moisture Content

Equilibrium moisture content of a material relates to the moisture content attained in (pavement material) or beneath a road pavement (subgrade) after a period of in situ service.

- *When a material is at a moisture level equal to the equilibrium moisture content it will be at the optimum stability.*
- *In a clayey material susceptible to volumetric instability, moisture contents outside of the equilibrium value will cause shrinkage or swelling, causing pavement movement and even premature failure.*

3.7.4 Maximum Dry Density and Optimum Moisture

Purpose of the test

The determination of maximum dry density (MDD) and optimum moisture (OMC) of a pavement material allows the material to be compacted to the highest density (lowest void content) during construction.

There is an optimum moisture at which the maximum density will be achieved for a particular compactive effort (compaction is the process by which the air void ratio of a soil is reduced).

Test method

There are two common methods for determining the MDD and OMC of a pavement material. The test method is the same except for the compactive effort applied.

Standard compaction

Material of a known moisture content is compacted into a 105 mm diameter by 115 mm high cylindrical steel mould using a 2.7 kg hammer falling 300 mm. The material is compacted in three separate layers.

Modified compaction

This is based on standard compaction using instead a 4.9 kg hammer falling a height of 450 mm and compacted over five layers.

Compaction testing of pavement materials larger than 20 mm

For both compactive effort methods, larger sized moulds (150 mm diameter) are used for maximum aggregate sizes coarser than 19 mm or alternatively a numerical oversize correction is applied.

Modified vs Standard Compaction

Standard (600 kJ/m^3 compactive effort)

- *2.7 kg hammer falling 300 mm, 3 layers of material*
- *Specified for subgrade and earthworks construction*
- *Provides OMC at standard maximum dry density (SMDD)*

Modified (2700 kJ/m^3 compactive effort)

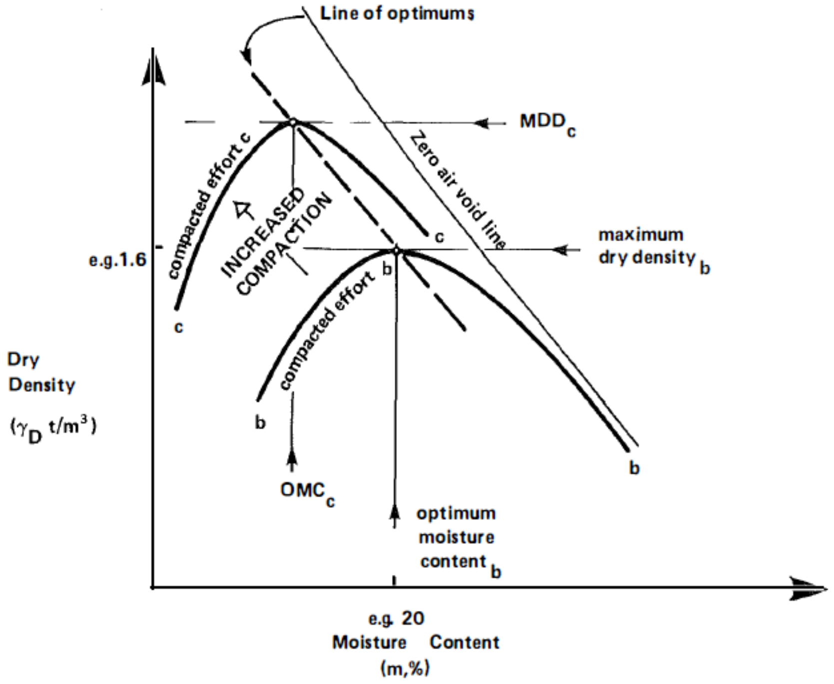
- *4.9 kg hammer falling 450 mm, 5 layers of material*
- *Specified for base and subbase layers*
- *Provides OMC at modified maximum dry density (MMDD)*

Presentation and description of results

The MDD and OMC can be presented in tabular form or in graphical form as a compaction curve. The graphical form will present the three or four tested moisture contents along the horizontal x-axis and the calculated dry density on the vertical y-axis. A curve is also drawn through the points to help identify the peak of dry density at the varying moisture contents.

This allows the MDD and OMC to be inferred from the graphical presentation of the test results.

Figure 3.22: Dry density moisture curve



Influencing pavement performance

A well compacted layer of material has greater stability and will be less likely to undergo deformation under traffic. It is important to be able to achieve the maximum density in-service to ensure ongoing pavement performance. By understanding the moisture density relationship of a soil, the specification density can be targeted through the addition of a specific amount of moisture during compaction works.

General experience in roadmaking is that the modified compaction values better represent field conditions. Figure 3.22 indicates the compaction curves for standard and modified compactive effort where the higher modified compactive effort gives a higher density but lower moisture content. This can be significant in practice where selecting a heavier roller can achieve the desired density at lower moisture content which can be advantageous in areas where construction water is scarce.

Dry-back

Dry-back is a term used in compaction specifications to prevent entrapment of moisture in the pavement during construction of pavement layers. In principle each layer must be allowed to dry-back from OMC prior to the next layer being placed.

Dry-back increases stability by generating suction forces within a pavement material. It is commonly specified as a percentage of OMC (80% OMC) or as a degree of saturation (DOS) of the material.

If density and dry-back specifications are not met, the stability and long-term strength of the granular proportion of the pavement system may be compromised, increasing the risk of premature failure of the whole pavement system.

3.7.5 California Bearing Ratio

Purpose of the test

The California bearing ratio (CBR) is a test which classifies the load carrying capacity of a material. For pavement applications CBR is often undertaken to assess the strength of subgrade materials and granular basecourse and subbase materials.

Test method

The CBR is conducted on material finer than 19 mm (i.e. oversize removed) by compacting the material into a 150 mm diameter cylindrical mould at the required nominated dry density ratio. A 50 mm plunger is then forced into the surface of the specimen and the resistance force measured at penetrations of 2.5 mm and 5.0 mm.

The measured force recorded at 2.5 mm and 5.0 mm penetration are then portioned as a percentage of the standard penetration loads 13.2 kN for the 2.5 mm and 19.8 kN for the 5.0 mm. The higher of the two results represents the CBR of the material.

A test condition of soaking for 4 days and/or unsoaked applies and the compacted density should replicate the in-service density specified.

Presentation and description of results

Results are presented in tabular form. The CBR of a material is calculated as a percentage of the standard penetration loads.

Influencing pavement performance

Higher values of CBR indicate a material which will be able to support higher traffic loads. CBR of a subgrade material is used in the empirical design of pavements as one of the major design input parameters.

High quality materials often have a high CBR due to the material's mechanical stability and interlock when compacted influenced by grading and plasticity characteristics.

California Bearing Ratio

Subgrade

- *High CBR subgrades require a thinner pavement*

Pavement layers

- *Materials with higher values of CBR are often used in upper pavement layers*
- *Standard quality materials*
  - *subbase soaked CBR > 30%*
  - *basecourse soaked CBR > 80%*

Moisture

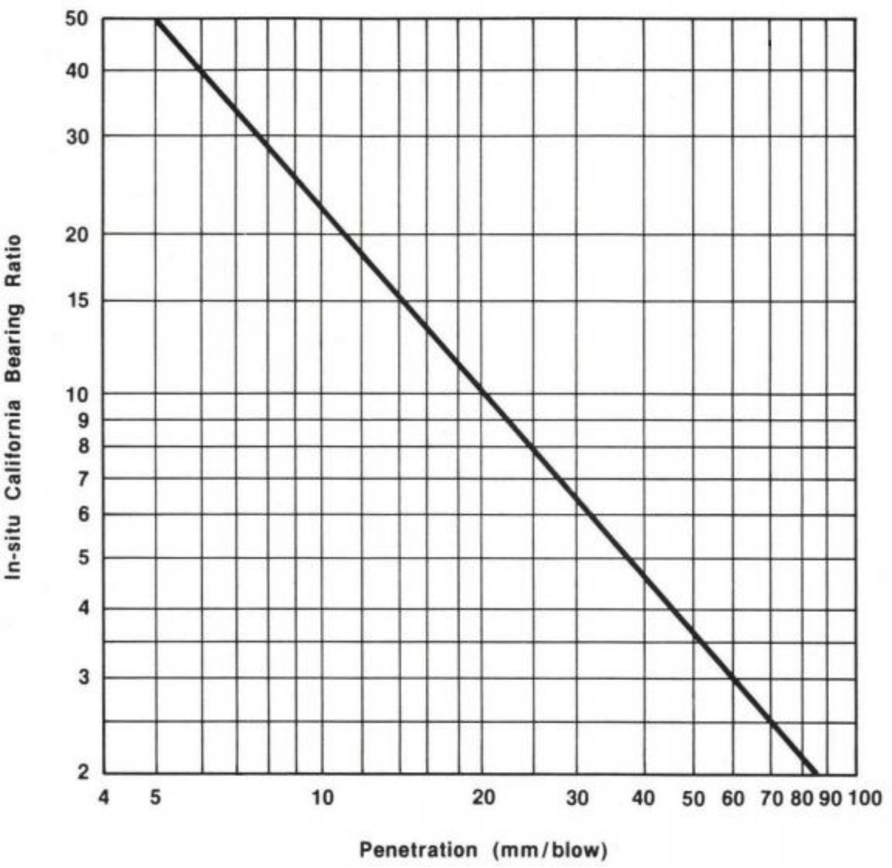
- *In drier climates judgement of the adoption of a design CBR close to OMC rather than soaked may be considered*
- *Compacted samples are commonly soaked for 4 days.*
- *Longer soaking periods can be specified.*
- *The unsoaked CBR will be higher than the soaked CBR*
- *A sample which has been dried back before testing will have a higher CBR than a sample tested at 100% OMC*

Dynamic cone penetrometer

The dynamic cone penetrometer (DCP) can be used as a simplified method for estimating the CBR of an in situ, cohesive, subgrade material for design purposes (Figure 3.23).

Description of the test method used for the DCP is presented in Section 4.3.2.

Figure 3.23: Correlation of cone penetrometer and California bearing ratio for cohesive soils



3.7.6 Resilient Modulus

Purpose of the test

The resilient modulus of a material quantifies magnitude of vertical deformation in relation to the applied dynamic load and is commonly referred to as 'stiffness'. When the load is removed the pavement 'rebounds' however under repeated applications a permanent deformation (rutting) is initiated.

The test used to determine the resilient modulus and permanent deformation characteristics is known as a repeated load triaxle (RLT) test and can be undertaken on all types of granular materials including modified and bound.

Test method

The resilient modulus is obtained by preparing specific size compacted cylindrical material samples in the laboratory or by obtaining field cores from previously laid and compacted materials. Sample core sizes depend on the nominal size of the material.

A core sample is placed in the testing apparatus commonly known as a repeated load triaxial machine (Figure 3.24). Under a static lateral pressure within the test cell varying repeated vertical loads are applied to the specimen since the stiffness of a material is stress dependent.

A combination of the rebound deformation and the load applied is used to calculate the stiffness i.e. dynamic applied stress/dynamic recovered strain. Further information can be found in AS 1289 6.8.1 (1995).

Figure 3.24: Repeated load triaxial apparatus

Presentation and description of results

Resilient modulus is commonly presented in tabular form and is expressed in MPa.

Influencing pavement performance

Higher values of resilient modulus indicate a stiffer material which will spread load over a larger area, reducing the stresses on underlying materials. Resilient modulus is used in the mechanistic design of pavements as one of the major design input parameters.

High quality materials often have a high resilient modulus due to the material's mechanical stability when compacted influenced by grading and plasticity characteristics.

3.7.7 Unconfined Compressive Strength

Purpose of the test

The unconfined compressive strength test (UCS) defines the compressive strength of a pavement material when lightly bound or bound. It is unsuited to granular and modified materials.

Multiple UCS tests are often undertaken at different curing periods to demonstrate the change in strength with curing time. Common cure intervals are 7 days and 28 days,

Test method

Samples can either consist of laboratory prepared samples or core samples from the field (Figure 3.25).

For laboratory prepared samples a cylindrical specimen is prepared by compacting material in a mould at the moisture and density conditions expected in-service. Prepared samples are removed from the mould and left to cure for the specified number of days.

Cured samples are carefully measured to determine the average diameter of the sample, saturated for 4 hours then placed in a UCS apparatus. A vertical compressive load is then applied at a constant rate to failure of the specimen recorded and the associated stress calculated as the UCS of the specimen.

Figure 3.25: Unconfined compressive strength test apparatus and prepared sample

Presentation and description of results

The UCS is presented in tabular form and is measured in MPa.

Influencing pavement performance

The UCS is used to characterise the strength of bound granular materials and can be used to estimate the material modulus or stiffness. It is also used to differentiate between modified, lightly bound and bound granular materials (see Section 3.3).

Materials with higher UCS values indicate higher material stiffness and may also be more prone to fatigue cracking failure.

3.7.8 Marshall Properties

Purpose of the test

The Marshall properties of HMA provide a prediction of likely strength performance mix when in-service. They are also used to optimise the proportion of binder, aggregate and voids during the mix design process (see Section 3.2).

Test method

Asphalt properties are obtained by preparing compacted cylindrical HMA samples in the laboratory with compaction using a Marshall compaction hammer (manual or automated) weighing 4.535 kg and which falls freely from a height of 457 mm. Both faces of the specimen are compacted with the same number of blows. The number of blows is dependent on the intended application of the HMA and is typically 35, 50 or 75 blows per face.

A diametric load is applied to the test specimens under a controlled temperature environment.

Presentation and description of results

The Marshall properties include the two following parameters:

- Marshall stability (kN)
- Marshall flow (mm).

The Marshall properties can be presented in tabular or graphical form. Marshall stability may be plotted against binder content to demonstrate the change in stability with change in mix design parameters so an optimal mix can be chosen.

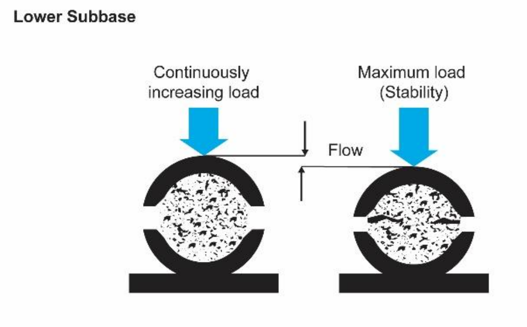
Marshall Properties

Marshall stability (kN)

- *Force in kN a cylindrical sample can withstand before squashing*
- *Lower limit specified*

Marshall flow (mm)

- *Amount of vertical deformation in mm caused by the squashing*
- *Upper and lower limit specified*



Influencing pavement performance

Different design applications have varying target values for Marshall properties.

The higher the Marshal stability the better the HMA mix will perform in-service under traffic loads. Mix stability should be maximised while keeping the Marshall flow and mix air voids within acceptable limits.

A HMA with a flow value below the minimum limit is considered a brittle mix and would be at a higher risk of premature fatigue failure. A mix with a flow value above those specified would be considered a plastic mix and would be at a higher risk of premature rutting and deformation failure.

3.7.9 Aggregate Durability

Purpose of the test

The durability of aggregates used for HMA or spray sealing aggregate is its ability to retain its size, shape and mechanical properties without breaking down under repeated traffic loads and changing environmental loads.

Aggregate Durability

Durability can be broken into four categories:

- *Strength*
  - *ability to withstand traffic load*
- *Hardness*
  - *ability to withstand abrasion when in contact with other materials*
- *Toughness*
  - *ability to withstand impact loads (mixing and construction loads)*
- *Soundness*
  - *ability to withstand varying environmental loads such as wet, dry, heat and cold.*

Test method

There are several tests which quantify the durability of an aggregate under different conditions including repeated loads, wet and dry load cycles, hot and cold load cycles, chemical alteration and mineral composition analysis. Common tests include:

- Wet/dry strength variation
- Los Angeles value.

Wet/dry strength variation

This test involves crushing a test portion of aggregate in a steel cylinder and adjusting the applied load to produce a final material with at least 10% fines (Austroads 2008). The crushing force at which 10% fines are produced is the aggregate strength. The test is repeated under both dry and saturated conditions.

Los Angeles value

The test involves placing a portion of aggregate in a steel drum fitted with steel balls and rotated a fixed number of times. The test result is determined by assessing the decrease in material retained on the 1.7 mm sieve after conclusion of the test.

Presentation and descriptions

Results are presented in tabular form.

The wet/dry strength is the ratio between wet and dry strength and is expressed in terms of percentage.

The Los Angeles value is the change in material mass greater than 1.8 mm in size and is expressed in terms of percentage.

Influencing pavement performance

Wet/dry strength variation

The wet strength is a direct measure of load-carrying ability of saturated materials. High wet/dry variation normally correlates to poor soundness properties (Austroads 2008). The test measures strength loss due to saturation with higher wet/dry strength variation indicating poor soundness.

Los Angeles value

The LA value is a measure of dry abrasion resistance. The higher the LA value, the less durable the rock.

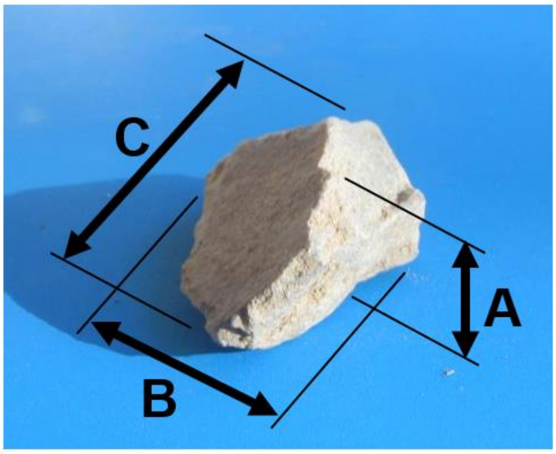
3.7.10 Aggregate Average Least Dimension

Purpose of the test

The average least dimension (ALD) of an aggregate provides data on the shape and size of aggregate material for use in spray sealing.

The ALD is defined as the smallest dimension of a particle when placed on a horizontal surface as shown in Figure 3.26.

Figure 3.26: Dimensions of a sealing aggregate



Test method

A specified number of sorted aggregate particles are passed through a multi-slot sample divider. The smallest width slot for each particle to be able to pass through is recorded and tallied. The average width of the aggregate particles is then calculated based on the tally of results.

Presentation and descriptions

Results are presented in tabular form and expressed in terms of mm.

Influencing pavement performance

The ALD is used in the design of spray seal surfacings to calculate both the aggregate spread rate and the design binder application rate.

Poor sampling techniques and/or inaccurate testing procedures to determine ALD will result in incorrect aggregate design spread rates and inaccurate design binder application rates.

Aggregate shape – elongation and flakiness

Elongation and flakiness of an aggregate can influence the performance and stability of a HMA.

Elongation is defined as particles which have a length considerably larger than the other two dimensions. An elongated particle will have a greater dimension which is 1.8 times its mean size.

Flaky aggregate is defined as an aggregate particle with a least dimension (thickness) less than 0.6 of the mean of the smallest sieve size through which the particle passes and the largest sieve size on which the particle is retained.

3.8 Transport Infrastructure Product Evaluation Scheme

There are numerous materials and products available in the market that can be used in the construction and maintenance of road assets. It can be difficult to ascertain whether these materials and products are suitable for a project purely based on the information and data provided by the suppliers. A way to determine their suitability is to utilise independent assessment and certification schemes such as the Australian Paint Approval Scheme (APAS) or Transport Infrastructure Product Evaluation Scheme (TIPES).

TIPES is a process aimed at providing an independent fit-for-purpose assessment of innovative road construction products. TIPES is intended for the evaluation products that fall outside the scope of established standards and specifications.

Understanding how well a proprietary product will perform for pavement applications reduces risk and can also provide cost-saving design options or construction techniques.

TIPES is a national scheme endorsed by all Australian state and territory road agencies as well as IPWEA (QLD), the Queensland Local Roads Alliance and WALGA.

3.8.1 Process of Obtaining TIPES Certification

Products are assessed by an expert panel (inclusive of road agency representatives), who determine what is required to substantiate the proponent's claims for a product. This involves products being evaluated through a gating process where products need to pass each stage to move to the next phase of evaluation.

The stages of a TIPES production evaluation are:

1. Stage 1: Evaluation
   a. an evaluation of available product information by the expert panel
2. Stage 2: Test
   a. an independent series of laboratory tests recommended by the expert panel based on the product application and claims
3. Stage 3: Trial
   a. field trials to assess real-world performance. These are often incorporated into existing road agency and Local Government projects

4. Stage 4: Certification

    a. final assessment of results and certification of product (Figure 3.27).

Figure 3.27: TIPES certification

4 Construction

4.1 Sourcing, Extraction and Specification of Materials

Extractive industry sites for natural engineering materials are generally associated with quarries or local borrow pits operated under strict licensing and regulatory requirements.

Most major extractive industry sites are approved under a Planning Act and administered according to development permits issued by the relevant local or state government. The various standards are set under a State Environmental Protection Act which applies to the operations.

4.1.1 Quarries

A quarry is a site where material for construction purposes, such as construction sand, gravel, and quarry rock is extracted from the earth and generally processed to meet a product specification.

Depending on the nature of the source rock, extraction can be undertaken by mechanical ripping or excavating in softer rocks and river gravels but in the case of hard rock sources extraction by drilling and blasting a quarry face for excavation.

Quarries are a licensed facility generally operated commercially as a supplier of quarry products.

4.1.2 Borrow Pits

Borrow pits are locally excavated sources of naturally occurring pavement materials which are:

- on road construction projects, typically located along the alignment of the site in adjacent land holdings
- in Local Government districts as a periodic source of material extraction, manufacture and supply.

The properties of materials can vary with depth and a prior investigation of the materials source should be undertaken to understand the properties and variability within a borrow pit.

For new borrow pit applications both environmental and heritage approvals must be sought from the respective state bodies which in some cases can be a lengthy period which should be taken into account in project planning.

Borrow pits are generally a limited term source for materials extraction with strict regulations related to the different phases of their operation including rehabilitation and environmental management before, during and after operation has ceased.

Operation of Borrow Pits

Common phases of borrow pit operation:

1. Licensing and approvals
   a. *access and clearing permits*
   b. *development of management plans*
2. Site preparation
   a. *vegetation clearing*
   b. *removal and stockpiling topsoil*
   c. *instatement of diversion drains*
   d. *establishment of pit access*
3. Opening the pit
   a. *removal and stockpiling overburden*
   b. *pit wall shaping for safety*
   c. *in pit drainage*
4. Excavation of targeted material
   a. *extraction*
   b. *in pit processing or mixing*
   c. *stockpiling*
   d. *hauling material*
5. Rehabilitation
   a. *reinstatement*
   b. *surface shape and topography*
   c. *replacement of topsoil*
   d. *vegetation seeding and mulching*

It is important to understand and follow all local, state and federal regulations related to borrow pit operation.

Planning and operation

Before a borrow pit is established the location of the pit, operation processes and rehabilitation planning all need to be accounted for and documented. This will ensure efficient material extraction and minimal environmental impact.

- The location of borrow pits is an important consideration in terms of their environmental impact and aesthetics.
  – Borrow pits should be located in consideration of the landscape aesthetics of the area as well as ensuring that natural water-flows and drainage paths are not impeded to any degree.
- Any drainage within the extremities of the borrow pit licensed area shall be contained within it and not permitted to be discharged outside the licensed area into natural drainage paths, rivers or creeks.
- It is desirable that dedicated well-managed pits be developed rather than numerous smaller pits with a lower level of management.
- Borrow pit sites should be selected with consideration of erosion and sediment control during their operation.
- A catch drain should be installed on the high side of the borrow pit to prevent excess water entering the pit.
- Material taken from a borrow pit has the potential to spread soil-borne pathogens unless careful management is undertaken.
  – Ensure material is free from soil-borne diseases before use. This may need to be determined by an expert, but care should be taken near areas of dead or unhealthy vegetation, as the cause of the vegetation death may still be present in the soil.

- The topsoil at a borrow pit site should be graded to one side and used in the rehabilitation of the area when the pit is no longer required.

Topsoil

When preparing an area for borrow operations, the surface soil (topsoil) is removed and stored for later pit rehabilitation. Consideration of removal and storage must consider that the soil may contain a majority of a tree's surface roots and the seeds of local native vegetation. Topsoil also contains weed seeds in areas where weeds have established.

Topsoil is vital for the rehabilitation of sites which have previously been cleared or disturbed and should therefore be handled, stockpiled and managed effectively.

Topsoil Management

Appropriate practices for management of topsoil

- *Grade off topsoil from work sites and stockpile for rehabilitation operations*
  - *Topsoil is generally graded to a depth of between 100 and 200 mm*
- *Topsoil should not be moved from an area where weeds exist to areas of significant conservation value.*
- *Topsoil should not be stockpiled higher than 1 m or for more than 12 months,*
  - *This will ensure the survival of local native seeds, which will germinate when the soil is spread*
- *Do not mix topsoil with poorer quality subsoil/overburden*
- *Stockpiled topsoil can be temporarily resown with sterile grasses*
  - *This will help maintain organic matter and stockpile structure by erosion prevention*
  - *It will also reduce the risk of weed invasion*

Overburden

Overburden is the material underlying the topsoil (also referred to as subsoil) and overlying the targeted borrow material. The properties of overburden material are often extremely variable and may also include deleterious materials such as organic matter, tree roots, rocks and gravels.

Overburden can also be used as a rehabilitation material for pit reinstatement once a pit is no longer required and should be stockpiled for this use. The depth of overburden removal should also be carefully controlled to ensure efficient use of the targeted underlying material.

Scalps and ripped rock

Scalps are produced via a process called 'scalping' where fines contained within the source rock delivered to the crushing plant are removed before the rock enters the first stage of crushing.

Ripped rock is produced from the softer, weaker rock material mechanically removed during material stockpiling or during the quarrying processes of sound rock.

Scalps and ripped rock may be processed through a combination of crushing and screening to obtain more appropriated material properties.

Even with processing, scalps and ripped rock are often of lower quality to crushed rock due to partial weathering and depending on the pavement application may be suitable as a lower quality base material or as a subbase or fill material.

Geological deposits

The type of material extracted from a borrow pit will depend on the geological deposit. The type of deposit commonly reflects characteristic material properties such as particle shape or clay content. The type of deposit will also determine how material from a borrow pit is best extracted to obtain optimised material properties. summarises common geological deposits found throughout Australia.

Table 4.1: Common geological deposits of Australia

Deposit name	Deposit characteristics
Class A – in situ weathered rocks (residual deposits)	• Material remaining after a rock has been removed by chemical weathering processes such as solution or leaching in tropical conditions • Weak or poorly cemented • High plasticity and moisture sensitivity can be treated with the addition of lime or cement or a combination
Class B – soft rock	• Formed by the deposition from either water or air, of the organic remains of plants and animals and by the crystallisation of soluble materials from solution • Usually mechanically weak and can be ripped and grid rolled • Tend not to be widely used in road building
Class C – ridge gravels	• Formed through in situ weathering of sedimentary or metamorphic rocks • Angular shaped gravel sometimes rounded • Occur extensively and have been of great value in road construction for unsealed gravel surfacing and as a road base for sealed roads • Can be very variable and may require ripping, screening and grading control • May be modified by stabilisation with cement or lime • Silcrete may not be suitable for lime stabilisation
Class D – transported deposits	• Occur alongside both existing watercourses and the paths of ancient prior streams • Rounded alluvial gravels • Due to their rounded nature they are best crushed before use as a road base. • Cement and lime stabilisation of these soils is not generally effective

Class	NSW	NT	QLD	SA	TAS	VIC	WA
A	• Grey earth • Clay	• Granite sands • Laterites	• Basaltic clay • Black soil	• Laterites		• Scoria • Granitic sands	• Laterites • Coral
B	• Sandstone • Shale	• Siltstones	• Siltstone • Sandstone • Calcareous siltstone	• Sandstone • Siltstone • Shale	• Sandstone • Siltstone	• Sandstone	• Sandstone
C	• Calcrete • Calcareous soil	• Calcrete • Iron pan	• Silcrete • Ferricrete • Calcrete • Colluvial gravel	• Calcrete • Iron pan	• Quartz gravel	• Limestone	• Calcrete • Limestone • Ironstone
D	• Prior streams	• River gravel • Sand-clay	• River gravel • Sand-clay	• River gravel • Sand-clay	• River gravel	• River gravel • Sand-clay • Tertiary gravel	• River gravel • Sand-clay

Source: Robinson, Giummarra and Oppy (1999).

Investigation of local sources

To understand the materials which are available within a local area it is important to undertake an in-depth investigation of all materials sources. Having an overview of all possible material options, whether it be several sources or a single source, will help tailor a fit-for-purpose material solution to a design problem.

Material sources for pavements will vary depending on the project setting being either urban or regional. The project setting will therefore determine the level of source investigation required for a specific design scenario.

The level of detail required by a material source investigation will also depend on other factors including:

- budget
- road category
- required pavement level of service
- road function.

The optimum level of detail and subsequent cost of a material source investigation should be assessed in the context of the expected whole of life cycle cost profile of the pavement.

Material Sources: Urban vs Regional Setting

Urban settings:

- *Supplied materials*
- *Properties can be specified*
- *Available volumes known*
- *Simpler haulage logistics*
- *Minimal permits*
- *Clear unit cost*

Regional settings:

- *Natural materials*
- *Local borrow pits*
- *Properties are variable*
- *Volumes unknown*
- *Complex haulage logistics*
- *Access and permits*
- *Landowner compensation*

Desktop study

Desktop studies are undertaken as a preliminary step in the investigation of material sources. They collate information which is readily available including information from internal databases, documents, reports and maps.

Relevant information about materials sources can also be obtained through conversations with current staff, past staff, state and territory road agencies, local material supply contractors, and agricultural landowners. Table 4.2 summaries the information which should be gathered during a desktop study and why this information is relevant to design.

Table 4.2: Material source investigation: Desktop study information

Information required	Information function
Design scenario	• project location and extent • required pavement level of service • preliminary material specification requirements • preliminary pavement and surfacing type selection • preliminary design • required material volumes
Location	• material haulage distances • access and logistics • construction planning • environmental and heritage site risks • required permits and exclusion areas • social and agricultural considerations • borrow pit and extraction design
Type of material	• physical description of source material i.e. clayey gravel etc. • material suitability for pavement function • preliminary stabilisation or modification assessment • borrow pit and extraction design
Material properties from past testing	• material suitability for pavement function • material suitability for traffic and climate • preliminary stabilisation or modification assessment • preliminary pavement and surfacing type selection • preliminary design
Past usage and performance	• material suitability for pavement function • material suitability for traffic and climate • preliminary stabilisation or modification assessment • preliminary pavement and surfacing type selection • preliminary design • expected pavement performance
Volume available	• required permits • source access and logistics • environmental and heritage site risks • rehabilitation plan • use of alternative sources for extra volume • construction planning • borrow pit and extraction design
Access and permit requirements	• landowners consent • council planning regulations • state or territory regulations • federal government regulations • environmental and heritage site risk management plans • rehabilitation plan

Field investigation

The information collated by a desktop study can be used to plan a field investigation. A field investigation allows specific areas of interest to be targeted to obtain more information or to confirm existing information.

It is important to plan a field investigation based on the results of the desktop study to ensure the relevant information is collected in an efficient manner. This plan can be used to undertake an investigation in-house or used to develop tender documents for external consultants to undertake larger, more complex investigations.

Field investigations may also require permits and access permissions depending on the location. Management plans and rehabilitation considerations also need to be accounted for depending on the extent of the investigation and disturbance of ground.

Field Investigation

Information to be collected

- *Mapping and survey of source location*
- *Visual inspection of material*
- *Sampling of material*
  - *manual or mechanical depending on laboratory testing*
- *Laboratory testing*
  - *tests will depend on budget, past information and use of material*
- *Deposit profile*
- *Accurate area and volume estimates*

Materials extraction

Most natural materials are variable, mixing and blending to obtain a homogeneous mixture will usually be required during material extraction. The layout and working plan of the pit should be influenced by the geology of the site to ensure consistent and acceptable quality of the material. The working face should be oriented to intersect the variety of material quality in the pit rather than be located in a single form of the material.

It is important to work the full depth of the face in the pit, and then move material parallel to the face to ensure thorough mixing. If placed unsorted on the road formation, windrowing and cross-blade mixing with a grader will be required.

Equipment

Depending on the types of material to be extracted from a borrow pit different methods of excavation may be required (Figure 4.1). The type of equipment chosen for extraction should be based on achieving the most economical extraction with the available plant. Table 4.3 summaries the common types of plant used for mechanical extraction of material from a borrow pit.

Figure 4.1: Dozer working a local borrow pit

Table 4.3: Common types of mechanical extraction plant

Criteria	Bulldozer	Front end loader	Hydraulic excavator	Dump trucks or scrapers
Excavation mode	• Digs and pushes • Adequate control	• Minor digging of soft material • Lifts and carries • Good control	• Digs, swings and deposits • Excellent control • Can avoid mixing materials	• Scrapers can load • Small quantities
Operating distance	• 91 m • Pushing downhill preferred	• 91 m on good traction surfaces	• 23 m limited to swing distance	• No practical limits • Trucks must be loaded

Mixing and processing

The material, as raised directly at the pit face, may not be immediately usable and may require processing in order to achieve suitable properties like PSD and plasticity. Materials can be bulldozed and processed into suitable stockpiles inside the pit boundaries, and then hauled from these stockpiles directly to the road in a relatively consistent and uniform form. A separate working area or pad may be required when there are area restrictions within the pit area. Alternatively, it may be possible to do this directly on the road formation.

It is preferable that the processing of the materials to the required specifications be undertaken in the pit area instead of on the road to minimise disruption to any existing traffic and minimise the haulage of unsuitable material likely to be spoiled during construction. Figure 4.2 shows a mobile crushing plant undertaking material processing.

Figure 4.2: Mobile crushing plant

Borrow Pit Operations – Mixing & Processing

Altering grading

- *breaking down oversize material to no larger than 50 mm*

Altering plasticity

- *addition of additives*
- *adjusting the quantities of the finer material (i.e. smaller than 0.425 mm)*

Screening or size knockdown

- *portable screening may also be called power screens or grizzlies*
- *removes oversize particles while not influencing the smaller fractions of the material*

Crushing

- *can be undertaken using portable crushing, rock busters and grid rolling*

In pit processing

In pit processing may require a single crusher unit or, in the other extreme, a multi-stage crushing and screening plant. This can depend not only on what end-product is required and the economics of supply but also on the type of plant that is available at the time required. In pit processing with a mobile crushing plant permits high production rates (up to 400 tonne per hour) whilst also producing a consistent, graded product.

Depending on the type of material being crushed, there are some characteristics, such as particle shape and Atterberg limits, which can be influenced by the inherent nature of the rock. The selection of the appropriate crusher type can modify these characteristics to some extent in the final product.

Schematics of different mobile crusher types are presented in Appendix A.1.1.

On road crushing

Crushing extracted material on the road may be a preferable option due to space limitations, low processing requirements or other reasons. There are a number of machinery options to breakdown material including:

- grid rollers
- rock busters
- other forms of drum rollers such as heavy smooth drum, padfoot or sheepsfoot rollers (with or without vibration), landfill compactors and in some cases square drum rollers have been successfully used.

Pictures and characteristics of various on road crushing plant are presented in Appendix A.1.2.

Stockpiles and waste storage sites

Stockpiles and waste storage sites play an important part in road construction and maintenance systems. Stockpiles allow roadwork materials to be stored close to a work site for use during a construction or maintenance operation and allow excess material to be stored for future work. Waste sites allow unwanted material to be collected in one place before removal from the work site. The management of stockpiles and waste storage sites involves consideration of the adverse impact they may have on the surrounding vegetation, waterways and landscape. A typical stockpile is shown in Figure 4.3.

Figure 4.3: Stockpile of extracted natural material

Guidelines for the management of stockpiles and waste storage sites include the following:

- Stockpiles and waste storage sites should be located throughout a municipality or region, to allow quick and easy access during roadworks operations.
  - They should be located away from roadsides with significant conservation value and in areas with effective drainage systems.
  - They may be able to be located on cleared private land, after permission is granted from the landholder.
  - Their location should also take into consideration their aesthetic impact on motorists using the road. Location behind roadside vegetation can reduce the visual impact and allow the protection of existing vegetation (Roadside Conservation Committee of Victoria 1995).
- The boundaries of stockpiles and waste storage sites should be clearly marked and fenced to protect surrounding vegetation.
  - Areas for vehicle access and turning should be provided.
- Clean material stored at stockpile and waste storage sites should be kept away from material that is infested with weed seeds or soil-borne pathogens, to prevent cross-contamination.
  - Contaminated material should not be stored near vegetation of significant conservation value, where weed invasion can occur.
- Avoid stockpiling material under trees, as this leads to soil compaction and reduces the effectiveness of surface roots.
- Use weed control measures before stockpiling material.
  - Monitor stockpiles for weed growth and undertake follow-up weed control if necessary.
  - The cleaning of vehicles and machinery before leaving a weed-infested stockpile or waste storage site will help to prevent the spread of weeds.
- The rehabilitation of stockpile and waste storage sites can involve either returning an area to its original condition or converting it into another function that can be used by passing motorists, such as a wayside stop.
  - Rehabilitation to the original condition involves the removal of all non-natural material, deep ripping to reduce soil compaction and replanting of local native vegetation.

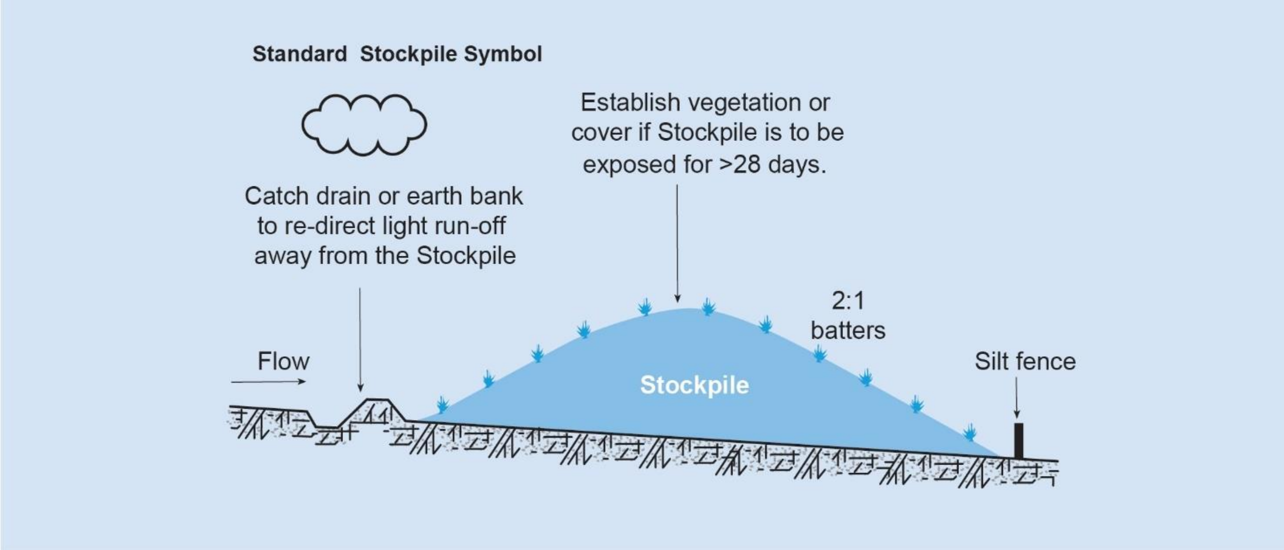
One of the most important management measures for stockpiles, whether they be comprised of road materials, topsoil or waste materials, is to protect them from erosion.

Stockpiles can be protected from erosion by applying the following measures (EPA 2004):

- up slope catch drains/banks
- down slope sediment retention structures (e.g. silt fence)
- temporary grassing for stockpiles in place greater than 28 days
- positioning away from drainage lines and at least 10 m from waterways
- covering stockpiles with tarpaulins, geotextile, stabilisation matting or other suitable material
- minimising the number and size of stockpiles
- maximum 2:1 height to width ratio.

Figure 4.4 demonstrates a suitable arrangement for a protected stockpile, including positioning of catch drains, silt fencing and acceptable batter slope gradients.

Figure 4.4: Stockpile protection



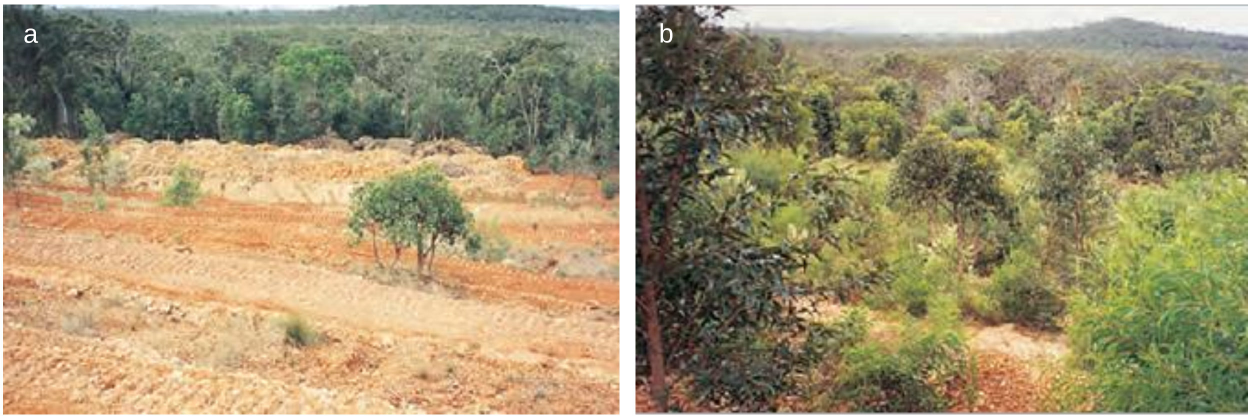
Rehabilitation

The rehabilitation of a borrow pit is best undertaken progressively as excavation moves along a pit. As a new section of the pit is dug, the topsoil is transferred to a previously excavated section of the pit, which is then rehabilitated. This reduces the amount of exposed area that is at risk of water and wind erosion (Western Australian Roadside Conservation Committee 1994).

Restrict access to a borrow pit to a single access road, as this avoids unnecessary later rehabilitation works.

The final restoration of a borrow pit involves either returning the site to its original condition or converting it to another use such as a farm dam. Returning it to its original condition involves filling the pit with clean material, returning the topsoil and removing all non-natural material and establishing a vegetative cover, as shown in the two stages in Figure 4.5. If the site is to be converted into a farm dam, special requirements such as clay lining need to be considered.

Figure 4.5: Typical quarry at the end of its life before revegetation (a) and the same quarry 18 months later (b)



4.1.3 Granular Material Specifications

Importance of specifications

Material specifications aim to maximise pavement performance by ensuring a range of material characteristics are within specific criteria. Using materials that meet the desirable pavement design specifications can significantly reduce maintenance compared with pavements constructed from materials outside of the specification limits.

> ***Specifications***
>
> ***Specifications vary by pavement application and road type***
>
> - *Material specifications for unsealed roads are typically of a lower standard than for a sealed road*
>   - *due to limited funding available*
>   - *extensive coverage in the road network*
>   - *location and isolation of unsealed roads*
> - *Material specifications for subbase materials are typically of a lower standard than for base materials*
>   - *higher stresses at base level of a pavement*
>   - *encourages more efficient use of high-quality materials*

It is not uncommon to use materials that do not meet the required grading and plasticity indices for local roads, due to a range of project constraints such as budget, location or lack of material sources. In these instances it is important to understand the risk of using these non-standard materials relative to the climate and traffic loading to enable future planning of maintenance requirements to keep the pavement at a satisfactory level of service. Section 2.1 explains how material can be made to be fit-for-purpose.

Developing a material specification for local material

Local material sources are often variable and may not comply with standard specifications which may be available. To ensure consistency and to optimise the performance of a locally extracted, non-standard material, local material specifications or project specific specifications can be developed.

The aim of these specifications is to capture the optimal material properties of a local source while accounting for local climate and traffic loading conditions.

Experience and historic performance can help with the development of local specifications, as does understanding how the different aspects of a material specification influence performance. The challenge is to relate the material physical properties with performance in a particular environment.

Limits for the different aspects of a local granular specification will vary depending on the following:

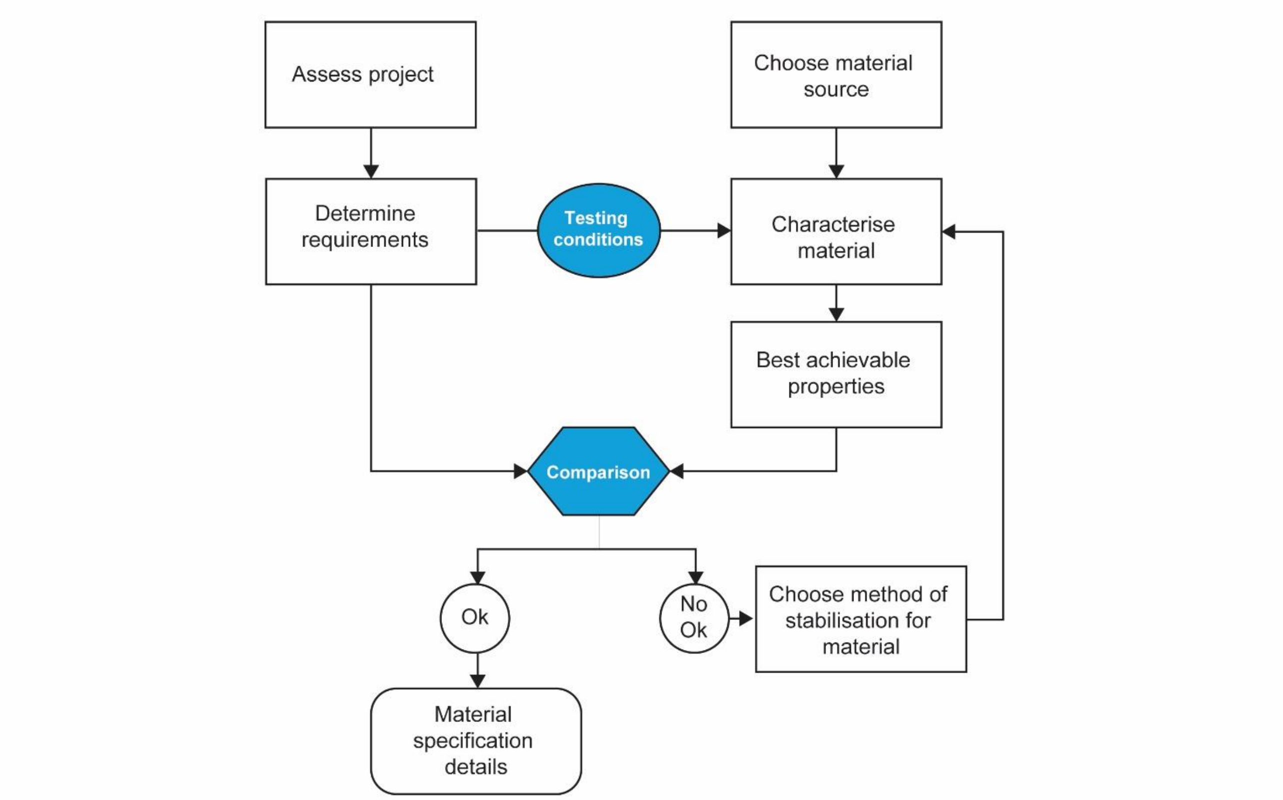
- location and climate
- traffic loading
- material purpose
- material available
- pavement level of service requirements

- budget and ongoing maintenance considerations.

Developing project or material specific specifications will require some laboratory testing to understand the typical properties of the source. The following flowchart (Figure 4.6) outlines the process for developing a local material specification.

Further information on developing a specification is provided in Appendix A.2. Common examples of specifications for various applications is included in Appendix A.3.

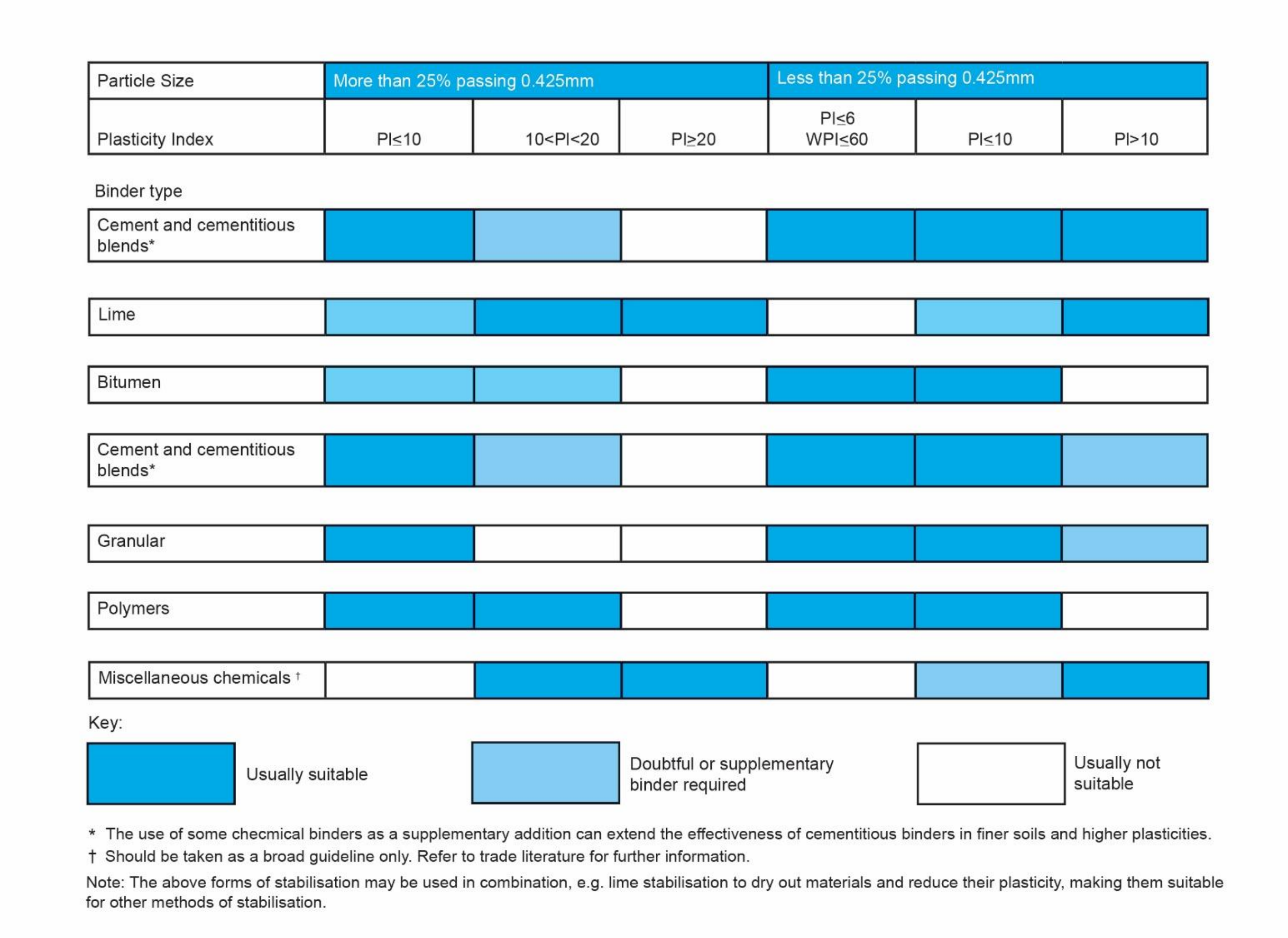
Figure 4.6: Process for development of a local granular specification



4.2 Stabilisation Methods

There are several common methods used for the stabilisation of granular pavement materials and subgrades. Each method utilises a different binder. The suitability and quality of the stabilised outcome is fundamentally dependent on the nature of the fine material i.e. the amount of fines in the parent material and its plasticity. Figure 4.7 and Table 4.4 summarises the common stabilisation binder types for different applications.

Figure 4.7: Suitability of stabilisation methods for different materials



Source: Austroads (2019).

Table 4.4: Common binders for different applications

Type of stabilisation	Common binders adopted
Subgrade (CBR > 5%)	• Addition of lime • Addition of chemical binders
Granular (40% < CBR < 120%)	• Blending other granular materials
Modified (0.7 MPa < UCS* < 1.5 MPa)	• Addition of lime or very small quantities of cementitious binders • Addition of polymer or chemical binders
Lightly bound (1.5 MPa < UCS* < 3.0 MPa)	• Addition of small quantities of cementitious binders • Addition of small quantities of bituminous or bituminous/cementitious binders
Bound (UCS* > 3.0 MPa)	• Addition of higher quantities of cementitious binder • Addition of a combination of cementitious and bituminous binders

** Characteristic UCS refers to the equivalent value determined from test specimens stabilised with GP cement and prepared using standard compactive effort normal moist cured for a minimum of 28 days.*

Source: Austroads (2019).

4.2.1 Granular Stabilisation or Blending

Applications

Where materials with a suitable grading and/or plasticity are unavailable locally, granular stabilisation may be possible by mixing two or more selected materials in the proportions required to modify particle size distribution and/or plasticity. The alternative is to use grid rollers or rock crushers on-site to arrive at an appropriate mix. Typical applications of granular stabilisation are:

- altering the coarse or fine component of a material grading by adding fine or coarse aggregate
- altering plasticity of a granular pavement material by the addition of non-cohesive material e.g. fine sand
- altering the plasticity and reactivity of a clay subgrade by the addition of lime
- addition of harder aggregate to meet hardness-abrasion specifications.

Granular Stabilisation: Rules of Thumb

Important considerations

- *Understand the properties of the materials to undertake a blend design*
- *Avoid complicated mix ratios*
- *Correction of grading below 0.075 mm is not feasible*
- *Undertake a blend trial to ensure the outcome is consistent with the requirements*
- *Control quality and consistency of materials used in a blend*
- *Undertake ongoing laboratory testing to ensure consistency of the mixing operations*
- *Use static or portable vibrating screens to sort material into discrete sizes before blending*
- *When regravelling an unsealed road check to ensure that the combined material properties of the new and existing gravel will continue to meet the required guidelines.*

Usage

The mix design, in terms of grading, can be determined using simple proportion calculations of the constituent materials passing respective sieves as demonstrated in Equation 1 below.

$$\text{\% passing allocated sieve after blend} = \frac{A\% \times A_{pass}}{100} + \frac{B\% \times B_{pass}}{100} \quad (1)$$

where

$A\%$ = percentage of material A being added

A_{pass} = percentage of material A passing allocated sieve

$B\%$ = percentage of material B being added

B_{pass} percentage of material B passing allocated sieve

A worked example of a blend design is presented in Appendix B.1.

4.2.2 Cementitious Stabilisation

Applications

Stabilisation with cement binder involves mixing blended cement (type GB) or less commonly Portland cement (type GP) in a variety of pavement materials to reduce the moisture susceptibility and to increase the strength. A wide variety of materials are stabilised from cohesionless sands and gravels, to plastic clays, silts, and high-quality granular pavement materials. Figure 4.8 shows cement stabilisation construction in the field.

Low percentages of cement are typically used to manufacture a lightly bound material whereas heavier applications are used to manufacture bound materials. The amount of cement added is detailed as a percentage of the dry compacted mass of the parent material.

At high percentages of cement (to manufacture a bound material) the potential for shrinkage cracking increases. Using other cementitious binders which include pozzolanic blends (i.e. lime and/or cement/ fly ash or lime and/or cement/granulated blast furnace slag) in conjunction with cement or lime can significantly reduce problems associated with cracking and allow greater time for completion of compaction.

Further guidance on the design of cementitious stabilisation can be found in AGPT04D-19 (Austroads 2019).

Figure 4.8: Cement stabilisation construction

Cementitious Stabilisation

Sealed roads

- *Increase strength of granular base or subbase layers*
- *Reduce moisture sensitivity of granular pavement layers*
- *Stabilise shoulder areas*
- *Improve the subgrade strength to significantly reduce pavement depth or where saturated subgrades are encountered*

Unsealed roads *Usually not an appropriate stabilising agent for unsealed wearing course or base layers*

a. *the bonds formed are not strong enough to resist the action of traffic without being protected by a seal*

b. *cement stabilised material is not amenable to being reworked with maintenance equipment such as graders*

- *Localised treatments on low volume roads, such as at floodways, sharp bends, steep sections, tight turning movements at intersections*
- *Improve the subgrade strength to significantly reduce pavement depth or where saturated subgrades are encountered*

Usage

Cement stabilisation is most suited to granular materials with some clay content, or clayey material with low plasticity. The mechanical properties of cement stabilised materials improve with cement content and time and will vary depending on the host material properties.

Once placed cementitious stabilised materials cannot be reworked and should be compacted within the working time of the selected binder. Typical working times for cementitious binders are:

- GB cement – 2.5 hours
- GP cement – 2 hours
- Pozzolanic blends – 4 to 8 hours.

To prevent damage to the stabilised material, a typical curing period of 3 to 7 days with no heavy traffic must be adhered to.

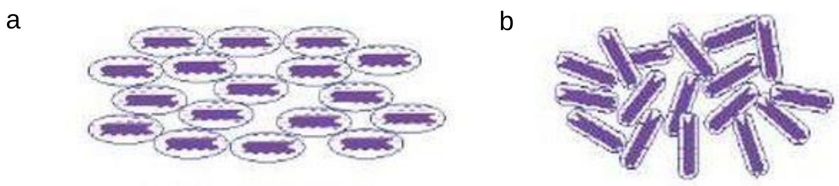
The process of designing and constructing a cementitious blend can be found in Austroads AGPT-04D (Austroads 2019) in addition to the AustStab *Pavement recycling and stabilisation guide* (AustStab 2015) and the AustStab *In situ stabilisation construction guide* (AustStab 2006).

4.2.3 Lime

Applications

Lime reduces the plasticity of a material, increases its workability, reduces swell and modifies the material to provide optimum strength. It also improves strength, decreases permeability and moisture susceptibility. For each type of material there is both a minimum amount of lime to induce a permanent chemical reaction (lime demand) and an optimum lime content where the addition of further quantities in excess of that required to correct plasticity and/or strength has no benefit. Figure 4.9 demonstrates the effect of lime stabilisation on clay particles.

Figure 4.9: Effect of lime stabilisation on clay particles (a) before lime addition (b) after lime addition



Lime demand

The lime demand test estimates the lime content required for the pH of the parent material to be stabilised at an alkalinity of pH12.4. This is undertaken by mixing an increasing percentage of lime with a parent material and plotting the pH results (Figure 4.10).

Figure 4.10: Lime demand test plot

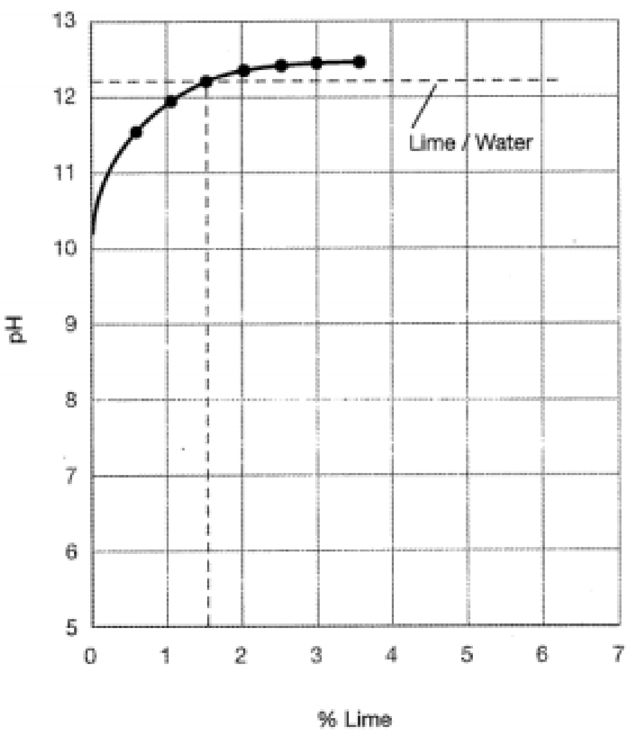


Figure 4.11: Checking lime spread rate during lime stabilisation

Purpose of Lime Stabilisation

Sealed roads

- *Improve the subgrade strength to significantly reduce pavement depth*
- *Decrease movement of reactive subgrades*
- *Decrease moisture susceptibility of base and subbase materials*

Unsealed roads

- *Reduce dust generation in dry areas*
- *Lower re-sheeting frequency*
- *Reduce surface defects*
- *Extend life between patrol grading*
- *Decrease moisture susceptibility of base and subbase materials*
- *Improve the subgrade strength to significantly reduce pavement depth*

Appropriate operational safety precautions and worker apparel should be adhered to when using hydrated lime because of its light weight, fine and dusty consistency and quicklime which will burn skin.

`

Usage

The amount of lime added is detailed as a percentage of the dry compacted mass of the parent material (Figure 4.11).

The amount of lime necessary to stabilise a material depends on the amount and type of clay mineral predominate in the material. The assessment of lime demand, as part of the mix design process, ensures the benefits of the addition of the lime are permanent.

Factors to be considered in the use of lime include:

- Materials properties
  - reacts with most plastic materials with PI < 10%
  - materials with lower plasticity should contain at least 15% passing the 0.075 mm sieve
  - testing is necessary to determine the reactivity of the material to lime
- Stabiliser form (two forms of lime are used in stabilisation)
  - quicklime which is calcium oxide produced from burning calcium carbonate
  - hydrated (slaked) lime which is produced by adding water to quicklime
- Construction processes
  - the performance of lime-stabilised materials is affected significantly by the construction practices.

Table 4.5 summaries the effect on material properties varying percentages of lime stabilisation binder will have.

Table 4.5: Varying percentages of lime stabilisation agent and effect on materials

Dosage amount by weight	Effect on material
Low amounts, 1 to 3%	• Reduces the plasticity index • Sufficient to stabilise some materials such as clayey gravel
Moderate amounts, 3 to 6%	• Considerable change in the material constitution
High amounts, 6 to 8%	• Can produce high strengths

Unsealed Pavement and Lime Stabilisation

General observations when using lime stabilisation to improve unsealed roads:

- *Soils containing organic matter do not normally react to lime.*
- *Normally 2 to 4% stabiliser is required for satisfactory results.*
  - *Local conditions and material will dictate the application rate.*
  - *A trial section, built using the proposed application rate, is often the most practical way of checking whether suitable results will be achieved.*
- *In temperate regions, construction should take place well before winter, to allow the stabilised layer to develop strength.*
- *Drainage must be adequate before stabilising commences.*
- *The surface should be shaped and compacted to a tight finish.*

The process of designing and constructing a lime stabilised pavement material or subgrade can be found in Austroads AGPT-04D (Austroads 2019) in addition to the AustStab *Pavement recycling and stabilisation guide* (AustStab 2015) and the AustStab *In situ stabilisation construction guide* (AustStab 2006).

4.2.4 Bitumen

Applications

Bitumen stabilisation coats or binds soil aggregate providing cohesion in non-plastic materials. It also retards moisture absorption and alters clay minerals providing a waterproofing effect and is commonly used to stabilise granular basecourse material.

The methodology of adding bitumen to a granular pavement material can be undertaken in the following ways:

- Foaming hot C170 bitumen by the addition of a small amount of water and a foaming agent. When mixing the foam bubble bursts on contact with the pavement material projecting many very fine droplets of bitumen onto the fine particles.
- Bitumen emulsion which is directly added to the pavement material in association with additional water for OMC considerations. The use of emulsions in pavement stabilisation is not common bearing in mind that it contains 40% water.

Bitumen stabilisation almost exclusively includes the addition of a secondary binder, generally hydrated lime but in some cases may be cement where higher strengths are required.

Bituminous stabilisation is effective on granular materials providing improved performance with minimal risk of shrinkage cracking. Gravels, sandy loam, sand-clays and crushed rock with a PI less than 10 have been successfully treated using bituminous emulsions.

Figure 4.12: Foamed bitumen stabilisation construction train

Bitumen Stabilisation

Sealed roads

- *Application requires consideration of the full grading of the parent pavement material*
- *Produces a lightly bound pavement material*
- *Reduces moisture sensitivity and flood inundation resistance*
- *Does not display cracking and good bonding to bituminous seals*

Unsealed roads

- *Not economical for wearing course stabilisation*
  - *Large amounts needed to prevent ravelling*
- *Can be cost effective for localised problem areas*

Usage

Construction practices of bitumen stabilisation generally follow those for other stabilising agents. Application rate and level of compaction are directly related to the ongoing performance of a material treated by bitumen stabilisation. Figure 4.12 shows foamed bitumen stabilisation construction.

The process of designing and constructing a bitumen stabilised pavement material can be found in Austroads AGPT-04D (Austroads 2019) in addition to the AustStab *Pavement recycling and stabilisation guide* (AustStab 2015) and the AustStab *In situ stabilisation construction guide* (AustStab 2006).

4.2.5 Chemical Additives

Applications

The primary function of chemical stabilisation is either to:

- bind the fine fractions such that they hold aggregate fractions in place for a longer period of time
- provide waterproofing of the fines to inhibit moisture ingress and maintain the 'dry strength' of the parent material.

Chemical binders are generally separated into either stabilisers or dust suppressants. Dust suppressants are often used in unsealed road applications (Figure 4.13).

Chemical Stabilisation

Chemical stabilisation additives are generally suited to:

- *surface bonding and moisture penetration resistance on unsealed road surfaces*
  - *can reduce gravel loss, dust and erosion and subsequent maintenance requirements*
- *stabilisation of moderate to poor materials*
- *improvement in the properties of marginal pavement materials and subgrades*
- *pavement material bonding and moisture migration resistance of sealed roads*
- *reducing compaction water demand*
- *reducing plastic shrinkage in cement stabilisation*

Field trials should be undertaken to understand the effectiveness of a chemical stabilisation agent relative to the local climate, materials and design application.

Usage

Various chemical stabilisation binders are available in the market and have been generally categorised as follows:

- Adhesives (lignin sulphonates)
  - These are organic non-bituminous binders from by-products of the pulp and paper industry and the compounds provide a seal over the pavement surface. They act as a clay dispersant, making the clay more plastic at low moisture content.
- Electro-chemical stabilisers (sulphonated petroleum, enzymes)
  - These are mainly derived from sulphonated petroleum products and are highly ionic. They work by expelling absorbed water from the soil which decreases air voids and increases compaction.
- Petroleum products
  - Dust is controlled primarily through agglomeration of fine soil particles. These substances comprise recycled waste oils, bituminous emulsions and tars. In the past waste oil has been used satisfactorily as a dust suppressant but for environmental reasons this is no longer acceptable.
- Synthetic polymers

- Comprise vinyls (PVA and PVC) and acrylimides (PAM) which coat soil grains reducing permeability and enhancing dry strength of the fine material to hold coarser aggregate in place.
- Polymer powders are applied in a similar manner to cement or lime stabilisation agents and create bonds between the fine particles which increase the bearing capacity of the material.
- Polymer stabilising agents are often proprietary products which are developed for base and subbase stabilisation applications.
- They are most suited to granular materials with some clay, or clayey material with low to medium plasticity.
- Can be combined with lime for clay applications

- Other products
  - These include microbiological binders and others. The industry is always developing new products or variations that may not always fit into the main generic types mentioned above.

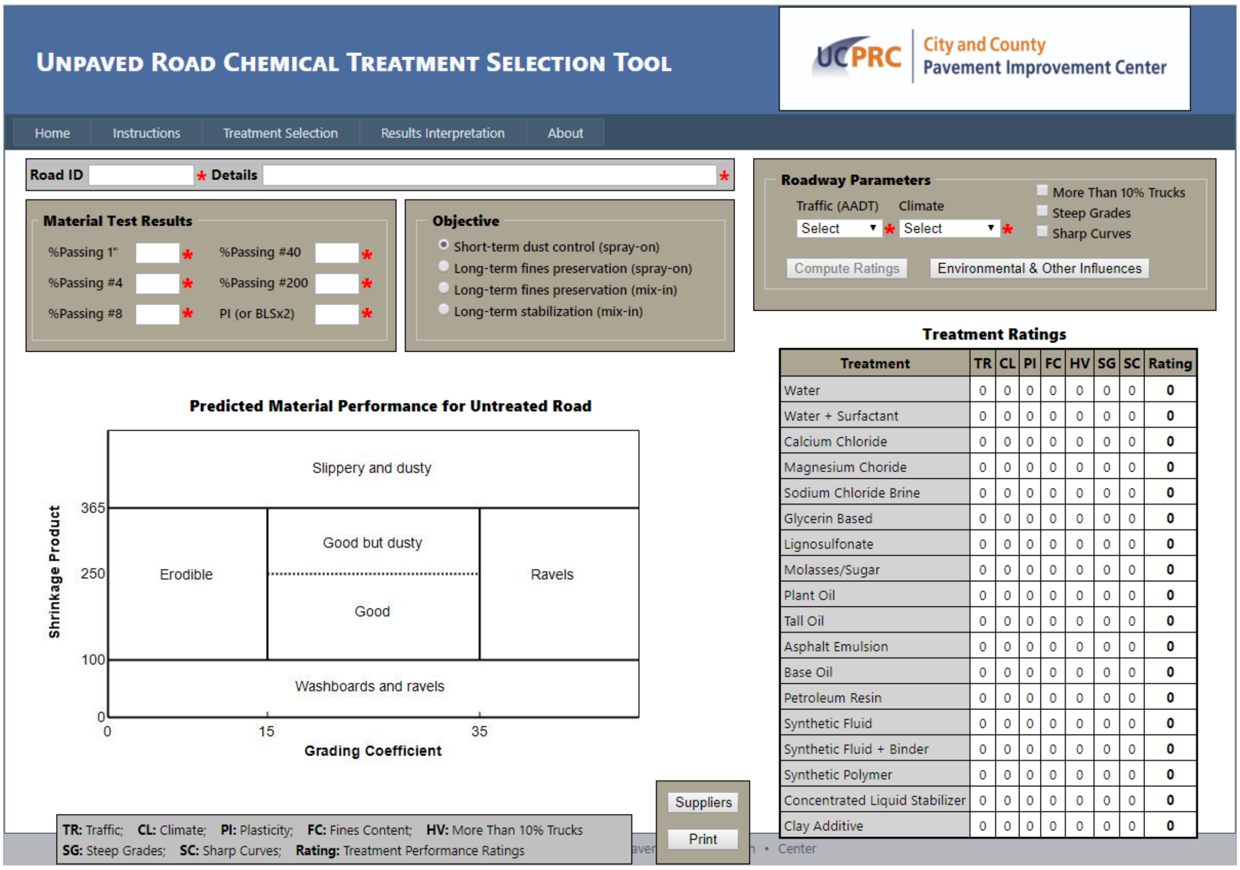
Further guidance on the selection of chemical stabilisation is provided in Appendix B.4.

Figure 4.13: Unsealed road dust generation

Chemical binder selection

Because of the variety of chemical binders available and their lack of a manufacturing standard, their selection is a matter of conjecture. However, the most recent guide to selection based upon the category of the binder can be undertaken using an online tool which uses the properties of the material being considered for chemical stabilisation as an input (Figure 4.14) .

Figure 4.14: Selection of chemical binder



Source: http://www.ucprc.ucdavis.edu/dustcontrol/.

Test for chemical stabilisation

Capillary rise and vertical saturation tests (Figure 4.15) are used to understand the suitability and expected performance of a chemical binder on a chosen parent material. These tests assess the ability of the chemical agent to inhibit moisture ingress and maintain the 'dry strength' of the parent material (Figure 4.16).

Figure 4.15: Vertical saturation test of chemical treated and untreated specimens

Figure 4.16: Strength test of chemical treated and untreated saturated specimens

Chemical Stabilisation for Unsealed Material

The important properties of chemical stabilisation are:

- *prevention of particles becoming airborne*
- *resistance to traffic wear*
- *retention in pavement i.e. not lost through evaporation or leaching*
- *resistance to ageing*
- *environmental compatibility*
- *easily applied with common road maintenance equipment*
- *workable and responsive to maintenance*
- *cost competitiveness.*

4.2.6 Geotextiles

Applications

In swampy locations where there is a high subgrade moisture content, low CBR < 3 and a high potential for fines from the subgrade to be 'pumped up' by passing traffic into the pavement, use of a geotextile layer can restrict the ingress of fines particularly into the subbase and base materials, thereby avoiding contamination and subsequent adverse effects on the particle size distribution of the pavement materials.

Geotextiles can also be used over very soft soils to increase the load spreading capacity and provide reinforcement. Geotextiles are manufactured from a mix of polymers and can be woven or non-woven (Figure 4.17).

Geotextiles Types

Woven type

- *Varying strength in two directions; warp and weft*
- *Very high tensile strength*
- *Strength at low strain levels*

Non-woven type

- *Uniform strength*
- *Lower tensile strength*
- *Higher damage resistance*
- *Used for geotextile reinforced seals (GRS)*
  - *grade of 140 to 180 g/m²*

Figure 4.17: Various types of geotextiles

Usage

Separation

Geotextiles commonly used as a separation layer, would have a geotextile strength rating, G, in excess of 2000 and an equivalent opening size of 0.085 mm for cohesive subgrade soils and 0.150 mm for granular soils.

Sealing

Geotextile reinforced seals may be used as an initial treatment to seal extremely poor quality pavements which cannot be successfully treated by normal sprayed seal treatments, or where it is uneconomical to bring in acceptable natural or crushed granular type pavement materials on very long leads, and treated with conventional seals. The fabric should be non-woven, needle-punched and formed from mechanically entangled, continuous filaments. Figure 4.18 demonstrates a geosynthetic being laid before sealing.

Figure 4.18: Applying a geosynthetic before sealing

Geotextiles: Sealing Applications

- *Where the existing surface texture is too coarse for the proposed GRS aggregate or irregular, then a correction course comprising a small sized aggregate seal or reseal, should be applied well in advance of a GRS.*
- *Where the existing surface is smooth, with little or no texture, or is recently applied asphalt or slurry surfacing, then a small sized aggregate seal should be applied at least six weeks in advance of the GRS treatment to provide a friction key.*
- *Polyester geotextiles are widely used because they do not melt when sprayed with hot binder. Where polypropylene fabric is proposed, the binder temperature should not exceed 170 °C.*
- *A minimum fabric mass of 130 g/m^2 is recommended for sealing applications.*
  - *When used on expansive clays or untreated soft pavements, and larger sized sealing aggregates (e.g. > 10 mm) are proposed, a heavier grade of fabric with a fabric mass of 175 g/m^2, should be used to reduce the risk of puncturing the fabric.*

4.3 Field Quality Testing

Field quality tests ensure the various pavement material components have been constructed in alignment with specification requirements and meet design intent. Field quality testing also allows confirmation that materials supplied comply with the relevant specification. Performance can only be ensured if construction standards specified are met.

As a measure of field achievement and performance assurance (structural integrity), compaction measurement is commonly used. Compaction of both subgrade (and select fill) as well as pavement materials increases shear strength, bearing capacity, and resistance to deformation and shoving in addition to decreasing permeability and susceptibility to moisture content changes.

Table 4.6 summaries various field quality tests used throughout Australia.

Table 4.6: Field quality tests

Field test	Material relevance	Test purpose
Nuclear density gauge (NDG)	• All granular materials • HMA	• Field density • Degree of compaction • Strength/stiffness
Dynamic cone penetrometer (DCP)	• All granular materials	• Field density • Degree of compaction • Strength/stiffness
Clegg Hammer	• All granular materials	• Degree of compaction • Strength/stiffness
Embedment test	• Granular base materials	• Base suitability for sealing • Degree of compaction • Dry-back
Quick field tests[(1)]	• All granular materials	• Moisture content relative to OMC • Degree of compaction

1 *The quick field tests provide simplified insight into the moisture condition and degree of compaction of a pavement material for immediate site surveillance purposes. This test must be supplemented by laboratory moisture testing or NDG testing for QA/QC purposes.*

4.3.1 Nuclear Density

Purpose of the test

A nuclear density gauge uses a nuclear isotope to measure the field density of compacted pavement or subgrade layers including granular, stabilised and HMA material. This field test is undertaken to ensure the degree of compaction of the constructed layer meets the specification requirement.

NDGs can also be used to measure the moisture of a material which can provide an indication of dry-back condition. However, the use of NDG for this application is not widespread in Australia due to the complex nature of equipment calibration and variability of test results in certain materials. A typical NDG is shown in Figure 4.19.

Nuclear Density Gauge Operation

Due to the high-risk nature of nuclear isotopes, the storage, transport and operation of nuclear density gauges is covered by strict federal and state government regulations. Operators must be suitably qualified and hold a valid licence.

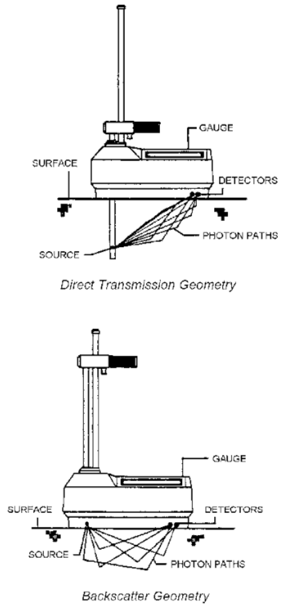
Test method

The operation, transport, and use of an NDG requires engagement of a licensed facility (geotechnical laboratory) and licensed operator with clear signage on vehicles and advisory signs when undertaking tests on site.

The test measures wet density and moisture content in order to calculate a dry density which is related to the laboratory compaction test (MDD and OMC). The moisture source is located at the base of the apparatus and is limited to measuring moisture content to around 75 mm depth (backscatter mode). Therefore, it is usual for a physical moisture content sample to be extracted from the compacted pavement.

NDG testing is undertaken as near to completion of compaction as possible in order to assess moisture condition as well as density. A steel rod is hammered into the material to allow the placement of the gauge probe to the correct depth i.e. 25 mm below the pavement layer being measured. Operation of the gauge though the user interface is then initiated, and a reading is recorded.

Figure 4.19: Nuclear density gauge



Interpretation of results

The output of a NDG test is used in conjunction with the density/moisture curve for the material to calculate the field density in terms of a percentage of the maximum dry density.

4.3.2 Dynamic Cone Penetrometer

Purpose of the test

The dynamic cone penetrometer (DCP) is a simplified method for determining the CBR of the compacted material at the moisture content at the time of test. Figure 4.20 demonstrates a DCP test being undertaken.

Figure 4.20: Use of a dynamic cone penetrometer

Test method

The DCP consists of an upper fixed 575 mm travel rod with 8 kg falling weight, a lower rod containing an anvil, and a replaceable cone with a diameter of 20 mm and apex angle of 60° or 30° (depending on material).

The test is conducted by first seating the cone into the material. The weight is then dropped from the 575 mm height and the number of blows versus depth is recorded.

Interpretation of results

The number of blows between a depth of 150–450 mm below ground level is used to provide insight into the compaction of that layer (i.e. 10 blows/300 mm equivalent to 96% MDD).

4.3.3 Clegg Hammer

Purpose of the test

The Clegg Hammer provides a quick non-destructive way of determining the adequacy of pavement compaction, particularly as a means of construction control and as a determinant of construction uniformity. Figure 4.21 shows the Clegg Hammer apparatus.

The device can be used for subgrade, bound and unbound courses. The device's mechanical parts are essentially those of a laboratory compaction hammer with a base, an accelerometer fitted to the top of the hammer body and a carrying handle added to the guide tube.

Figure 4.21: Clegg Hammer

Test method

The test apparatus is placed on the material to be tested either in a mould or on naturally occurring or compacted soil in the field. The hammer is raised to a set height and allowed to free-fall. The instrumentation of the test apparatus displays a value in terms of gravity (g) of the peak deceleration of the hammer impact as recorded by the accelerometer.

A total of four blows or more of the hammer are applied on the same spot to determine the Clegg Impact Value (CIV) for each test performed. CIV is a dynamic force penetration property and is used to set a strength parameter.

A standard hammer has 4.5 kg mass. However, hammers having mass in the range of 0.5–20 kg have been used to cover different material conditions.

Interpretation of results

A Clegg Impact Value is determined and may be used to calculate both CBR and resilient modulus.

4.3.4 Embedment Test

Purpose of the test

The embedment test or ball penetration test is used to ensure the surface of a granular basecourse is ready for the placement of an overlying spray seal. The test provides insight into the degree of compaction and dry-back of the constructed layer. It can also be used to provide an insight into a bituminous surface such as a primer seal or other soft bituminous surface.

Test method

A steel ball with a 19 mm diameter is placed on the chosen test location. A standard Marshall compaction hammer (Section 3.7.4) is then used to impart one blow on the top of the steel ball. The ball is removed and the depth of embedment measured and recorded.

The temperature of the surface is also required to be measured and recorded if the test is being undertaken on a bituminous surface.

Embedment tests are normally carried out in the wheel path as seal design is based on this measurement.

Interpretation of results

This test is repeated a number of times over a test lot and an average embedment value calculated. The embedment depth is then compared to a specified embedment allowance.

4.3.5 Quick Field Tests

Field density

Where no measurement device is available for assessing field density some simplified alternatives can be used for quick assessment. This is useful for surveillance purposes or as a quick check to ensure compaction is being undertaken correctly. Test options include:

- Proof rolling using a dual tyre axle loaded to the standard axle or a fully laden truck (usually the water cart)
  - The test is subjective in that observation of deformation indicates the pavement is not fully compacted or is wet and maybe soft, requiring additional compaction.
- When a sheepsfoot or padfoot roller is being used
  - material may be regarded as having sufficient compaction when the roller is observed to 'walk out' of the layer being compacted (i.e. it no longer leaves an imprint)
  - if thin layers of material start to delaminate from the top of the compacted layer during rolling, it may have been over-compacted.
- Most soil materials change volume when compacted:
  - Rock fill will occupy 1.2–1.5 times more space than solid rock.
  - Excavated soil will expand when loaded in the dump truck but when compacted can shrink to 0.6 – 0.8 times the original volume depending on soil type.

Field moisture

To obtain maximum compaction the material needs to have a moisture content which is the same as the determined OMC (Section 3.7.4) of the material.

Hand Squeeze Test

A simple and practical field measurement to assess whether the moisture content is close to OMC:

1. *Grab a handful of pavement material from the works site and squeeze it in the hand.*
2. *If the material oozes out of the hand the moisture content is too high.*
3. *If it is too dry when the hand is opened, the ball of material will not stick together.*
4. *However, if the material remains in a ball, then the moisture content is close to OMC (*Figure 4.22*).*

Figure 4.22: Simple field test for moisture content

5 Operation and Maintenance

5.1 Rehabilitation and Maintenance Materials

5.1.1 Surfacing Applications

Cold mix asphalt

Cold mix asphalt is pre-mixed asphalt which have been treated heavily with cut back bitumen or bitumen emulsion which allows it to be stored for months and still retain workability.

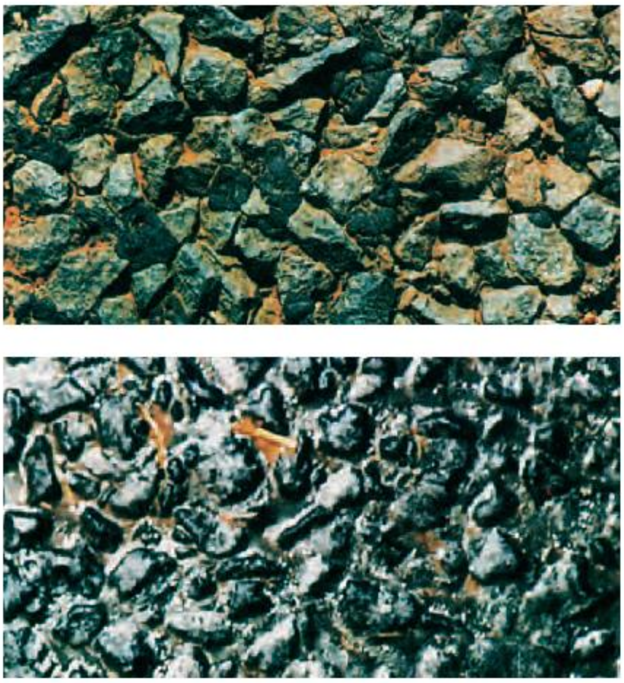
Cold mix is commonly used for pothole repair or edge repair.

Enrichment

Surface enrichment is the light application of a cutback bitumen or bitumen emulsion to an existing sealed surface to increase the binder content at the surface.

Surface enrichments are commonly applied to an existing sprayed seal where the binder has oxidised and has become brittle causing some loss of aggregate or cracking (Figure 5.1).

Figure 5.1: Spray seal before and after enrichment treatment



Coarse aggregate seal (top) before and after (bottom) application of a surface enrichment of about 0.7 L/m^2

Rejuvenation

Surface rejuvenation is the light application of a commercially available rejuvenating agent to an existing sealed surface to improve the condition of an oxidised or hardened binder.

Rejuvenation can be used on existing asphalt or spray seal surfacings.

Slurry seals/micro-surfacings

Slurry seal or micro-surfacings involve the application of a fine aggregate and bitumen emulsion mix to an existing road surface by means of a specially designed vehicle which both mixes and spreads the material through a distribution box and levelling screed (Figure 5.2).

The bitumen employed is often polymer modified.

Figure 5.2: Application of a slurry seal

5.1.2 Granular Base, Subbase and Subgrade Applications

See Section 3.6.

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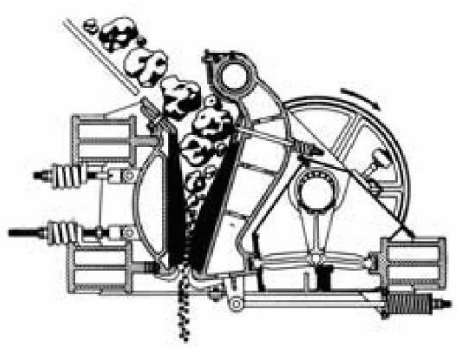
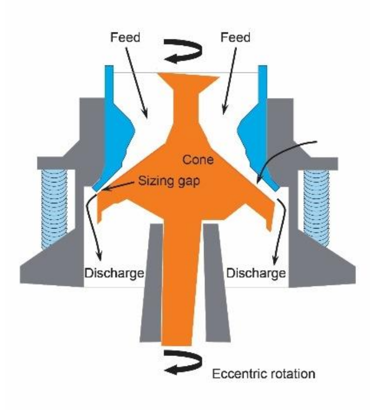
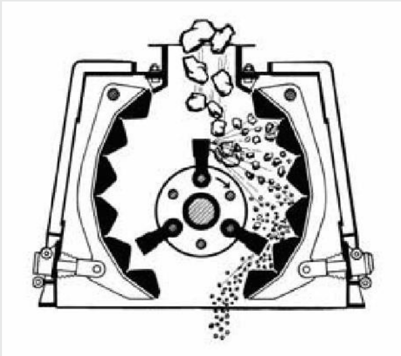
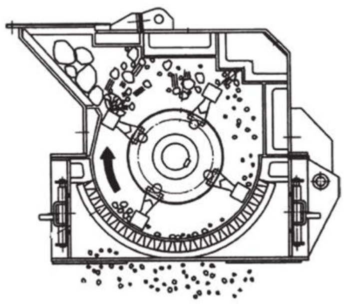
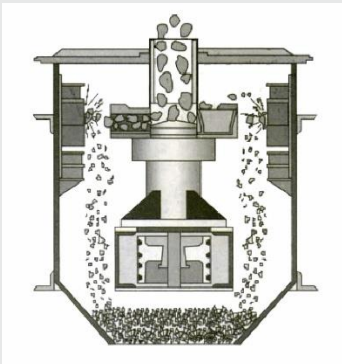
Appendix A Material Extraction and Specification

A.1 Material Processing Equipment

A.1.1 Mobile Crushing Plant

Table A 1: Crushing plant for material processing

Crusher type	Characteristics	Diagram
Jaw crusher	• Two plates • Compression and fracture • Processed size is determined by plate gap	
Gyratory crushers	• Cone and spindle • Compression and fracture • Processed size is determined by cone and spindle gap	

Crusher type	Characteristics	Diagram
Cone crushers	• Cone and mantle • Grinding type action • Produces finer material sizes	
Impact crushers	• Striking hammer or bar • Impact fracture or pulverisation • Can suffer high wear rates	
Hammermill crushers	• Acceleration by hammer or bar to anvil impact • Impact fracture or pulverisation • Size control adjusted through hammer aperture	
Vertical shaft impact crushers	• Acceleration by hammer or bar to anvil impact • Impact fracture or pulverisation	

A.1.2 On Road Crushing Plant

Table A 2: On road crushing plant for material processing

Crusher type	Characteristics	Diagram
Grid roller	• Heavy mesh drum • Towed along the road • High contact pressure on large material	**Figure 5.3: Static grid roller**  *Source: ARRB Group*
Rockbuster	• Patented plant item • Towed along the road • Impact hammer crushing • Can over-process material • Best to process larger sizes and then re-blend • 1000 m^3/day production • Can suffer high wear rates depending on material	

A.2 Developing a Local Granular Specification

When developing a new specification for a granular material the following should be considered:

- Keep specifications simple, limiting the number of properties specified to those pertinent to performance.
- Limits must be set such that they can be achieved in consideration of the nature of the source and manufacturing processes adopted.
- Property limits should be as wide as possible and not restricted to a narrow range of a significant property (e.g. a tight grading envelope), but comprehensive enough to accept and reject materials on a rational basis.
- The properties specified should require inexpensive, quick, simple tests, which are repeatable and reproducible and need minimal sophisticated equipment and a relatively low level of operator training.
- Specifications should be practical to implement and apply to the total area for which they are intended.
- Specifications should adequately define important properties (indirectly if necessary) such as cohesion and strength and eliminate obvious problems such as oversize material.
- Specifications should preferably be in terms of existing test methods or combinations of results from existing methods, although scope exists for the development of simple new methods.
- Specifications should be based on performance related studies.
- Specifications should be rigidly adhered to; however, the user should appreciate the consequences of use of non-complying materials e.g. increased construction, maintenance and road user costs, increased dust and poor safety standards.

The use of specifications can result in higher initial materials location and construction costs; however, substantial reductions in the total life cycle costs of the road are indicated.

A.2.1 Development

Step 1. Understand the design scenario and subsequent specification requirements

- Material application (i.e. base, subbase, select fill etc.)
  - this will determine the severity of the specifications
  - this will determine the required field density and dry-back requirements for the material
- Traffic loads
  - this will determine the required strength and stability of the overlying material
- Climate and rainfall
  - this will determine the operating moisture levels for testing conditions and the plasticity limitations
- Pavement level of service
  - this will determine the target quality and durability of the pavement
  - this will determine the severity of the specifications
- Budget
  - this will determine the achievable quality and durability of the pavement.

Step 2. Understand the typical properties of the source in the context of Step 1

- Grading
  - is the grading of the material optimised for stability or is modification required?
  - what is the closest grading to maximum density grading that can be achieved with this material to meet performance requirements?
- Plasticity and shrinkage
  - are the plasticity and shrinkage properties optimised for stability appropriate to climate and rainfall conditions or is modification required?
  - what is the limiting plasticity and shrinkage achievable for the intended application?
- Density moisture relationship
  - this information is used to prepare the CBR samples to match the expected field density
  - this information is used to plan construction water requirements
  - this information is used as a specified compaction achievement required in construction
- CBR (soaked or unsoaked)
  - is the CBR high enough for the intended material application or is modification or stabilisation required?
  - what is the expected CBR of the material in-service?

Step 3. Consider stabilisation and the revised properties

- Grading
  - Is blending with another source an option or the pit worked to include some over/under burden to meet grading and plasticity requirements?
  - Can the material be processed using screens or crushing?

  - What is the closest grading that can be achieved with the modified material?
- Plasticity and shrinkage
  - Is lime or cement stabilisation (or a combination) an option?
  - What is the limiting plasticity and shrinkage achievable with the revised material?
- CBR (soaked or unsoaked)
  - Is cement or bitumen or lime stabilisation an option?
  - What is the expected CBR of the revised material in-service?

Step 4. Detail specification limits

- Grading envelope
  - upper and lower limits for % passing for common sieve sizes
  - upper and lower limits for fines ratio
- Plasticity and shrinkage
  - maximum value for PI
  - maximum value for LS
  - maximum value of WLS (calculated based on grading envelope and LS requirements)
- Field density
  - minimum value as percentage of maximum dry density
  - standard or modified compaction
  - OMC range
- CBR
  - minimum value
  - density and moisture test conditions for determining minimum value
- Stabilisation information (where required)
  - maximum UCS value
  - stabilisation binder
  - percentage or dosage of treatment agent
  - curing time (if required).

A.3 Common Granular Specification Limits Based on Application

The following sections present common granular specifications based on the required application, including:

- Sealed road base and subbase
- Unsealed road wearing course
- Unsealed roads base and subbase.

A.3.1 Sealed Roads

Basecourse and subbase

Sealed Road: Base and Subbase

Subbase and base materials are the main structural support to the wearing course, and therefore these materials should be:

- *durable*
- *high stiffness to provide good load spreading characteristics*
- *high fatigue resistance to prevent or delay fatigue crack initiation and propagation due to repeated traffic stresses*
- *good resistance to permanent deformation to prevent rutting*

Table A 3: Recommended grading limits for bases: natural gravels

Sieve size (mm)	Percent passing for nominal size (mm)		
	40	30	20
53.0	100	–	–
37.5	95–100	100	–
26.5	86–95	98–100	100
19	–	–	93–100
9.5	50–74	60–82	71–87
4.75	35–59	42–66	47–70
2.36	25–46	30–52	35–56
0.425	10–26	12–30	14–32
0.075	4–17	4–18	6–20

Source: Mulholland (1989).

Figure A 1: Recommended grading limits for bases: natural gravels

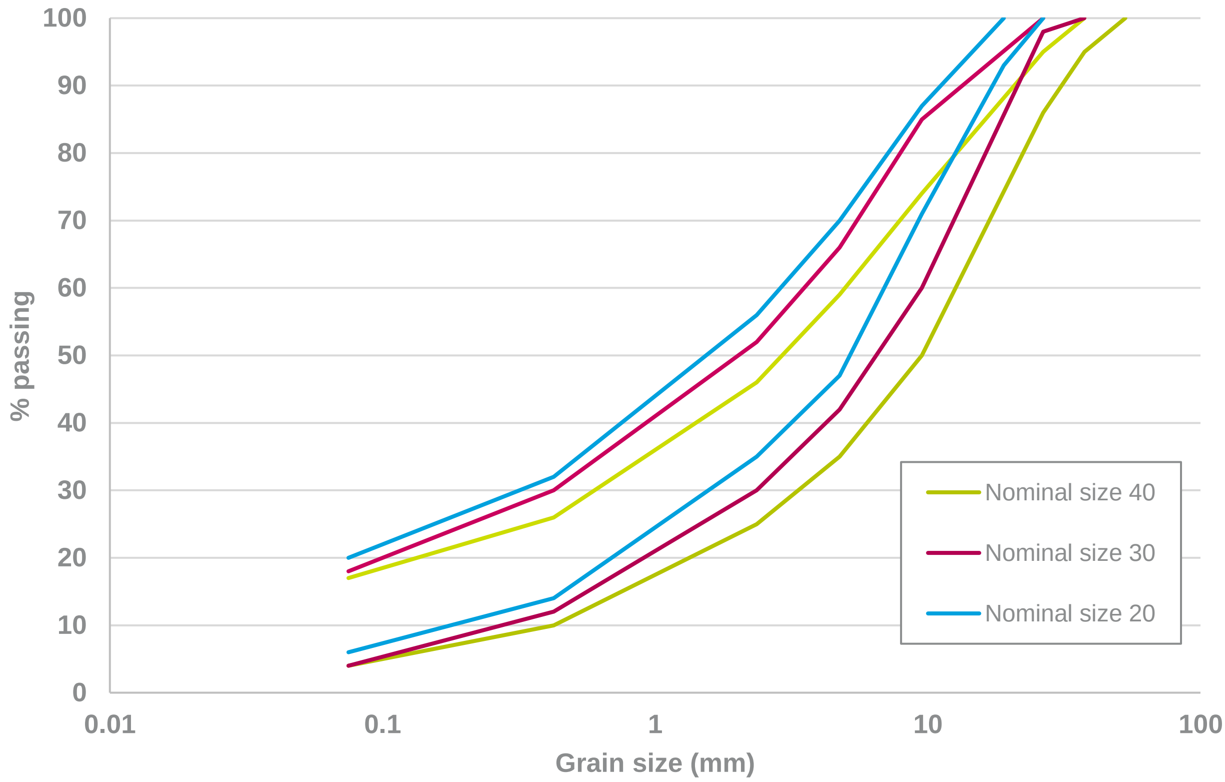
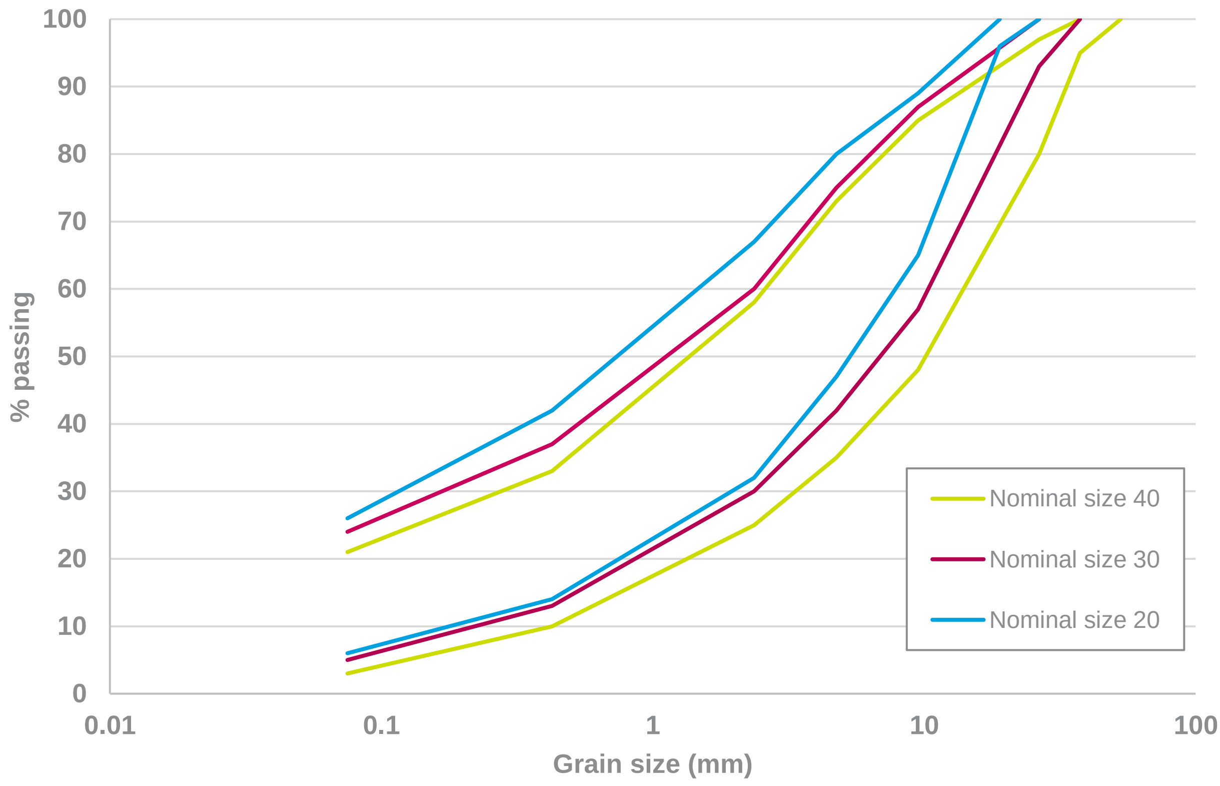


Table A 4: Recommended grading limits for subbases: natural gravels

Sieve size (mm)	Percent passing for nominal size (mm)		
	40	30	20
53.0	100	–	–
37.5	95–100	100	–
26.5	80–97	93–100	100
19	–	–	96–100
9.5	48–85	57–87	65–89
4.75	35–73	42–75	47–80
2.36	25–58	30–60	32–67
0.425	10–33	13–37	14–42
0.075	3–21	5–24	6–26

Source: Mulholland (1989).

Figure A 2: Recommended grading limits for subbases: natural gravels



A.3.2 Unsealed Roads

Wearing course

Unsealed Road: Wearing Course

Suitability

- *Soil-aggregate consisting of a well-graded gravel–sand mixture with a small proportion of clayey fines are the most suitable for an unsealed wearing course*
- *Gravels and sands that are low in fines will be porous, lack stability when dry and will ravel under traffic*
  - *Fines in the form of a sand–clay may be incorporated into these materials to give added stability*
- *The least desirable materials are those with silty fines, lacking gravel-sized particles, i.e. silts and silty-sands*
  - *likely to be porous and unstable*
  - *ravel under traffic*
  - *generate considerable dust*
- *Predominantly clay soils can provide a good dry-weather surface but will be slippery and/or will rut or shove when wet*
  - *Sand–clay or sand–silt–clay mixtures can provide a satisfactory surface course for low traffic volume roads*
- *PI × % passing 0.425 mm sieve (WPI)*
  - *High values of WPI will help identify materials which are lacking in strength as a result of the combined effect of high fines and high plasticity*
  - *Typically, WPI should be no higher than 300–400*
- *Particle strength and susceptibility to weathering will affect the ultimate grading and plasticity of a paving material.*

Table A 5: Wearing course attributes and grading requirements

Wearing course attributes	Grading requirements
Ease of compaction, safety and traffic comfort	100% passing 26.5 mm sieve
Resistance to ravelling	Between 20% and 60% of material retained on the 2.36 mm sieve
Stability and reduced permeability	Fines to sand ratio between 0.25 and 0.45 $0.25 < \frac{\%\,passing\ 0.075\ mm}{\%\,passing\ 2.36\ mm} < 0.45$

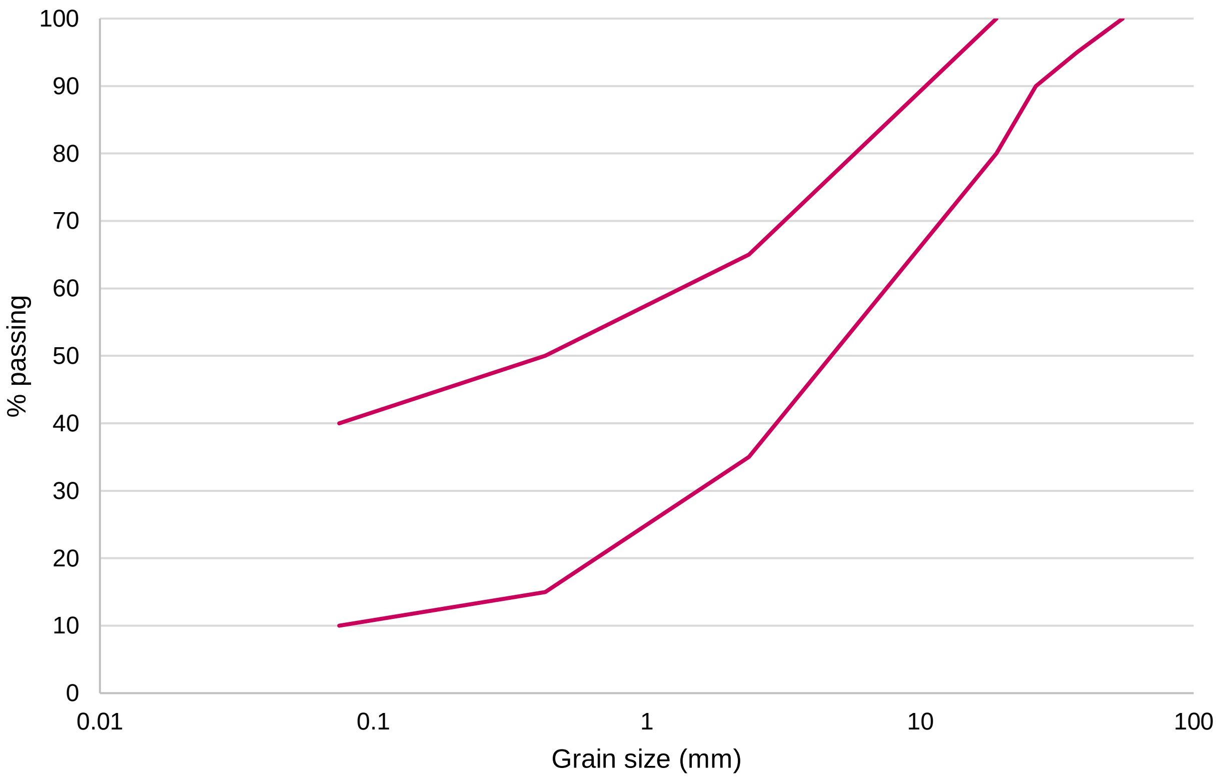
Common Australian specification limits

Table A 6: Suggested unsealed wearing course grading specification

Sieve size (mm)	% passing	
	Lower limit	Upper limit
55	100	100
37.5	95	100
26.5	90	100
19	80	100
2.36	35	65
0.425	15	50
0.075	10	40
Plasticity	**Rainfall below 500 mm/year**	**Rainfall above 500 mm/year**
Plasticity Index	< 20	< 12
WPI (PI x 0425 mm)	< 500	< 250
Strength		
CBR (soaked)	> 40%	

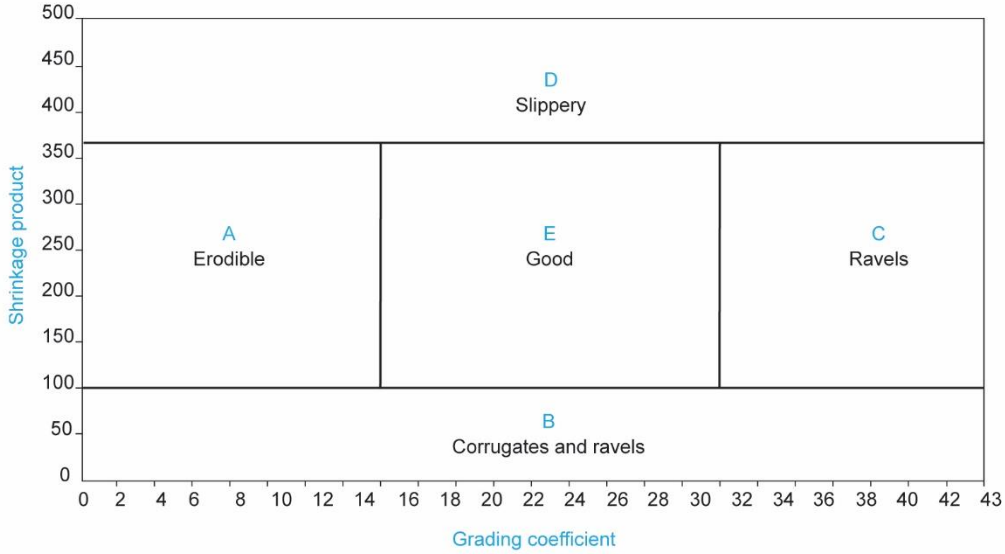
Source: NAASRA (1980).

Figure A 3: Suggested PSD range for unsealed wearing course



Common South African specification limits

Figure A 4: Performance of unsealed roads using shrinkage product and grading coefficient



Zone	Expected performance	Material description
A	Erodible	• Satisfactory performance • Typically fine graded • Prone to erosion by water • High gravel loss due to water erosion • Avoid on steep grades and sections with steep cross-falls and/or superelevations • May require periodic labour-intensive maintenance over short lengths
B	Corrugates and ravels	• Generally lack cohesion • Highly susceptible to the formation of loose material (ravelling) and corrugations • Regular maintenance necessary if roughness is to be restricted to reasonable levels
C	Ravels	• Fine, gap-graded gravels lacking adequate cohesion • Ravelling and production of loose material
D	Slippery	• Materials with shrinkage product (WLS) in excess of 365 tend to be slippery when wet
E	Good	• Materials in this zone perform well in general • Oversize material should be restricted

Source: Department of Transport (1990).

$$GC = \frac{((P_{26.5} - P_{2.0})P_{4.75})}{100}$$

where

GC	=	grading coefficient
$P_{26.5}$	=	percentage passing 26.5 mm sieve
$P_{2.0}$	=	percentage passing 2.0 mm sieve
$P_{4.75}$	=	percentage passing 4.75 mm sieve

Basecourse and subbase

Unsealed Road: Basecourse

Suitability

- *Specification requirements for unsealed road basecourse materials are generally broader than is the case for sealed roads.*

Basis

- *Particle size distribution (PSD)*
  - *Strength is achieved from particle interlock and the maximum density principle (i.e. strength is directly related to density).*
  - *PSD controls the permeability of a soil; particular emphasis is placed on the percentage of material finer than 0.5 mm.*
- *Shape of the stone*
  - *This is important in achieving good compaction.*
  - *Ideally the stone shape should be equant (cubical) with rugged edges to assist in mechanical interlocking. Flat pieces (e.g. slate) or round shape (e.g. river gravel) will not be desirable because of the difficulty of compaction.*
  - *Sharp stone edges should be avoided to prevent vehicle tyres being cut.*
- *Plasticity*
  - *Fine material contributes to densification of the aggregate through the reduction of interlock when wet*
  - *Important to provide cohesive strength to hold the aggregate in place when dry.*
- *Aggregate hardness*
  - *The aggregate should be of sufficient hardness to resist significant breakdown under compaction and trafficking*

Figure A 5: Attributes of various granular material gradings

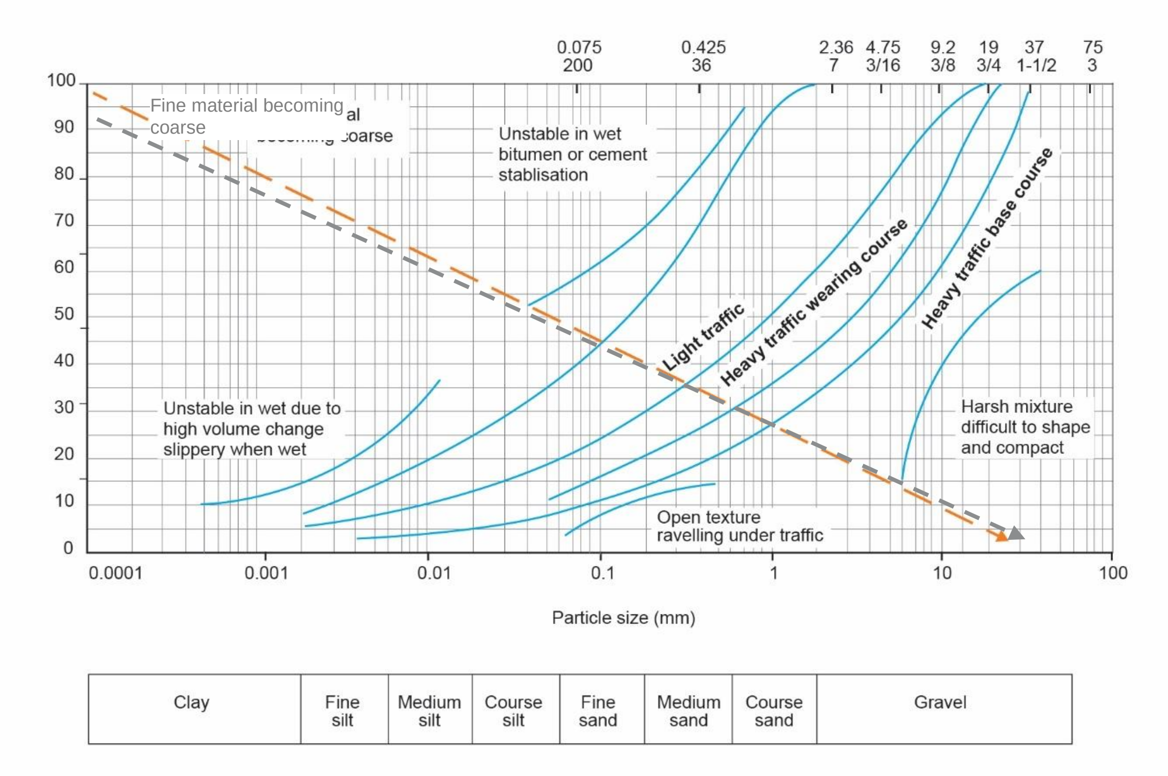
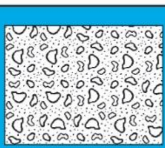
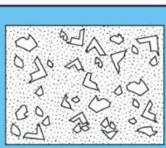
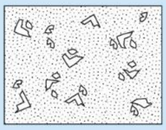


Figure A 6: Characteristics of varying material mixtures

Diagram			
Type of mixture	Coarse stone low fines	Well graded coarse to fine	Excess fines
Compaction	Difficult	Moderate	Difficult
Flexibility	Relatively stiff after compaction	Moderate	Relatively easy
Stability	Variable	Good	Fair
Frost	Not affected	Susceptible	Very susceptible
Drainage	Good	Low	Variable
Effect of water	Low	Moderate	Very significant strength loss
Chemical stabilisation	Not suitable	Suitable	Very suitable
Dust generation	Low	Moderate	High
Roughness	High	Moderate	Variable
Capillary effects	Very low	Beneficial suction	High suction but potential instability

Appendix B Stabilisation

B.1 Stabilisation Applications

In situ stabilisation may be applied equally as well to the subgrade as it is the pavement material to correct deficiencies or modify performance attributes:

- Subgrades – Typically lime is used to correct plasticity and increase CBR however the depth of stabilisation required to achieve the design CBR is determined from:

  $CBR_{\text{selected or stab Subgrade}} = CBR_{\text{underlying material}} \times 2^{(\text{thickness of selected subgrade or stab subgrade layer}/150)}$

- Pavement materials typically cementitious blends or foam bitumen/lime are used.

B.2 Choosing an Appropriate Stabilisation Binder

When considering stabilisation an assessment should be made which compares the cost of undertaking the stabilisation with the expected benefits or reductions in design requirements caused by applying the stabilisation method.

For example, if stabilisation of an existing damaged basecourse with foamed bitumen is anticipated to cost less than the re-construction of a new basecourse when considering factors such as the cost of the foamed bitumen and stabilisation activities versus the cost of carting and placing new basecourse material in addition to the long term performance expected within the operating environment, stabilisation would be the best whole-of-life cost choice in addition to providing a material which will perform adequately.

Before selecting the appropriate stabilisation binder for a specific scenario, there needs to be an understanding of what the properties of the material in question are (grading, plasticity and strength) and which of these properties needs to be corrected to ensure ongoing performance.

For example, if the material has a high clay content, is highly plastic and tends to swell when wet and the operating environment has high rainfall, moisture sensitivity needs to be reduced. However if the material is a clayey gravel with low strength and the operating environment is high traffic a stabilisation method which increases strength is required.

Step 1. Understand material properties and suitable stabilisation options

- grading and plasticity
- comparison with Figure 4.7.

Step 2. Understand moisture, loading conditions and pavement purpose

- annual rainfall
- local drainage and topography
- sealed shoulders
- crossfall
- design traffic and heavy vehicles
- sealed or unsealed
- haul road, rural road, urban road.

Step 3. Identify material shortfall

- poorly graded, gap graded, coarse or fine graded

- moisture sensitivity (high clay content/plasticity)
- fine material
- coarse material
- low cohesion
- low bearing capacity.

Step 4. Identify stabilisation method/s

- granular
- cementitious
- lime
- foam bitumen/lime blend
- chemical
- geotextiles
- combinations of the above to treat multiple material shortfalls.

Step 5. Undertake stabilisation design and testing of stabilised outcome

- stabilisation binder/s and proportions
- see AGPT04D-19 (Austroads 2019) for further guidance on specific stabilisation design processes.

B.3 Undertaking Blend Design

B.3.1 Example – Proportion Calculation

The mix design, in terms of grading, can be determined using simple proportion calculations of the constituent materials passing respective sieves.

$$\%\text{passing allocated sieve after blend} = \frac{A\% \times A_{pass}}{100} + \frac{B\% \times B_{pass}}{100} \qquad 1B$$

where

$A\%$ = percentage of material A being added

A_{pass} = percentage of material A passing allocated sieve

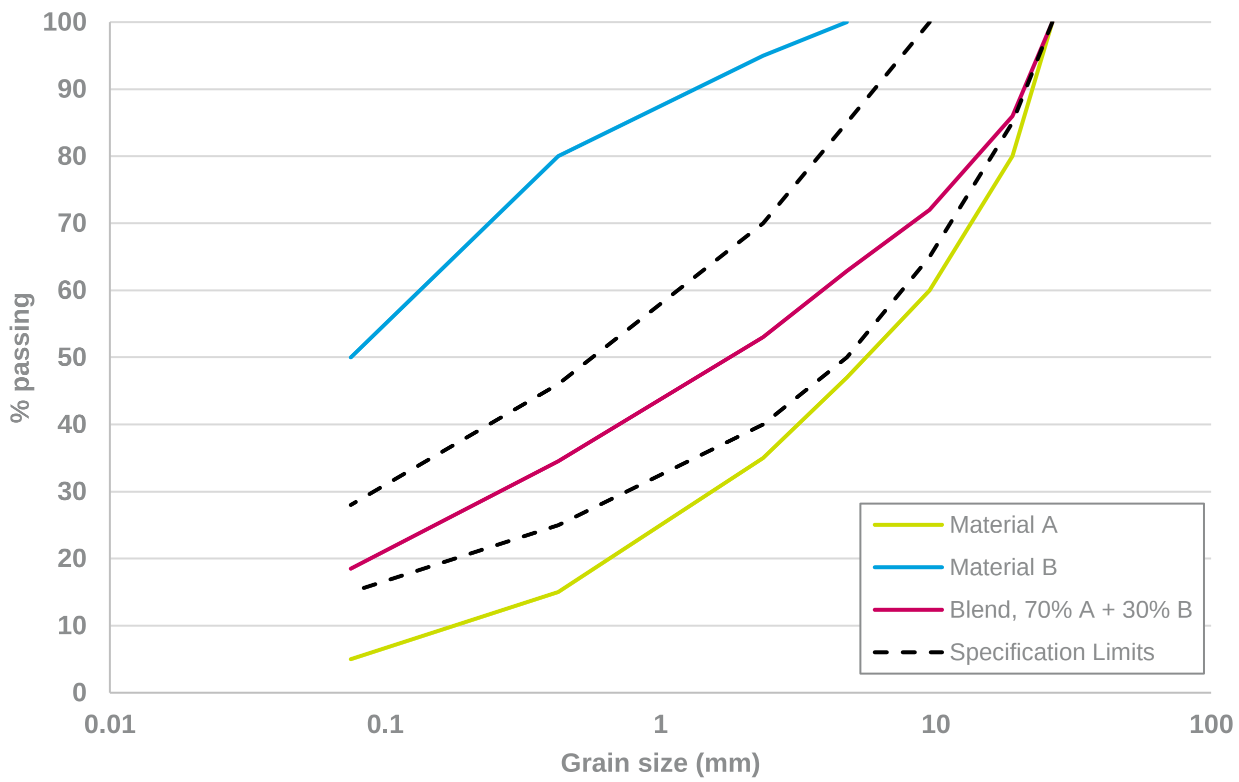
$B\%$ = percentage of material B being added

B_{pass} = percentage of material B passing allocated sieve

Table B 1: Material grading and proportion blend grading

Sieve size (mm)	Specification limits	Material A	Material B	Blend, 70% A + 30% B
25.0	100	100	100	100
19.0	85–100	80	100	86
9.5	65–100	60	100	72
4.75	55–85	47	100	63
2.36	40–70	35	95	53
0.425	25–46	15	80	35
0.075	15–28	5	50	19

Figure B 1: Material grading and proportion blend grading



B.4 Chemical Additives

B.4.1 Use

Chemical binders are primarily used on low-volume low-cost roads however they may be equally used on higher trafficked sealed pavements with granular layers.

When considering chemical stabilisation the structural competency of the pavement must be considered adequate in relation to structural thickness over the subgrade and the imposed traffic loading.

Chemical stabilisation is also used in unsealed wearing surfaces to resist moisture ingress and in some cases provide additional cohesion.

B.4.2 Selection

The selection of the type of stabilisation binder should be made bearing in mind the quantity of fines in the surface material or the subgrade (if there is no surfacing structure), climatic conditions and traffic volumes. As a general rule, total fines should range from 10 to 20%, to provide a dense compacted surface free from loose gravel.

The product that best fits the local conditions should be used, even though it may not rate highly on all selection criteria. If dust-free conditions are to be maintained for prolonged periods, then more than one treatment per year will be required as the chemicals migrate downwards through the pavement.

Figure B 2: Selection of chemical binders based on climate and material properties

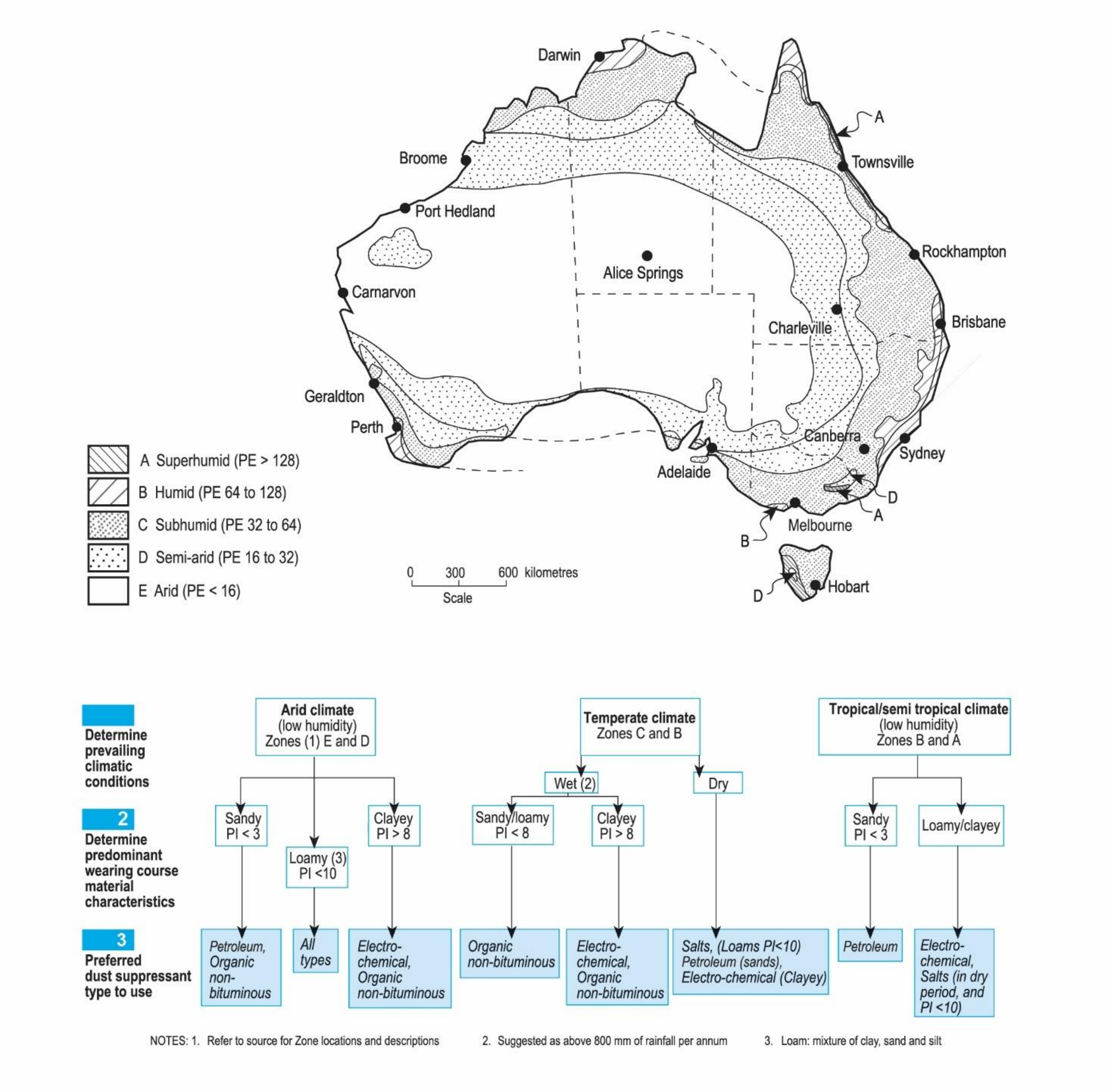


Figure B 3: Suitability of various chemical additives

	Traffic volumes		Subgrade type [2]			Surface material fines content passing 75µm sieve					Climate			Environmental impacts [5]
	light <100		clay	silt	granular	<5%	5-10%	10-20%	20-30%	>30%	rainy	normal	dry spells >20 days <40%RH	
Surfactants	fair		poor	fair	poor	poor	fair	fair	fair	poor [3]	poor [1,3]	fair	poor	fair
Salts $CaCl_2$ M9C$_2$	good		good	fair	poor	poor	fair	good	fair	poor [3]	poor [1,3]	good	fair [8]	poor
Lignin sultanates	good		good	fair	poor	poor	fair	good	good	fair [3]	fair [1]	good	good	fair
Petroleum products	fair		fair	fair	fair	poor	fair	fair				fair	fair	fair

Notes:

1. May leach out in heavy rain
2. Subgrade will mix with surface material and impact on the quality of fines
3. May become slippery in wet weather
4. Difficult to coat all particles and prevent 'dust pockets'
5. All products listed may have an adverse environmental impact if used improperly
6. Hard surface crust promotes potholes and breakup under heavy traffic
7. All products may require higher or more frequent application rates with high truck volumes
8. $CaCl_2$ is likely to act poorly to fair under these conditions

Dust suppressant performance: good, fair, poor

B.4.3 Application

General procedures for applying chemical binders include the following:

1. Remove surface defects and add gravel as required, to provide the correct shape, superelevation and crown and compact the surface.
2. Dampen the surface, except when using non-emulsified petroleum products.
3. Apply stabilisation binder uniformly to the surface.
4. Lightly compact using a rubber-tyred roller when the stabilisation binder is chloride or lignin sulphonates.

Traffic may use the surface immediately following application of chlorides; however, other products require time to be absorbed before allowing traffic to use the road.

B.4.4 Treatment Rate

Treatment rates of chemical binders will depend on a number of factors including type of product, degree of dust control required, type of wearing surface, traffic volumes, types of vehicles and speeds, frequency of maintenance procedures, and climatic conditions.

Manufacturers' recommended application rates should be adopted along with any specific site requirements and application procedures.

B.4.5 Trialling Chemical Binders

If a proper assessment is to be made of the effectiveness of a product, a full-scale road trial with an experimental section(s) and at least one control section being laid at the same time should be undertaken.

The control section(s) must be identical in all respects to the experimental section(s), except that no additive is used. The difference in performance between the experimental and control section(s) is then used to determine the effectiveness of the additive.

If possible, the experimental section(s) and control section(s) should be duplicated. The extra information this provides will help if it is difficult to tell whether an improvement is real or due to natural variability in performance.

It is useful to decide before a trial how success or failure will be judged. This avoids complaints and disagreements over the interpretation of results.

B.5 Geotextiles for Reseals (GRS)

B.5.1 Design

Geotextile reinforced seals (GRS) are designed in accordance with conventional seal design procedures. Allowances are made for binder retention of the fabric and the binder absorption of the granular base, (if not primed, primer sealed or sealed). The 'binder retention by fabric allowance' (according to ASTM D6140-00) is the volume of bitumen required to saturate the fabric and varies from 0.8 to 1.3 L/m^2 (cold) of binder, depending on the thickness of the geotextile.

It is preferable to use only 10 mm or larger aggregate for single/single GRS treatments as smaller aggregates (i.e. 5 and 7 mm) have a tendency to flush or bleed in GRS applications. Aggregate sizes 5 and 7 mm are acceptable for use in double/double applications as the second layer. Aggregates larger than 10 mm have an increased potential for puncturing the fabric and this should be considered when selecting the fabric.

On an initial treatment, it is imperative to first prime the pavement. Generally these pavements, constructed from poor quality materials, would be classed as 'porous' for the selection of the type and grade of primer and determining the rates of application.

The general design is as follows:

Stage 1: Primer tack coat

- determine the standard base rate as for a normal double/double seal from the void factor, adjustments and the ALD of the aggregate
- allow 0.8 to 1.3 L/m^2 for binder retention by the fabric
- determine allowances, such as aggregate absorption, surface texture or pavement absorption
- add the base rate and allowances to determine the design binder rate.

Stage 2: Second binder application

- Generally this is size 7 mm aggregate and the application rate is a standard base rate.
- If a double/double seal is used, the first application is designed as above, and the second application is designed as for a normal seal, using generally a standard rate for the conditions and traffic. The aggregate rate of application is designed as for a normal seal.

For geotextile seals with PMBs, the design procedure to determine the rate of application of the PMB in the sprayed seals is the same as for a SAM. This procedure can be found in AGPT-4K (Austroads 2018).

B.5.2 Life Expectancy

GRS treatments have performed satisfactorily for periods exceeding 6 years however it is dependent on environmental conditions such as flooding etc. As a reseal on cracked granular pavements GRS should be considered equal to or better than a multiple application PMB seal and should have a service life in the order of 6 to 10 years depending on the strength of the pavement treated.

B.5.3 Application of GRS on Clay Formed Pavements

Geotextile seals have been used successfully and economically when applied directly to stabilised clay subgrades where there is an absence of suitable granular materials. These pavements are generally built on very flat terrain and so the formation is raised above the natural surface by excavating material from borrow pits outside the road reserve.

The raised formation of a clay pavement is such that table drains are eliminated so that water will not lie next to the pavement during heavy rainfall and possible flooding. In addition, the formation should minimise moisture movements in order to maintain a constant moisture regime which limits volume stability (swelling and softening as well as shrinkage cracking) which may induce premature failure of the pavement. The formation must be high enough above the natural terrain to minimise moisture infiltration during floods and yet not so high as to cause the pavement to desiccate (dry out) during drought periods.

Items that need to be carefully considered are:

- height of embankment and location, to minimise interference with flood levels
- batter slope – which will involve a compromise between erosion and stability considerations
- crossfall recommended to be at least 4%, will be steeper than normal
- additional seal width generally 8.2 m has been adopted to suit traffic and geotextile width
- design traffic loading
- equilibrium moisture content retention, including shoulder maintenance techniques
- flooding – if the pavement becomes inundated, clay pavements with a geotextile reinforced seal should not be used, particularly by heavy commercial vehicles, until the pavement dries out because:
  a. the geotextile seal does not bond to the wet pavement surface and water will infiltrate between the seal and the pavement. This leads to rapid structural failure under traffic
  b. the presence of the geotextile reinforced seal will slow the drying out of the wet pavement when the floodwaters recede.

Figure B 4: Geotextile reinforced seal and shoulder erosion

One of the important aspects of the design is also to ensure that the pavement surface is extremely well drained. GRS pavements have also been used successfully in car parking areas using a double/double seal over the geotextile. The second application seal was delayed by about 12 months to provide an opportunity to repair any failures.

Appendix C Assessment of Material Options

Assessment of materials options allows different material scenarios to be compared and consider the use of alternative or additional sources, risk reduction options or a combination of both.

To determine the best material option a rating assessment of each option can be carried out. This rating assessment assigns a score to various assessment items relevant to each of the options. The assessment items are those expected to influence whole-of-life cost of the pavement option. Each of assessment item ratings are added together to produce a final fit-for-purpose rating.

C.1 Options Assessment Process

Step 1. Identify the base scenario and all other viable options

- This choice will be based on project location, material sources, material volumes, material risk, and required level of service and risk reduction

Step 2: Assess each option

- Select a baseline option and understand how each other option will differ from it as it relates to the project considering the following assessment items:
  - Material quality risk: higher risk with poorer materials versus lower risk
    - based on material properties, traffic, climate
  - Haulage costs: higher cost or lower costs
    - based on source location relative to project
  - Construction costs: higher costs or lower costs
    - based on special treatment including stabilisation
  - Stabilisation material cost: higher costs or lower costs
    - based on the type and amount of stabilisation binder required
  - Ongoing maintenance costs: higher cost or lower costs
    - linked to material risk with higher risk materials requiring higher ongoing maintenance.

Step 3: Quantify each option

- Assign a rating to each assessment item relative to the base scenario
  - very low is assigned a value of 1 and very high assigned a value of 5
  - where an assessment item is not relevant to the option, a value of 0 is assigned.

Step 4: Fit-for-purpose option

- The sum of the individual ratings for a specific material option is the fit-for-purpose rating
  - The option with the lowest rating is considered the most fit-for-purpose option.

C.2 Worked Example

C.2.1 Project Information

Table C 2: Worked example: Project information

Material purpose	Climate	Traffic level	Level of service required
Sealed basecourse	Wet (> 500 mm/year)	Medium	Medium

C.2.2 Material Information

Table C 3: Worked example: Material information

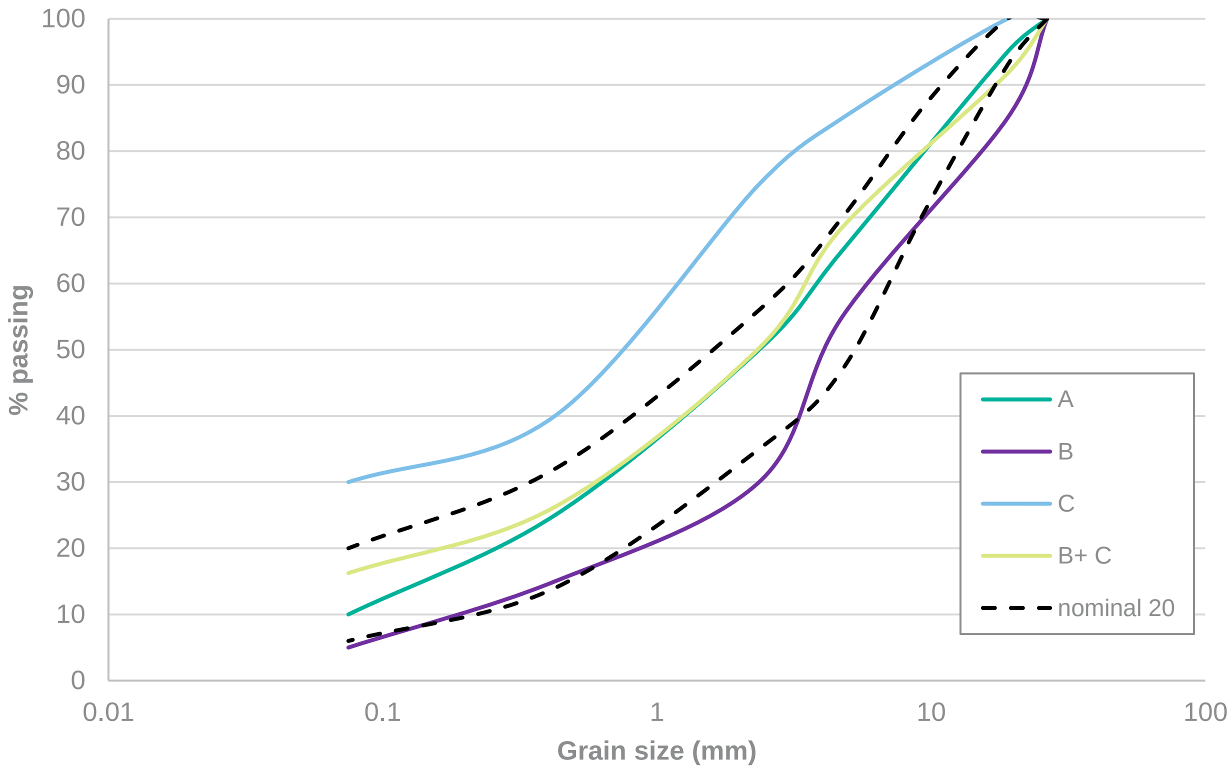
Material ID	Material properties				Material characteristics	Risk
	Grading suitability	LS	PI	WLS		
Material A	Within envelope	7	12	140	• Stable grading • Good cohesion	Very low
Material B	Slightly coarse	0	1	0	• Stable grading • No cohesion	Medium
Material C	Outside of envelope, fine	9	24	360	• Unstable grading • High clay content	High
Blend of B and C (55%B + 45%C)	Within envelope	4	10	106	• Stable grading • Good cohesion	Very low

Notes:
- *LS – linear shrinkage*
- *PI – plasticity index*
- *WLS – weighted linear shrinkage*

Table C 4: Worked example: Material source information

Material ID	Haulage distance	Source volume information
Material A	High	High volume
Material B	Medium	Medium volume
Material C	None	High volume

Figure C 1: Material options – grading and specification envelope



C.2.3 Options Assessment

The four material options for this example are:

- Option 1: base scenario, use closest material C with high risk of poor performance
- Option 2: Blend material C with nearby material B to lower risk of poor performance
- Option 3: Stabilise material D with a suitable stabilising agent
- Option 4: Haul material A with a very low risk of poor performance.

C.2.4 Comparison of Options

Option 1

This option requires the least amount of haulage. However, due to the high risk of poor performance combined with the medium level of service requirement, ongoing maintenance costs are anticipated to be higher than the other options.

Option 2

There is not high enough volume of material B to use as a standalone material. There is enough to blend with material C to reduce risk by altering material grading. A blend of 55% material B and 45% material C was chosen resulting in a low risk material blend.

The haulage cost is anticipated to be higher than option 1. Construction costs are anticipated to be slightly higher due to the extra processing. Maintenance is expected to be much lower than option 1.

Option 3

Suitable stabilisation binders for material C include the addition of lime. This stabilisation would reduce plasticity and moisture sensitivity in the wet climate. The grading of Material C is fine and is anticipated to be of low strength and may not be adequate strength for a medium traffic level even with the addition of lime.

Stabilisation would also require higher construction costs than the other options. It is anticipated to have ongoing maintenance costs similar to Option 1.

Option 4

This option requires the highest haulage costs but is expected to have low ongoing maintenance costs due to the very low risk material.

C.2.5 Options Rating

Table C 5: Worked example: Options rating

Assessment item	Base scenario	Risk reduction options		
		Option 2: Blend	Option 3: Stabilise	Option 4: Haul
Performance risk	High (4)	Very low (1)	Medium (3)	Very low (1)
Haulage cost	Nil (0)	Medium (3)	Nil (0)	Very high (5)
Stabilisation binder cost	Nil (0)	Nil (0)	High (4)	Nil (0)
Extra construction costs	Nil (0)	Very low (1)	Low (2)	Nil (0)
Maintenance costs	Medium (3)	Very low (1)	Medium (3)	Very low (1)
Fit-for-purpose rating (as sum of all individual ratings)	***7***	***6***	***12***	***7***

From the above assessment (Table C 3), Option 2 would provide the best fit-for-purpose pavement option for the design scenario. This option requires some haulage of material a short distance and some extra construction costs due to material blending but is expected to have very low material risk and therefore lower maintenance costs.